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Female athlete representation and dietary control methods among studies assessing chronic carbohydrate approaches to support training

Megan A Kuikman[1], Alannah KA McKay[1], Ella S Smith[1], Kathryn E Ackerman[2], Rachel Harris[3,4], Kirsty J Elliott-Sale[5], Trent Stellingwerff[6,7], Louise M Burke[1]

[1]Mary MacKillop Institute for Health Research, Australian Catholic University, Melbourne, Victoria, Australia

[2]Female Athlete Program, Boston Children's Hospital and Harvard Medical School, Boston, MA, USA

[3]Female Performance and Health Initiative, Australian Institute of Sport, Canberra, ACT Australia

[4]Perth Orthopaedic and Sports Medicine Research Institute, West Perth, WA, Australia

[5]Department of Sport and Exercise Sciences, Institute of Sport, Manchester Metropolitan University, Manchester, UK

[6]Canadian Sport Institute-Pacific, Institute for Sport Excellence, 4371 Interurban Road, Victoria, BC V9E 2C5, Canada

[7]Exercise Science, Physical and Health Education, University of Victoria, Victoria, BC, Canada

Running Head: Female representation in carbohydrate research

Address for correspondence

Megan Kuikman, Mary MacKillop Institute for Health Research,

Australian Catholic University, Melbourne, Victoria, Australia 3000

Email: Megan.Kuikman@acu.edu.au

Abstract

The aim of this audit was to assess the representation of female athletes, dietary control methods and gold-standard female methodology that underpins the current guidelines for chronic carbohydrate (CHO) intake strategies for athlete daily training diets. Using a standardized audit, 281 studies were identified that examined high versus moderate CHO, periodized CHO availability, and/or low CHO, high fat diets. There were 3,735 total participants across these studies with only ~16% of participants being women. Few studies utilised a design that specifically considered females, with only 16 studies (~6%) including a female-only cohort and 6 studies (~2%) with a sex-based comparison in their statistical procedure, in comparison to the 217 studies (~77%) including a male-only cohort. Most studies (~72%) did not provide sufficient information to define the menstrual status of participants, and of the 18 studies that did, optimal methodology for control of ovarian hormones was only noted in 1 study. While ~40% of male-only studies provided all food and beverages to participants, only ~20% of studies with a female-specific design used this approach for dietary control. Most studies did not implement strategies to ensure compliance to dietary interventions and/or control energy intake during dietary interventions. The literature that has contributed to the current guidelines for daily CHO intake is lacking in research that is specific to, or adequately addresses, the female athlete. Redressing this imbalance is of high priority to ensure that the female athlete receives evidence-based recommendations that consider her specific needs.

Keywords: women, audit, periodized, carbohydrate availability, low carbohydrate, high fat, menstrual status

Introduction

Guidelines for carbohydrate (CHO) intake in the athlete's everyday training diet have been a central and evolving theme over the 60-year history of sports nutrition. Whereas early guidelines promoted high absolute intakes of CHO based on maximising rates of daily glycogen storage (Coyle, 1991), more recent approaches support individualized and periodized intakes to match the needs of the changing training loads, or to target different acute sessions with high or low CHO availability according to the priority of performance or enhanced adaptation (Burke et al., 2018). In addition, there has been interest in the effects of chronic adaptation to low CHO, high fat (LCHF) diets with a goal of possibly enhancing competition performance via reduced reliance on the relatively limited CHO stores as the key substrate for exercise.

Studies have investigated the effects of these different dietary approaches on exercise metabolism, adaptation to training, and exercise capacity/performance. For instance, investigations of LCHF dietary approaches have failed to provide evidence of a performance enhancing benefit over traditional CHO recommendations for athletes (Burke, 2021). However, there is increasing awareness that research across various areas of sports science and medicine is predominantly conducted in male populations (Cowley et al., 2021; Smith et al., 2022c). This creates uncertainty around the application of the results to female athletes due to sex-based physiological, morphological and performance differences (Hilton & Lundberg, 2021; Tarnopolsky, 2008; Wells, 2007; Yanovich et al., 2020). For instance, sex differences exist in body composition with a ~45% greater magnitude in lean body mass, and ~30% less fat mass in men compared to women (Hilton & Lundberg, 2021). Yet, current CHO guidelines are expressed relative to body mass and do not consider sex difference in body composition, which could impact the ability to store consumed CHO. Furthermore, when women are included in such studies, it is unclear if the physiological changes, which occur over the menstrual cycle or via alterations to ovarian hormones due to scenarios such as hormonal contraceptive usage, have been considered (Elliott-Sale et al., 2021). Failure to follow best-practice guidelines for the methodological control of ovarian hormones may result in erroneous findings and recommendations (Elliott-Sale et al., 2021; Janse de Jong et al., 2019).

We recently conducted an audit of the literature from which guidelines for acute strategies to manipulate CHO availability around a single session of exercise have been derived (Kuikman et al., 2022). Therein we showed both a dearth of female participants and poor attention to hormonal characterization and standardization in the studies that included females. Whether there is even greater under-representation within literature supporting current guidelines for chronic approaches to CHO intake that are incorporated into the daily training diet of an athlete is of interest. The longitudinal nature of these studies creates even greater challenges in controlling for ovarian hormones, since measurements may extend over multiple phases of the menstrual cycle, or with hormonal contraceptive regiments. Additionally, the prolonged commitment required for these studies may contribute to volunteer bias such that there may be sex differences in willingness to participate in this research, resulting in a greater difficulty in recruiting female participants for study involvement (Nuzzo, 2021). Female athletes may be particularly reluctant to participate in projects that focus on chronic CHO intake and involve periods of prolonged dietary control due to increased rates of disordered eating in female athletes compared to male athletes (Bratland-Sanda & Sundgot-Borgen, 2013). Furthermore, female athletes are more likely to consume lower/sub-optimal CHO intakes (Burke et al., 2001) or fail to adjust intakes according to changes in daily training (Heikura et al., 2018). While the cause of this is likely multifactorial, inadequate CHO intake may be secondary to inadequate energy intake (Burke et al., 2001).

We were interested in studies assessing chronic CHO intake strategies that are incorporated into an athlete's daily diet and consequently influence and must consider daily energy intake, as failure to do so could confound study results. Chronic CHO intake strategies assessed included studies that compare habitual/moderate CHO intakes versus higher CHO diets, studies of periodized approaches to CHO availability (P-CHO) in training, and studies of LCHF diets. Accordingly, this project employed a standardized auditing tool (Smith et al., 2022a) to assess the male versus female representation in studies assessing these strategies. The dietary control methods implemented within these studies were also assessed to provide information on possible barriers that contribute to inequities in female inclusion and factors that may result in either erroneous or consensus findings.

Methods

The methods of this audit are in accordance with a standardized protocol (Smith et al., 2022a) with an electronic search from inception to January 18, 2022 being conducted in PubMed. Methods specific to this audit are outlined below.

Data Selection and Extraction

After removal of duplicates, papers were screened using Rayyan online software (Ouzzani et al., 2016) to identify papers that met inclusion criteria. Studies were included if the primary investigation involved the effects of the various approaches to chronic CHO intake on a performance outcome, health outcome or underlying mechanism (Table 1). Studies using statistical methodology to examine more than one approach were classified into all applicable categories.

-Table 1-

During data extraction, two authors independently classified papers into a chronic CHO intake fuelling strategy and a third author resolved any conflicts. The following were exclusion criteria: participants were >50 years and untrained, children, were not explicitly described by sex or had lifestyle diseases; the study involved an occupational task (e.g., soldiers, firefighters), the CHO-based intervention was the control condition and the investigation/outcome was irrelevant to the area of interest (Figure 1). Papers examining the effects of an acute CHO fuelling strategy were included in a sister analysis (Kuikman et al., 2022).

-Figure 1-

For articles that met inclusion criteria, data were extracted into Microsoft Excel and included retrieving the following metrics:

A. Study Design: females-only, males-only, mixed-sex cohort, male versus female design features (MvFdes), and male versus female sub-analysis (MvFsub).

B. Athletic Caliber as previously established (McKay et al., 2022): Tier 0 (Sedentary), Tier 1 (Recreationally Active), Tier 2 (Trained/Developmental), Tier 3 (Highly trained/National), Tier 4 (Elite/International), and Tier 5 (World-Class).

C. Menstrual Status and Grade: Naturally menstruating or eumenorrheic women, hormonal contraceptive users, women with menstrual irregularities, mixture of one of the aforementioned categories with studies then being graded as Gold, Silver, Bronze, or Ungraded standard based on methodological control of ovarian hormones as per Best Practice Guidelines (Elliott-Sale et al., 2021). Supplementary table 1 outlines the full criteria as per Smith et al., (2022a) that was used to grade studies. With this grading protocol, if insufficient information was provided to determine menstrual status, then studies were defined as unclassified and were not graded.

D. Research Theme: Primary focus on performance outcome, clinically established health outcome, or indirect or emerging associations with performance or health.

E. Study Impact: Altmetric score and most recent 4-year impact factor (IF). Altmetric scores were only retrieved for studies published after 2012 and obtained between December 23, 2021-January 18, 2022.

F. Sample Size: Male and female participant number.

Studies that included a female specific design (females only, MvFdes, and MvFsub), enabling outcomes to contribute knowledge about sex-based differences or directly inform female-specific guidelines, were examined to determine methods of implementation of the dietary strategy; protocols to verify adherence to the strategy; and protocols used to set the energy characteristics of interventions. Male-only studies that implemented dietary control by providing all food and beverages to participants were also identified for comparison, since this is both the most highly controlled and resource-intensive methodology (Jeacocke & Burke, 2010). We noted the duration of the dietary intervention, including standardized dietary intake periods. In the case of cross-over designs, this involved the cumulative length of all dietary interventions excluding periods in which participants consumed their habitual diet. Dietary control periods of <24 hrs and case studies were not included here.

Statistics

Statistical analyses were performed using R Studio (v3.5.2) with significance accepted at an α level of $p \leq 0.05$. Frequency-based metrics were reported as a percentage of the total studies or participants. Histogram inspection revealed all outcomes were non-normally distributed data. A Mann Whitney U-Test was used to compare median number of male to female participants across study design, while a Kruskal Wallis Test with a post-hoc Dunn test assessed differences in IF, altmetric scores, and length of dietary interventions across study design. Data are reported as median ± interquartile range.

Results

A total of 281 studies were included across the three chronic CHO fuelling strategies. These involved a total of 3,735 participants with ~16% and ~84% being female and male participants, respectively (Figure 2). While ~94% of studies (n = 265) included at least 1 male participant, only ~23% of studies (n = 64) included at least 1 female participant.

-Figure 2-

Study Design and Sample Size

Across the different research categories, 16 studies (~6%) included a female-only design compared with 217 studies (~77%) that included a male-only design (Figure 3). Two studies (~0.7%) conducted a sex-based comparison (MvFsub) within the statistical procedure, and only 4 studies (~1%) included methodological designs (MvFdes) specifically comparing sex-based responses. Of the 22 studies with a female-specific design (female-only, MvFdes, or MvFsub), the majority examined LCHF diets (~73%, n = 16), while 5 studies compared moderate versus high (MvH) diets, and 1 study assessed P-CHO diets. Of the 64 studies that included female participants, most involved a mixed-sex cohort (~66%, n = 42). For studies with a mixed-sex cohort, the median number of male participants was 9 ± 12 whereas the median number of female participants was 6 ± 4 ($p = 0.01$). The median number of male and female participants was similar across other study designs.

-Figure 3-

Research Theme and Athlete Caliber

Most studies assessing LCHF diets (~53%, n = 79) and MvH diets (~63%, n = 29) investigated performance themes, whereas studies of P-CHO diets mostly examined indirect markers of health or performance (~60%, n = 52; Figure 4). No study was found to primarily investigate a health outcome according to the definition of Smith et al., 2022a. Of the 281 studies, 130 studies (~46%) failed to provide sufficient information to classify the caliber of athletes. For the remaining 151 studies, ~72% of participants were classified within Tier 0 (Sedentary) to Tier 2 (Trained/developmental). Tier 2 (Trained/developmental) athletes represented the majority of participants in studies of LCHF diets (~44%; n = 34) and MvH diets (~47%; n = 14), whereas Tier 1 (Recreationally Active) participants were primarily used to study P-CHO diets (~40%, n = 17). The one study involving Tier 5 athletes investigated a LCHF diet (Mujika, 2019).

-Figure 4-

Publication Statistics

The IF ($p = 0.34$) and altmetric score ($p = 0.75$) was similar between the 5 study designs and ~~this~~ remained similar when differences between study designs were examined for each of the three daily CHO fuelling strategies in isolation. The yearly publication rate from 1970-2021 of male-only studies was 4 studies/yr whereas the yearly publication rate of female-only studies was 0.3 studies/yr (see Figure 5).

-Figure 5-

Menstrual Status and Control

Most (72%) of the 64 studies that included women provided insufficient information to define the menstrual status of participants. Of the 18 studies that menstrual status was defined, 15 involved naturally menstruating women, and three included both naturally menstruating women and hormonal contraceptive users. Six studies described participants as being eumenorrheic although none met the gold-standard methodological criteria for defining eumenorrhea (Elliott-Sale et al., 2021), and 1 study inappropriately referred to hormonal contraceptive users as eumenorrheic. Within the three studies that included hormonal contraceptive users, two described the use of oral contraceptive pills while the other failed to provide information on the type of hormonal contraceptive. The only study with recognized methodological control of ovarian hormones involved a mixture of naturally menstruating women and hormonal contraceptive users (Figure 6), with the hormonal contraceptive users (0.5 of the study) being awarded Bronze standard and naturally menstruating females remaining ungraded (Duhamel et al., 2006). This resulted in 17.5 ungraded studies.

-Figure 6-

Menstrual and Hormonal Cycle Phase

Five studies described the standardized collection of study outcomes in the follicular phase of the menstrual cycle, while one study undertook investigations in the luteal phase. Two studies indicated measurements were always taken in the same phase of the menstrual cycle but did not identify the phase, while eight studies failed to provide information regarding timing of data collection according to menstrual cycle phase. Two of the studies with hormonal contraceptive users failed to identify the phase in which measurements were taken and one used confusing terminology by indicating that measurements were taken in the "mid-follicular phase." Finally, two studies assessed a daily CHO fuelling strategy across menstrual cycle phase with both comparing the mid-follicular and mid-luteal phase of the menstrual cycle.

Dietary Control

The duration of dietary interventions was 21 ± 39.5 days for female only studies, 14 ± 22 days for male only studies, 21 ± 32 days for mixed cohort studies, 28 ± 5 days for MvFdes studies, and 17 ± 11 days for MvFsub studies ($p = 0.089$). The length of dietary interventions between study designs remained similar when each chronic CHO fuelling strategy was assessed in isolation. Different protocols were used across studies to implement and verify the dietary interventions (Figure 7). Of studies with a female-specific design ($n = 22$), 4.5 (~20%) provided participants with all food/beverages. The 0.5 outcome denotes a study in which one group was provided with food while the other followed a meal plan (Berend et al., 1994). This contrasts with male-only studies, 40% of which directly provided participants with the dietary intervention. Various protocols were used to determine the energy content of dietary treatments and verify compliance with the intervention. Studies in which insufficient information or poor practices were identified, leaving 11 studies with a female-specific design with sufficient dietary control practices (Figure 7).

-Figure 7-

Discussion

We assessed the representation of female athletes in studies investigating different approaches to CHO intake in the daily training diet, and the methodological control of ovarian hormones and dietary intervention strategies employed within. Similar to other sports nutrition themes (Smith et al., 2022c), women were vastly outnumbered, representing only ~16% of participants (598 females vs. 3,137 males across 281 studies) among the studies that underpin the current global consensus recommendations for daily CHO intake (Burke et al., 2011; Burke et al., 2018). This was a slightly higher proportion than found in the sister audit (Kuikman et al., 2022) of studies assessing acute CHO fuelling strategies (~11%). Sixty-six percent of female participants were involved in studies of mixed-design, which fail to add specific knowledge about the female athlete and any difference in requirements to her male counterpart. Indeed, only ~5% of studies included a female-only cohort, and ~1% were specifically designed to examine sex-based differences. Similar to the audit of the literature on acute CHO fuelling, we found a smaller median number of female than male participants in studies with a mixed-sex design. This may reflect the addition of women to simply increase the total sample size and statistical power of these studies, or a sex-based volunteer bias that makes it more difficult to recruit female participants (Nuzzo, 2021).

Methodological Control of Ovarian Hormones

Only ~31% of studies (n = 18) provided sufficient information to define the menstrual status of female participants, and only 0.5 (one cohort within a two-population study) described methodological control of ovarian hormones to meet Best Practice Guidelines (Elliott-Sale et al., 2021). Many studies used poor and confusing terminology, such as describing participants as eumenorrheic despite failing to provide evidence to meet the gold-standard methodological criteria (Elliott-Sale et al., 2021). This may reflect failure of researchers to value the importance of controlling for ovarian hormones, and/or poor knowledge of the menstrual cycle and hormonal contraceptives. Although this is a general finding across many research themes (Smith et al., 2022a; 2022b), the chronic nature of the dietary interventions included in the current audit merits separate comment. The average duration of dietary interventions for studies with naturally menstruating females was ~20 days. As a result, these studies likely crossed over multiple phases of the menstrual cycle, adding expense and logistical challenges to attempts to control for ovarian hormones. Despite this, eight studies (~13%) managed to standardize the menstrual cycle phase during which study outcomes were measured. Methods to achieve this included the implementation of dietary interventions that extended across the entire duration of one or more menstrual cycles (Valsdottir et al., 2019; Vargas-Molina et al., 2020, 2021), or the use of a washout period to allow repeated measure designs to be conducted during the same phase of consecutive menstrual cycles (Berend et al., 1994; Dolins et al., 2003; Duhamel et al., 2006; Kłapcińska et al., 2002), or in the same phase of a single menstrual cycle (Lynch et al., 2000). We recognize that some research scenarios and designs preclude the implementation of ideal control for the menstrual or hormonal contraceptive phase of participants. Research-embedded training camps with simultaneous participation of large groups of athletes, all starting on the same day, make it very unlikely for athletes to synchronise their menstrual phase or hormonal contraceptive use. This can be particularly challenging with elite to world-class athlete cohorts who are unable to shift/change elements of training and timing of training camps. Furthermore, depending on the research question, it may not be necessary to verify and control the menstrual or hormonal contraceptive phase of participants, which will also improve ecological validity. In these situations, or when it is not possible to standardize the phase of the menstrual or hormonal contraceptive cycle, researchers should still characterize the menstrual status of participants according to Best Practice Guidelines (Elliott-Sale et al., 2021) and note why standardization was not possible. This was poorly done in the studies included in the current audit, with the majority (~72%) failing to provide sufficient information.

Dietary Control Methods

The methods used to implement and monitor dietary protocols in chronic intervention studies are of interest because they: 1) contribute a major time and resource cost to the study (which might need to be balanced against other costs, such as tracking menstrual status); 2) present a barrier for recruitment of female participants by removing dietary freedoms or instigating food monitoring to individuals who have poor relationships with nutrition and self-image; and/or 3) contribute to poor study methodology and erroneous findings. In the current audit, we showed no differences in the length of the dietary interventions across various study designs, and a trend towards a greater proportion (albeit low absolute number) of studies involving >20 d duration within female-only (~56%, n = 9) compared to male-only studies (~34%, n = 80). This suggests that the length of the dietary intervention is not a barrier for female participation in research. It may also reflect that the majority of female-only studies examined LCHF diets (~82%), in which a period of keto-adaptation of at least 3-4 w is recommended (Burke, 2021). A greater proportion of male-only studies (~40%) than female-only studies (~19%) provided participants with all food and beverages according to their dietary intervention, as is considered the gold standard for achieving dietary control (Jeacocke & Burke, 2010). Perhaps female participants are less willing to participate in projects involving this level of dietary control or maybe the funding and resources for female-only studies cannot meet the required increase in time, cost and logistical challenges associated with such methodologies. Interestingly, while the percent of published studies that provided all food to participants increased from 33% (n = 74) in 1981-2001 to 50%

(n = 80) from 2001-2010, this decreased back to 33% (n = 43) from 2011-2022, suggesting that there has not been an improvement in best practices for dietary control in more recent years.

Investigations that provide all food and beverages to participants generally achieve good compliance to study interventions (Hall & Most, 2005), especially in scenarios such as metabolic wards or research-embedded training camps (Mirtschin et al., 2018) where food intake can be well-monitored and supervised. Among female-specific studies in the current audit, other protocols to achieve the intervention of interest included provision of menus or nutrition education to enable participants to implement their own intervention. In most cases, researchers undertook protocols to verify the level of adherence to the diet(s) of interest; this included supervision of meals as well as scrutiny of self-reports and food records in which the potential for misreporting is recognised (Jeacocke & Burke, 2010). A few studies (n = 4) failed to provide information on compliance to the study intervention. This is concerning, as study outcomes may be attenuated because of discrepancies between the intended intervention and participants' actual food intake (Most et al., 2003).

Energy intake (EI) and exercise energy expenditure (EEE) represent separate, but important, characteristics of the study intervention. If EI and EEE are unknown, the measured outcome of the CHO manipulation may be due to significantly altered energy availability (EA), confounding the specific CHO-related research question. This has been demonstrated in other sports science topics, such as the outcomes of training interventions, which fail to adjust the EI of athletes involved (Stellingwerff et al., 2021). Furthermore, women may be more susceptible to the physiological effects of problematic low EA compared to their male counterparts (Koehler et al., 2016; Papageorgiou et al., 2017). Among the 16 female-specific studies included in the audit for which adequate dietary control was implemented, only 10 provide information on how EI targets were determined. However, some studies used methods to prescribe the EI that could result in low EA. This included the use of habitual intake (Lynch et al., 2000) as both the suitability of habitual intake or the method used to assess it from self-reports are potentially erroneous, or the failure to account for EEE when using the principle of EA (Vargas-Molina et al., 2020, 2021) to prescribe EI. We also note that in some studies, dietary interventions were not isoenergetic (O'Keeffe et al., 1989), which may have confounded results.

Moderate versus High Carbohydrate Diets

The scaling of CHO intake to body mass in 2004 was one of the first practical attempts to account for body mass differences in CHO recommendations, and indirectly addresses sex-based differences given the typically smaller body size of women compared to men (Burke et al., 2004). Yet, this may not adequately account for sex differences in substrate oxidation (Devries, 2016) and skeletal mass quantity and composition; on average women have more Type I oxidative fibers than men (Haizlip et al., 2015; Wells, 2007). Despite a biological rationale for differences in the daily CHO needs of male and female athletes, we were unable to locate a single study with a MvF design that could directly investigate this issue. Two studies with female-only cyclist cohorts compared the effects of a MvH diet on time to fatigue. Both of which found an insignificant numerical difference in time to exhaustion between dietary interventions (Dolins et al., 2003; O'Keeffe et al., 1989). While this may suggest that female athletes do not benefit from higher CHO intake, such evidence is limited by the low caliber of athletes (Tier 1; Recreationally Active and Tier 2; Trained/Developmental) with a low training volumes (~70 miles of cycling over 7 days (O'Keeffe et al., 1989) and ~100 miles of cycling over 6 days (Dolins et al., 2003)) that may have been successfully fuelled by the moderate CHO diet. Given that dietary surveys of female athletes report daily CHO intakes that are lower than their male counterparts (Burke et al., 2001), often secondary to apparently lower EI, investigation of whether higher CHO intakes are truly performance enhancing is needed.

Low Carbohydrate, High Fat Diets

Within our audit, six studies with a female-specific design examined changes in performance associated with LCHF diets. Outcomes due to the LCHF diets in women included performance decrements (Durkalec-Michalski et al., 2021; O'Keeffe et al., 1989; Sjödin et al., 2020), no differences in performance (Durkalec-Michalski et al., 2021; Lynch et al., 2000), and improvements in select strength parameters (n = 1; Sawyer et al., 2013). Limitations to this research include the low caliber of athletes involved and poor methodological control of ovarian hormones, with only 0.5 a study providing evidence of sufficient methodological control of ovarian hormones. Overall, LCHF diets do not seem to provide performance benefits in competitive male endurance athletes, either (Burke, 2021). In male athletes, there is evidence to suggest that this may be due to decreased pyruvate dehydrogenase activation (Stellingwerff et al., 2006). Further research is needed to examine sex-differences in response to a LCHF diet, including if performance decrements occur through similar mechanisms of reduced economy of higher-intensity exercise with greater oxygen cost of ATP production via fat oxidation.

Periodized Carbohydrate Availability

Only one study of P-CHO with a female-specific design was identified in this audit. This study examined a 4-week program involving 5 days/week of fasted or acutely fed training in untrained men and women (Stannard et al., 2010). Although maximal aerobic capacity increased by 9.7% with fasted training compared to 2.5% with fed training ($p = 0.015$), without evidence of sex-differences, men showed greater adaptations in muscle metabolism in the fasted condition, with a reverse outcome in the fed condition for women (Stannard et al., 2010). This is an interesting finding given that fasted training is an example of exercising in a state of both low EA and low CHO availability, with evidence that women are more negatively affected by periods of low EA than males (Koehler et al., 2016; Papageorgiou et al., 2017) and the outcomes of low EA and low CHO availability may share overlap (Areta et al., 2021). As research into various aspects of P-CHO is still in its infancy, it is important to include women in future studies to ensure that the evolving guidelines can be applied to both male and female athletic populations.

Conclusion

Like other audited areas, women are under-represented in studies examining different approaches to CHO in the everyday training diet, and the available research is limited by poor methodological design in the control of ovarian hormones, and the implementation and verification of chronic dietary interventions. Future research on CHO support for training should use Best Practice Guidelines for the conduct and reporting of these aspects of research. Specific studies of female athletes, including direct investigation of potential sex differences in response to manipulation of CHO support for training, when corrected and normalized for fat free mass compared to males, are needed to develop evidence-based guidelines that cover the whole of the athletic population.

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Table 1 Classification of different research interests regarding chronic strategies around CHO support for training

Strategy (Burke et al., 2011; Burke et al., 2018)	Study Features
Moderate versus high carbohydrate (MvH)	Investigates chronic CHO intakes (>3 days in duration) Manipulates the type or amount of daily CHO intake to compare "habitual" intakes to strategies promoting greater daily muscle glycogen storage/restoration
Periodization of carbohydrate availability (P-CHO)	Investigates the integration of acute strategies of "train low" and "recover low" (manipulation of low CHO availability around training session) within program otherwise providing CHO-supported training May include manipulations of dietary CHO intake and timing/sequences of training sessions to achieve low CHO availability Includes investigation of acute response to "train low" sessions as well as chronic training studies
Low carbohydrate, high fat diets (LCHF)	Investigates sustained responses (>24 h) to low CHO intake Includes both ketogenic (<50 g/day CHO) and non-ketogenic (<3 g/kg BM CHO) approaches to LCHF Includes implementation of a period of CHO restoration following adaptation to chronic CHO restriction

Note: *CHO* carbohydrate; *BM* body mass

Figure 1: Flowchart demonstrating the screening process to identify papers examining chronic approaches to CHO support for training including the number of studies of the three different research interests

Figure 2: The total number of male and female participants (A) and total number of studies with at least one male or one female participant (B) for each of three different research interests for chronic approaches to CHO support for training

MvH moderate versus high; *LCHF* Low carbohydrate, high fat; *P-CHO* Periodisation of carbohydrate availability

Figure 3: Frequency of study design for each of three different research interests for chronic approaches to CHO support for training with the number of studies indicated within the legend (A) and the median number of male and female participants within each study design (B). *Significantly different median number of male versus female participants.

MvH moderate versus high; *LCHF* Low carbohydrate, high fat; *P-CHO* Periodisation of carbohydrate availability; *MvFdes* male versus female design; *MvFsub* male versus female sub-analysis.

Figure 4: Proportion of studies examining performance, health or indirect themes (A) and proportion of participants within each athlete tier: Tier 0 (Sedentary), Tier 1 (Recreationally Active), Tier 2 (Trained/Developmental), Tier 3 (Highly Trained/National), Tier 4 (Elite/International) and Tier 5 (World-Class) for each of the acute carbohydrate fuelling strategies (B).

MvH moderate versus high; *LCHF* Low carbohydrate, high fat; *P-CHO* Periodisation of carbohydrate availability

Figure 5: Histogram of yearly publication rate for male only studies and female only studies for all investigations of chronic approaches to CHO support for training

Figure 6: Proportion of studies classified as Gold standard (best practice methodologies followed), Silver/Bronze standard (some best practice methodologies followed), Ungraded (menstrual status defined but insufficient information on methodological control of ovarian hormonal profiles) and Unclassified (insufficient information to define menstrual status) for each of three different research interests for chronic approaches to CHO support for training. Number of studies within each menstrual classification indicated on legend.

MvH moderate versus high; *LCHF* Low carbohydrate, high fat; *P-CHO* Periodisation of carbohydrate availability

Figure 7: Method of dietary control, verification to ensure dietary adherence, and control of energy intake for studies with a female specific design. Energy intake control method was not considered for studies that allowed ad libitum intake or failed to provide information on methods to ensure dietary adherence. For studies that estimated total energy expenditure, energy intake divided by Harris-Benedict Equation and body mass presented as average and range in brackets.

TEE total energy expenditure; *BM* body mass; *EI* energy intake; *HBE* Harris-Benedict Equation.

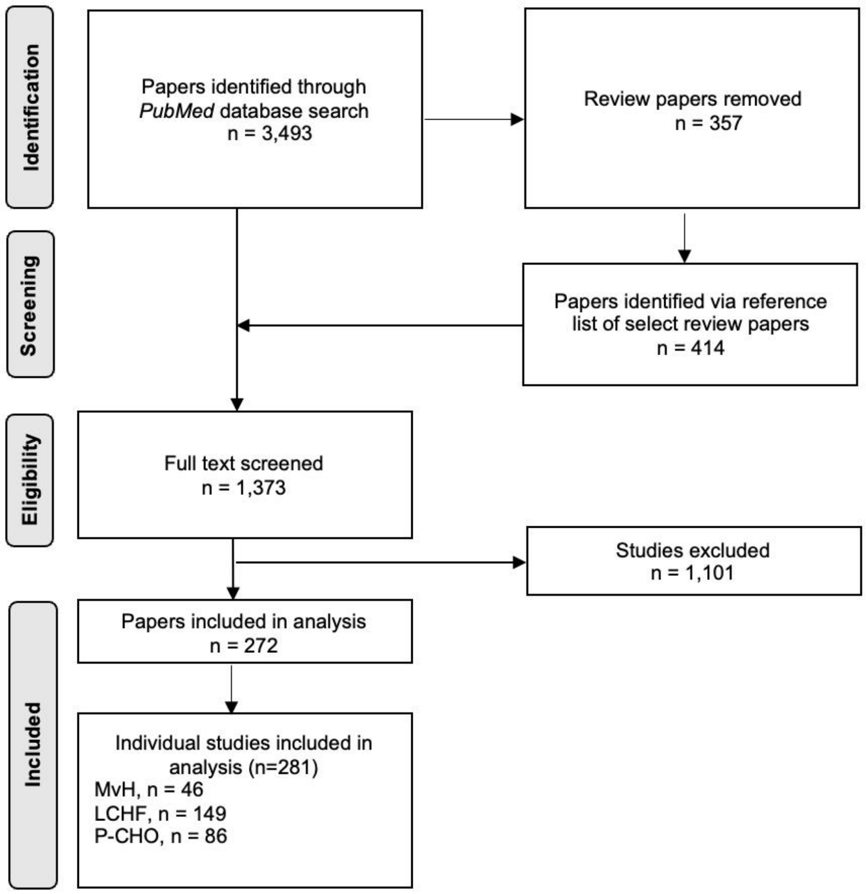

Figure 1: Flowchart demonstrating the screening process to identify papers examining chronic approaches to CHO support for training including the number of studies of the three different research interests.

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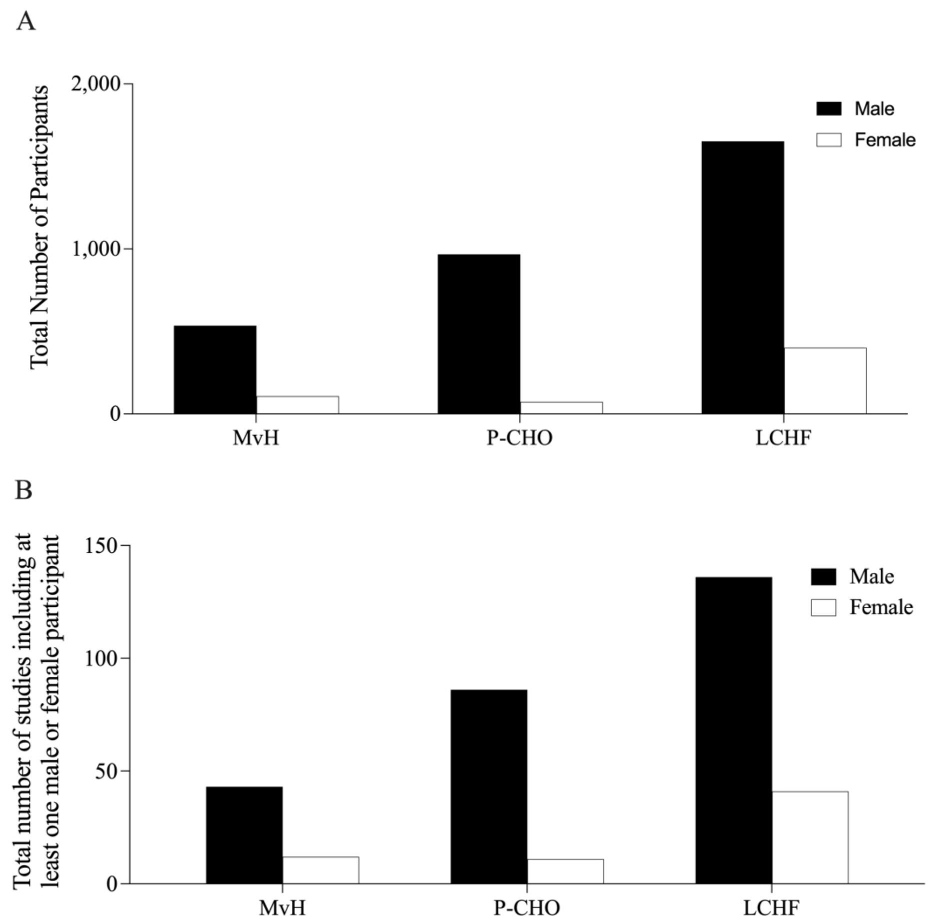

Figure 2: The total number of male and female participants (A) and total number of studies with at least one male or one female participant (B) for each of three different research interests for chronic approaches to CHO support for training. MvH Moderate versus high; LCHF Low carbohydrate, high fat; P-CHO Periodisation of carbohydrate availability.

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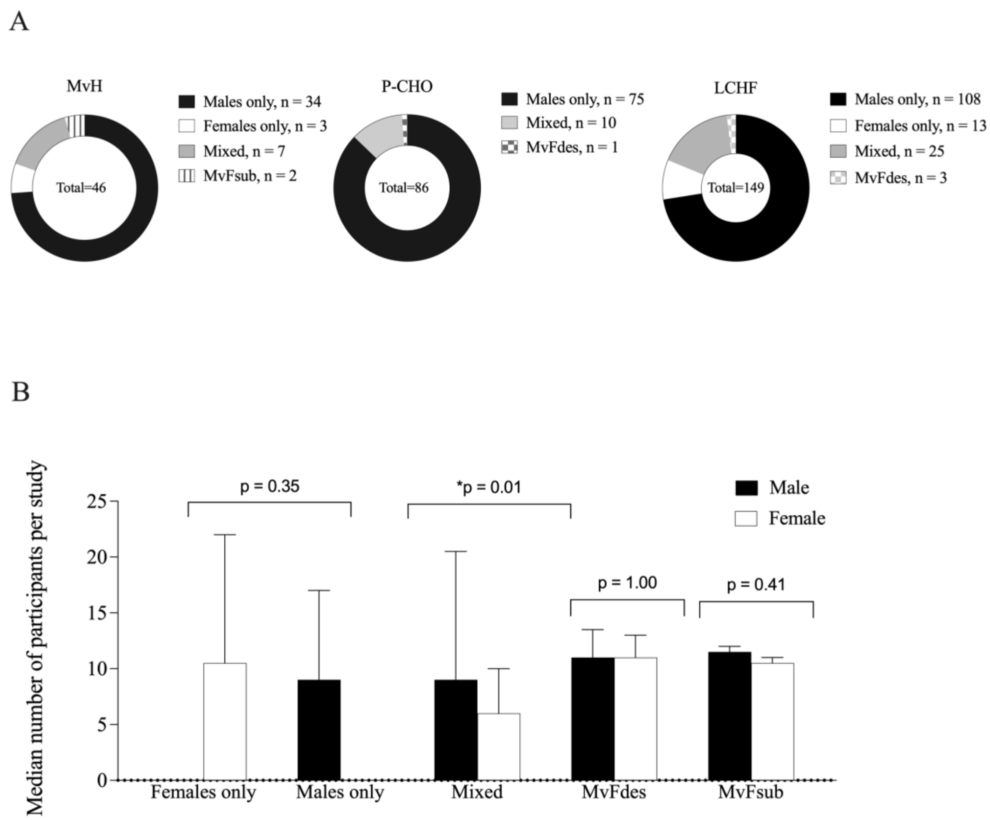

Figure 3: Frequency of study design for each of three different research interests for chronic approaches to CHO support for training with the number of studies indicated within the legend (A) and the median number of male and female participants within each study design (B). *Significantly different median number of male versus female participants.MvH moderate versus high; LCHF Low carbohydrate, high fat; P-CHO Periodisation of carbohydrate availability; MvFdes male versus female design; MvFsub male versus female sub-analysis.

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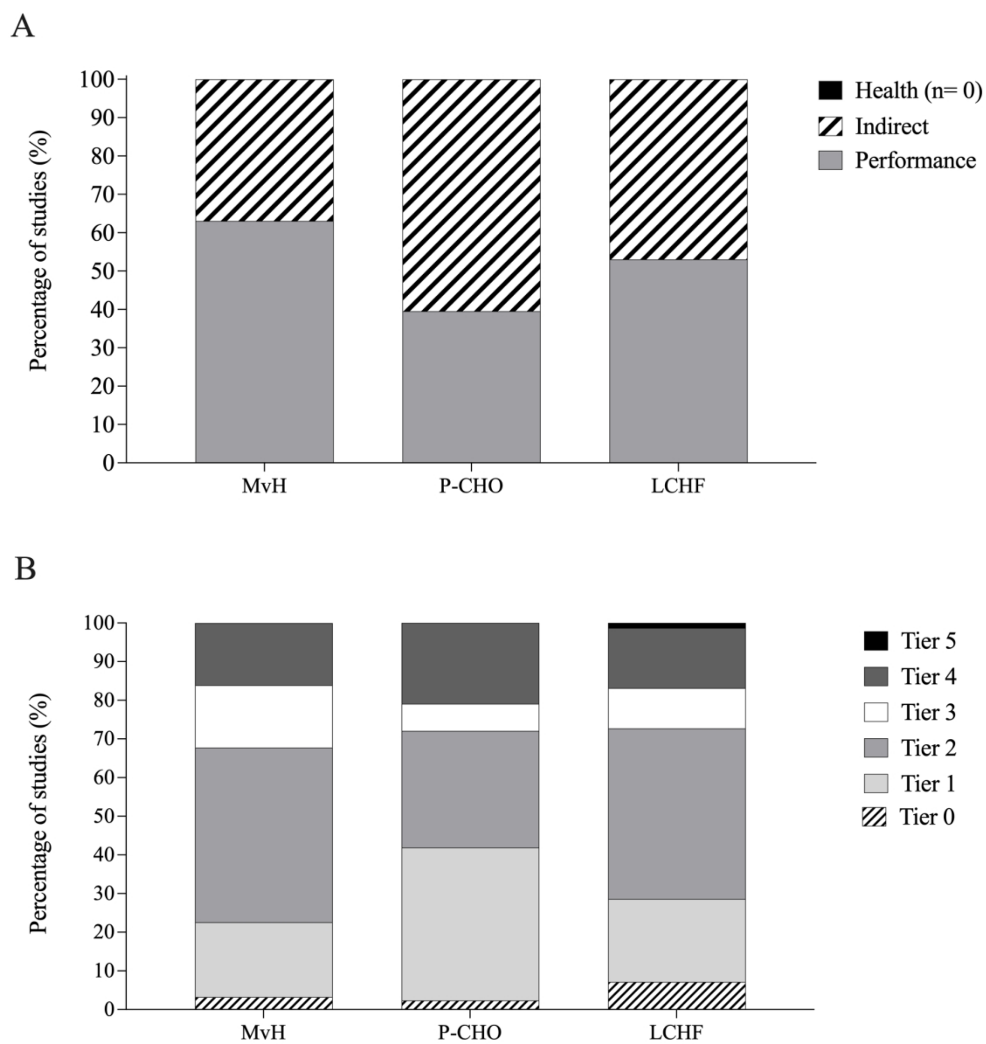

Figure 4: Proportion of studies examining performance, health or indirect themes (A) and proportion of participants within each athlete tier: Tier 0 (Sedentary), Tier 1 (Recreationally Active), Tier 2 (Trained/Developmental), Tier 3 (Highly Trained/National), Tier 4 (Elite/International) and Tier 5 (World-Class) for each of the acute carbohydrate fuelling strategies (B). MvH moderate versus high; LCHF Low carbohydrate, high fat; P-CHO Periodisation of carbohydrate availability.

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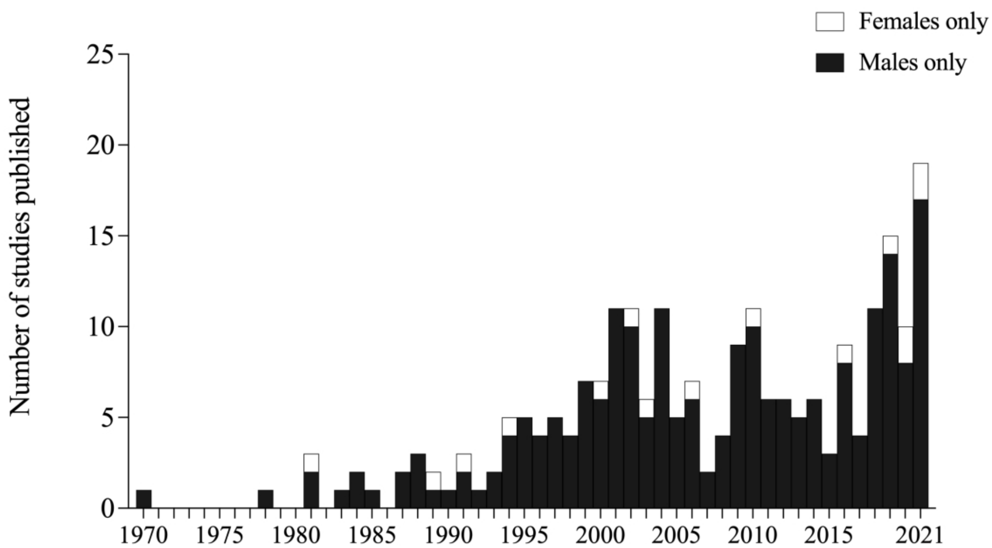

Figure 5: Histogram of yearly publication rate for male only studies and female only studies for all investigations of chronic approaches to CHO support for training.

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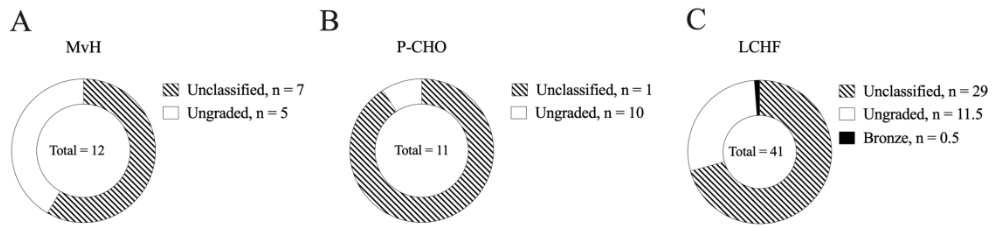
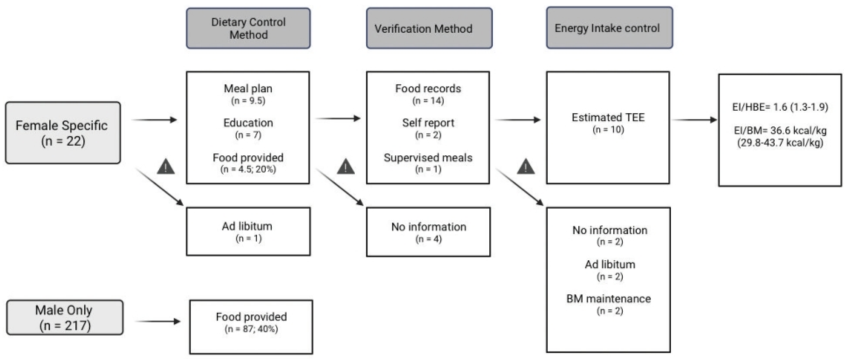


Figure 6: Proportion of studies classified as Gold standard (best practice methodologies followed), Silver/Bronze standard (some best practice methodologies followed), Ungraded (menstrual status defined but insufficient information on methodological control of ovarian hormonal profiles) and Unclassified (insufficient information to define menstrual status) for each of three different research interests for chronic approaches to CHO support for training. Number of studies within each menstrual classification indicated on legend. MvH moderate versus high; LCHF Low carbohydrate, high fat; P-CHO Periodisation of carbohydrate availability.

184x44mm (300 x 300 DPI)



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262x116mm (144 x 144 DPI)

TITLE	YEAR
Oral Glucose Ingestion Attenuates Exercise-Induced Activation of 50 -Amp-Activated Protein Kinase in Human Skeletal Muscle.	2006
Neither Beetroot Juice Supplementation Nor Increased Carbohydrate Oxidation Enhance Economy of Prolonged Exercise in Elite Race Walkers.	2021
Oral [13C]Glucose Oxidation During Prolonged Exercise After High- and Low-Carbohydrate Diets	1998
Carbohydrate Intake and Multiple Sprint Sports: With Special Reference to Football (Soccer).	1999
Regulation of Plasma Long-Chain Fatty Acid Oxidation in Relation to Uptake in Human Skeletal Muscle During Exercise.	2004
Effect of the Menstrual Cycle Phase and Diet on Blood Lactate Responss to Exercise	1994

Effects of Alterations in Dietary Carbohydrate Intake on Running Performance During a 10 Km Treadmill Time Trial.	1996
Effects of Moderate Dietary Manipulations on Swim Performance and on Blood Lactate-Swimming Velocity Curves.	1999
Human Skeletal Muscle Pyruvate Dehydrogenase Kinase Activity Increases After a Low-Carbohydrate Diet.	1998
High-Fat Diet Versus Habitual Diet Prior to Carbohydrate Loading: Effects of Exercise Metabolism and Cycling Performance.	2001
Regulation of Metabolic Genes in Human Skeletal Muscle by Short-Term Exercise and Diet Manipulation	2004
Carbohydrate Feeding During Recovery Alters the Skeletal Muscle Metabolic Response to Repeated Sessions of High-Intensity Interval Exercise in Humans.	2010
Carbohydrate Restriction Following Strenuous Glycogen-Depleting Exercise does not Potentiate the Acute Molecular Response Associated With Mitochondrial Biogenesis in Human Skeletal Muscle.	2021

Effect of the Intake of High Or Low Glycemic Index High Carbohydrate-Meals on Athletes' Sleep Quality in Pre-Game Nights.	2019
Overtraining Following Intensified Training With Normal Muscle Glycogen.	1995
Substrate Availability and Transcriptional Regulation of Metabolic Genes in Human Skeletal Muscle During Recovery From Exercise	2005
Dietary Carbohydrate Intake and Endurance Exercise Performance of Trained Female Cyclists	1989
Dietary Carbohydrate Intake and Endurance Exercise Performance of Trained Female Cyclists	1989
A 2 Week Cross-Over Intervention With a Low Carbohydrate, High Fat Diet Compared to a High Carbohydrate Diet Attenuates Exercise-Induced Cortisol Response, but not the Reduction of Exercise Capacity, in Recreational Athletes.	2021
A 3-Day High-Fat/Low-Carbohydrate Diet does not Alter Exercise-Induced Growth Hormone Response in Healthy Males.	2015

A 3-Week, Low-Carbohydrate, High-Fat Diet Improves Multiple Serum Inflammatory Markers in Endurance-Trained Males.	2020
A Low Carbohydrate Diet Affects Autonomic Modulation During Heavy but not Moderate Exercise.	2010
A Low-Carbohydrate Ketogenic Diet Reduces Body Mass Without Compromising Performance in Powerlifting and Olympic Weightlifting Athletes.	2018
A Short-Term Ketogenic Diet Impairs Markers of Bone Health in Response to Exercise.	2019
A Short-Term, High-Fat Diet Up-Regulates Lipid Metabolism and Gene Expression in Human Skeletal Muscle.	2003
Acute and Sustained Effects of a Periodized Carbohydrate Intake Using the Sleep-Low Model in Endurance-Trained Males	2019
Acute Carbohydrate Ingestion does not Influence the Post-Exercise Iron-Regulatory Response in Elite Keto-Adapted Race Walkers.	2019

Acute Dietary Carbohydrate Manipulation and the Subsequent Inflammatory and Hepcidin Responses to Exercise.	2015
Acute Ketogenic Diet and Ketone Ester Supplementation Impairs Race Walk Performance.	2021
Adaptation to a Ketogenic Diet Modulates Adaptive and Mucosal Immune Markers in Trained Male Endurance Athletes.	2021
Adaptation to a Low Carbohydrate High Fat Diet Is Rapid but Impairs Endurance Exercise Metabolism and Performance Despite Enhanced Glycogen Availability.	2021
Adaptations to Short-Term High-Fat Diet Persist During Exercise Despite High Carbohydrate Availability.	2002
Adaptations to Skeletal Muscle With Endurance Exercise Training in the Acutely Fed Versus Overnight-Fasted State.	2010
Alterations in Dietary Carbohydrate, Protein, and Fat Intake and Mood State in Trained Female Cyclists.	1991

Anaerobic Performance After a Low-Carbohydrate Diet (Lcd) Followed by 7 Days of Carbohydrate Loading in Male Basketball Players.	2019
Analysis of the Effects of Dietary Pattern on the Oral Microbiome of Elite Endurance Athletes.	2019
Autonomic and Perceptual Responses to Induction of a Ketogenic Diet in Free-Living Endurance Athletes: a Randomized, Crossover Trial.	2021
Beneficial Metabolic Adaptations Due to Endurance Exercise Training in the Fasted State.	2011
Case Study: Long-Term Low Carbohydrate, High Fat Diet Impairs Performance and Subjective Wellbeing in a World-Class Vegetarian Long-Distance Triathlete.	2018
Case Study: Nutrition and Training Periodization in Three Elite Marathon Runners.	2012
Changes in Body Composition and Substrate Utilization After a Short-Term Ketogenic Diet in Endurance-Trained Males.	2021

Changes in Metabolism but not Myocellular Signaling by Training With Cho-Restriction in Endurance Athletes.	2018
Changes in Metabolism but not Myocellular Signaling by Training With Cho-Restriction in Endurance Athletes.	2018
Chronic Adherence to a Ketogenic Diet Modifies Iron Metabolism in Elite Athletes.	2019
Chronic Ketogenic Low Carbohydrate High Fat Diet Has Minimal Effects on Acid-Base Status in Elite Athletes.	2018
Chronic Ketogenic Low Carbohydrate High Fat Diet Has Minimal Effects on Acid-Base Status in Elite Athletes.	2018
Concurrent Physical Activity Increases Fat Oxidation During the Shift to a High-Fat Diet.	2000
Crisis of Confidence Averted: Impairment of Exercise Economy and Performance in Elite Race Walkers by Ketogenic Low Carbohydrate, High Fat (Lchf) Diet Is Reproducible.	2020

Crisis of Confidence Averted: Impairment of Exercise Economy and Performance in Elite Race Walkers by Ketogenic Low Carbohydrate, High Fat (LCHF) Diet Is Reproducible.	2020
Daily Training With High Carbohydrate Availability Increases Exogenous Carbohydrate Oxidation During Endurance Cycling.	2010
Decreased Pdh Activation and Glycogenolysis During Exercise Following Fat Adaptation With Carbohydrate Restoration.	2006
Diet and Short Term Plasma Lipoprotein-Lipid Changes After Exercise in Trained Men.	2000
Dietary Carbohydrate and Intensity of Interval Swim Training.	1990
Dietary Carbohydrate, Muscle Glycogen, and Exercise Performance During 7 D of Training.	1993
Dietary Carbohydrate, Muscle Glycogen, and Power Output During Rowing Training	1991

Dietary Composition Influences Short-Term Endurance Training-Induced Adaptations of Substrate Partitioning During Exercise.	2004
Adaptive Stress Response of Glutathione and Uric Acid Metabolism in Man Following Controlled Exercise and Diet.	2002
Duathlon Performance Unaltered by Short-Term Changes in Dietary Fat and Carbohydrates.	2009
Effect of a Four-Week Ketogenic Diet on Exercise Metabolism in Crossfit-Trained Athletes.	2019
Effect of a Ketogenic Diet on Submaximal Exercise Capacity and Efficiency in Runners.	2019
Effect of a Low-Carbohydrate High-Fat Diet and a Single Bout of Exercise on Glucose Tolerance, Lipid Profile and Endothelial Function in Normal Weight Young Healthy Females.	2019
Effect of Caloric Deficit and Dietary Manipulation on Aerobic and Anaerobic Exercise.	1991

Effect of Carbohydrate Availability on Time to Exhaustion in Exercise Performed at Two Different Intensities.	2009
Effect of Diet on Muscle Glycogen and Blood Glucose Utilization During a Short-Term Exercise in Man.	1982
Effect of Dietary Modifications on Lactate Threshold and Onset of Blood Lactate Accumulation During Incremental Exercise.	1984
Effect of Fat Adaptation and Carbohydrate Restoration on Metabolism and Performance During Prolonged Cycling.	2000
Effect of High-Fat and High-Carbohydrate Diets on Pulmonary O2 Uptake Kinetics During the Transition to Moderate-Intensity Exercise.	2014
Effect of Low- and High-Carbohydrate Diets on Swimming Economy: a Crossover Study.	2020
Effect of Training in the Fasted State on Metabolic Responses During Exercise With Carbohydrate Intake.	2008

Effect of Variable Carbohydrate Intake on Exercise Performance in Female Endurance Cyclists.	2003
Effects of 3 Days of Carbohydrate Supplementation on Muscle Glycogen Content and Utilisation During a 1-H Cycling Performance.	1997
Effects of a 12-Week Very-Low Carbohydrate High-Fat Diet on Maximal Aerobic Capacity, High-Intensity Intermittent Exercise, and Cardiac Autonomic Regulation: Non-Randomized Parallel-Group Study.	2019
Effects of a 15-Day Low Carbohydrate, High-Fat Diet in Resistance-Trained Men.	2018
Effects of a 4-Week Very Low-Carbohydrate Diet on High-Intensity Interval Training Responses.	2018
Effects of a Diet Regimen on Pituitary and Steroid Hormones in Male Ice Hockey Players.	1992
Effects of a Ketogenic Diet on Body Composition and Strength in Trained Women.	2020

Effects of a Ketogenic Diet on Muscle Fatigue in Healthy, Young, Normal-Weight Women: a Randomized Controlled Feeding Trial.	2020
Effects of a Low-Carbohydrate Ketogenic Diet on Health Parameters in Resistance-Trained Women.	2021
Effects of a Short-Term "Fat Adaptation With Carbohydrate Restoration" Diet on Metabolic Responses and Exercise Performance in Well-Trained Runners.	2021
Effects of Ad Libitum Low-Carbohydrate High-Fat Dieting in Middle-Age Male Runners.	2018
Carbohydrate Balance in Competitive Runners During Successive Days of Intense Training.	1988
Effects of Carbohydrate Supplementation During Intense Training on Dietary Patterns, Psychological Status, and Performance.	1995
Effects of Carbohydrate Supplementation on Competitive Runners Undergoing Overload Training Followed by a Session of Intermittent Exercise.	2010

Effects of Carbohydrate Supplementation on Performance and Carbohydrate Oxidation After Intensified Cycling Training.	2004
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Plos One	Burke LM and Sharma AP and Heikura IA and Forbes SF and Holloway M and McKay AKA and Bone JL and Leckey JJ and Welvaert M and Ross ML
Journal of Applied Physiology	Cox GR and Clark SA and Cox AJ and Halson SL and Hargreaves M and Hawley JA and Jeacocke N and Snow RJ and Yeo WK and Burke LM
American Journal of Physiology, Endocrinology and Metabolism	Stellingwerff T and Spriet LL and Watt MJ and Kimber NE and Hargreaves M and Hawley JA and Burke LM
International Journal of Sport Nutrition and Exercise Metabolism	Bounds RG and Grandjean PW and O'Brien BC and Inman C and Crouse SF
the American Journal of Clinical Nutrition	Lamb DR and Rinehardt KF and Bartels RL and Sherman WM and Snook JT
the American Journal of Clinical Nutrition	Sherman WM and Doyle JA and Lamb DR and Strauss RH
Journal of Applied Physiology	Simonsen JC, Sherman WM, Lamb DR, et al.

International Journal of Sport Nutrition and Exercise Metabolism	Jacobs KA and Paul DR and Geor RJ and Hinchcliff KW and Sherman WM
Acta Physiologica Scandinavica	Svensson MB and Ekblom B and Cotgreave IA and Norman B and Sjoberg B and Ekblom O and Sjodin B and Sjodin A
International Journal of Sport Nutrition and Exercise Metabolism	Moncada-Jimenez J and Plaisance EP and Mestek ML and Ratcliff L and Araya-Ramirez F and Taylor JK and Grandjean PW and Aragonvargas LF
Journal of the International Society of Sports Nutrition	Durkalec-Michalski K and Nowaczyk PM and Siedzik K
Medicine and Science in Sports and Exercise	Shaw DM and Merien F and Braakhuis a and Maunder ED and Dulson DK
Frontiers in Physiology	Valsdottir TD and Henriksen C and Odden N and Nellemann B and Jeppesen PB and Hisdal J and Westerberg AC and Jensen J
International Journal of Sports Medicine	McMurray RG and Proctor CR and Wilson WL

Brazilian Journal of Medical and Biological Research	Lima-Silva AE and De-Oliveira FR and Nakamura FY and Gevaerd MS
Acta Physiologica Scandinavica	Jansson E and Kaijser L
European Journal of Applied Physiology and Occupational Physiology	Yoshida T
Journal of Applied Physiology	Burke LM and Angus DJ and Cox GR and Cummings NK and Febbraio MA and Gawthorn K and Hawley JA and Minehan M and Martin DT and Hargreaves M
Journal of Applied Physiology	Raper JA and Love LK and Paterson DH and Peters SJ and Heigenhauser GJ and Kowalchuk JM
Journal of the International Society of Sports Nutrition	Bestard MA and Rothschild JA and Crocker GH
Journal of Applied Physiology	De Bock K and Derave W and Eijnde BO and Hesselink MK and Koninckx E and Rose AJ and Schrauwen P and Bonen a and Richter EA and Hespel P

International Journal of Sport Nutrition and Exercise Metabolism	Reznik Dolins K and Boozer CN and Stoler F and Bartels M and DeMeersmane R and Contento I
European Journal of Applied Physiology and Occupational Physiology	Hawley JA and Palmer GS and Noakes TD
Frontiers in Physiology	Dostal T and Plews DJ and Hofmann P and Laursen PB and Cipryan L
Journal of Strength and Conditioning Research	Waldman HS and Krings BM and Basham SA and Smith JEW and Fountain BJ and McAllister MJ
Journal of Sports Science & Medicine	Cipryan L and Plews DJ and Ferretti a and Maffetone PB and Laursen PB
International Journal of Sports Medicine	Tegelman R and Aberg T and Pousette a and Carlstrom K
Journal of the International Society of Sports Nutrition	Vargas-Molina S and Petro JL and Romance R and Kreider RB and Schoenfeld BJ and Bonilla DA and BenÃ-tez-Porres J

Nutrients	Sjodin a and Hellston F and Sehlstedt E and Svensson M and Buren J
European Journal of Applied Physiology	Vargas-Molina S and Carbone L and Romance R and Petro JL and Schoenfeld BJ and Kreider RB and Bonilla DA and BenÃ-tez-Porres J
Nutrients	Che K and Qiu J and Yi L and Zou M and Li Z and Carr a and Snipe RMJ and Benardot D
Medicine and Science in Sports and Exercise	Heatherly AJ and Killen LG and Smith AF and Waldman HS and Seltmann CL and Hollingsworth a and O'Neal EK
Journal of Applied Physiology	Kirwan JP and Costill DL and Mitchell JB and Houmard JA and Flynn MG and Fink WJ and Beltz JD
International Journal of Sport Nutrition	Kreider RB and Hill D and Horton G and Downes M and Smith S and Anders B
European Journal of Applied Physiology	de Sousa MV and Madsen K and Simoes HG and Pereira RM and Negrao CE and Mendonca RZ and Takayama L and Fukui R and da Silva ME

Journal of Applied Physiology	Halson SL and Lancaster GI and Achten J and Gleeson M and Jeukendrup AE
Medicine and Science in Sports and Exercise	Muoio DM andLeddy JJ and Horvath PJ et al.
Medicine and Science in Sports and Exercise	Vogt M and Puntschart a and Howald H and Mueller B and Mannhart C and Gfeller-Tuescher L and Mullis P and Hoppeler H
Journal of Sports Science & Medicine	Russel RR and Willis KS and Ravussin E and Larson-Meyer ED
Journal of Applied Physiology	Carey AL and Staudacher HM and Cummings NK and Stepto NK and Nikolopoulos V and Burke LM and Hawley JA
Medicine and Science in Sports and Exercise	Brown RC and Cox CM
Metabolism: Clinical and Experimental	Rowlands DS and Hopkins WG

Journal of Strength and Conditioning Research	Wilson JM and Lowery RP and Roberts MD and Sharp MH and Joy JM and Shields KA and Partl JM and Volek JS and D'Agostino DP
Nutrients	Durkalec-Michalski K and Zawieja EE and Zawieja BE and Jurkowska D and Buchowski MS and Jeszka J
European Journal of Applied Physiology	Lynch NJ and Galloway DDR and Nimmo MA
Journal of Applied Physiology	Maunder E and Bradley HE and Deane CS and Hodgson AB and Jones M and Joanisse S and Turner AM and Breen L and Philp a and Wallis GA
Journal of Applied Physiology	Lane SC and Camera DM and Lassiter DG and Areta JL and Bird SR and Yeo WK and Jeacocke NA and Krook a and Zierath JR and Burke LM and Hawley JA
High Altitude Medicine & Biology	Oliver SJ and Golja P and Macdonald JH
Nutrients	Paoli a and Cenci L and Pompei P and Sahin N and Bianco a and Neri M and Caprio M and Moro T

Journal of the International Society of Sports Nutrition	Vargas S and Romance R and Petro JL and Bonilla DA and Galancho I and Espinar S and Kreider RB and BenÃtez-Porres J
International Journal of Sport Nutrition and Exercise Metabolism	Fleming J and Sharman MJ and Avery NG and Love DM and GÃ³mez AL and Scheett TP and Kraemer WJ and Volek JS
American Journal of Physiology-Regulatory, Integrative and Comparative Physiology	Edwards LM and Holloway CJ and Murray AJ and Knight NS and Carter EE and Kemp GJ and Thompson CH and Tyler DJ and Neubauer S and Robbins PA and Clarke K
European Journal of Applied Physiology and Occupational Physiology	Lambert EV and Speechly DP and Dennis SC and Noakes TD
Medicine and Science in Sports and Exercise	Marquet LA and Brisswalter J and Louis J and Tiollier E and Burke LM and Hawley JA and Hausswirth C
Journal of Sports Sciences	Killer SC and Svendsen IS and Jeukendrup AE and Gleeson M
European Journal of Applied Physiology	Psilander N and Frank P and Flockhart M and Sahlin K

Journal of Applied Physiology	Havemann L and West SJ and Goedecke JH and Macdonald IA and St Clair Gibson a and Noakes TD and Lambert EV
Journal of Applied Physiology	Yeo WK, Lessard SJ, Chen ZP, Garnham AP, Burke LM, Rivas DA, Kemp BE & Hawley JA
the American Journal of Clinical Nutrition	Smith SR and de Jonge L and Zachwieja JJ and Roy H and Nguyen T and Rood JC and Windhauser MM and Bray GA
the Journal of Physiology	Helge JW and Watt PW and Richter EA and Rennie MJ and Kiens B
International Journal of Obesity and Related Metabolic Disorders	Schrauwen P and Hoppeler H and Billeter R and Bakker AH and Pendergast DR
Physiological Reports	Impey SG and Hammond KM and Shepherd SO and Sharples AP and Stewart C and Limb M and Smith K and Philp a and Jeromson S and Hamilton DL and Close GL and Morton JP
the Journal of Physiology	Webster CC and Noakes TD and Chacko SK and Swart J and Kohn TA and Smith JA

Journal of Applied Physiology	Pruett EDR
Journal of Applied Physiology	Akerstrom TC and Fischer CP and Plomgaard P and Thomsen C and van Hall G and Pedersen BK
Experimental Physiology	Akerstrom TC and Krogh-Madsen R and Petersen AM and Pedersen BK
FASEB Journal	Leckey JJ and Hoffman NJ and Parr EB and Devlin BL and Trewin AJ and Stepto NK and Morton JP and Burke LM and Hawley JA
Journal of Sports Science & Medicine	Prins PJ and Noakes TD and Welton GL and Haley SJ and Esbenshade NJ and Atwell AD and Scott KE and Abraham J and Raabe AS and Buxton JD and Ault DL
Medicine and Science in Sports and Exercise	Brown RC and Cox CM and Goulding A
Journal of Applied Physiology	Achten J and Halson SL and Moseley L and Rayson MP and Casey a and Jeukendrup AE

American Journal of Physiology, Endocrinology and Metabolism	Zderic TW and Davidson CJ and Schenk S and Byerley LO and Coyle EF
Journal of Applied Physiology	Van Proeyen K and Szlufcik K and Nielens H and Deldicque L and Van Dyck R and Ramaekers M and Hespel P
Journal of Applied Physiology	Skovbro M and Boushel R and Hansen CN and Helge JW and Dela F
Applied Physiology, Nutrition, and Metabolism	Croft L and Bartlett JD and MacLaren DP and Reilly T and Evans L and Mattey DL and Nixon NB and Drust B and Morton JP
American Journal of Physiology, Endocrinology and Metabolism	Peters SJ and Harris RA and Wu P and Pehleman TL and Heigenhauser GJ and Spriet LL
Journal of Applied Physiology	Larson DE, Hesslink RL, Hrovat MI, et al
Nutrition & Metabolism	Urbain P and Strom L and Morawski L and Wehrle a and Deibert P and Bertz H

Medicine and Science in Sports and Exercise	Helge JW, Wulff B, Kiens B
Acta Physiologica Scandinavica	Nybo L and Pedersen K and Christensen B and Aagaard P and Brandt N and Kiens B
International Journal of Sports Medicine	Cole M and Coleman D and Hopker J and Wiles J
Diabetes	Schrauwen P and Wagenmakers AJ and van Marken Lichtenbelt WD and Saris WH and Westerterp KR
the Journal of Clinical Investigation	Hesselink MK and Greenhaff PL and Constantin-Teodosiu D and Hultman E and Saris WH and Nieuwlaat R and Schaart G and Kornips E and Schrauwen P
International Journal of Sports Medicine	Cox AJ and Pyne DB and Cox GR and Callister R and Gleeson M
Respiration Physiology	Hughson RL and Kowalchuk JM

American Journal of Clinical Nutrition	Martin B, Robinson S, Robertshaw D.
European Journal of Applied Physiology	Lane AR and Duke JW and Hackney AC
Medicine and Science in Sports and Exercise	Pogliaghi S and Veicsteinas A
International Journal of Food Sciences and Nutrition	Durkalec-Michalski K and Zawieja EE and Zawieja BE and Podgorski T and Jurkowska D and Jeszka J
International Journal of Sport Nutrition and Exercise Metabolism	McKay AKA and Heikura IA and Burke LM and Peeling P and Pyne DB and van Swelm RPL and Laarakkers CM and Cox GR
American Journal of Physiology, Endocrinology and Metabolism	Frost EA and Redman LM and de Jonge L and Rood J and Zachwieja JJ and Volaufova J and Bray GA and Smith SR
the Journal of Physiology	Helge JW and Richter EA and Kiens B

Nutrients	Durkalec-Michalski K and Nowaczyk PM and Glowka N and Ziobrowska a and Podgorski T
Metabolism: Clinical and Experimental	McSwiney FT and Wardrop B and Hyde PN and Lafountain RA and Volek JS and Doyle L
Journal of the International Society of Sports Nutrition	Zinn C and Wood M and Williden M and Chatterton S and Maunder E
Journal of the International Society of Sports Nutrition	Paoli A and Grimaldi K and D'Agostino D and Cenci L and Moro T and Bianco A and Palma A
Clinical Physiology	Kiens B and Essen-Gustavsson B and Gad P and Lithell H
the Journal of Physiology	Burke LM and Ross ML and Garvican-Lewis LA and Welvaert M and Heikura IA and Forbes SG and Mirtschin JG and Cato LE and Strobel N and Sharma AP and Hawley JA
the Journal of Physiology	Burke LM and Ross ML and Garvican-Lewis LA and Welvaert M and Heikura IA and Forbes SG and Mirtschin JG and Cato LE and Strobel N and Sharma AP and Hawley JA

Metabolism: Clinical and Experimental	Cutler DL and Gray CG and Park SW and Hickman MG and Bell JM and Kolterman OG
Sports (Basel, Switzerland)	McSwiney FT and Doyle L
the Journal of Sports Medicine and Physical Fitness	Wroble KA and Trott MN and Schweitzer GG and Rahman RS and Kelly PV and Weiss EP
American Journal of Physiology, Endocrinology and Metabolism	Coyle EF and Jeukendrup AE and Oseto MC and Hodgkinson BJ and Zderic TW
International Journal of Sport Nutrition and Exercise Metabolism	Cochran AJ and Myslik F and MacInnis MJ and Percival ME and Bishop D and Tarnopolsky MA and Gibala MJ
Clinical Nutrition (Edinburgh, Scotland)	Constantin-Teodosiu D and Cederblad G and Bergstrom M and Greenhaff PL
Metabolism: Clinical and Experimental	Goedecke JH and Christie C and Wilson G and Dennis SC and Noakes TD and Hopkins WG and Lambert EV

Clinical Nutrition (Edinburgh, Scotland)	Vidic V and Ilic V and Toskic L and Jankovic N and Ugarkovic D
the British Journal of Nutrition	Hurni M and Burnand B and Pittet P and Jequier E
American Journal of Physiology-Regulatory, Integrative and Comparative Physiology	Helge JW and Kiens B
International Journal of Sports Medicine	Hoppeler H and Billeter R and Horvath PJ and Leddy JJ and Pendergast DR
Journal of Applied Physiology	Dernbach AR and Sherman WM and Simonsen JC and Flowers KM and Lamb DR
Metabolism: Clinical and Experimental	Volek JS and Freidenreich DJ and Saenz C and Kunces LJ and Creighton BC and Bartley JM and Davitt PM and Munoz CX and Anderson JM and Maresh CM and Lee EC and Schuenke MD and Aerni G and Kraemer WJ and Phinney SD
Acta Physiologica Scandinavica	Jansson E

the Journal of Sports Medicine and Physical Fitness	Terada T and Toghi Eshghi SR and Liubaoerjijin Y and Kennedy M and Myette-Cote E and Fletcher K and Boule NG
Journal of Applied Physiology	Helge, J.W. and Watt, P.W. and Richter, E.A. and Rennie, M.J. and Kiens, B.
Nutrition Research	Graybeal AJ and Kreutzer a and Rack P and Moss K and Augsburger G and Willis JL and Braun-Trocchio R and Shah M
Nutrients	Marquet LA and Hausswirth C and Molle O and Hawley JA and Burke LM and Tiollier E and Brisswalter J
Journal of Applied Physiology	Mortensen OH and Plomgaard P and Fischer CP and Hansen AK and Pilegaard H and Pedersen BK
Medicine and Science in Sports and Exercise	Hammond KM and Impey SG and Currell K and Mitchell N and Shepherd SO and Jeromson S and Hawley JA and Close GL and Hamilton LD and Sharples AP and Morton JP
the Journal of Clinical Endocrinology and Metabolism	Johannessen a and Hagen C and Galbo H

American Journal of Physiology, Endocrinology and Metabolism	Putman CT and Spriet LL and Hultman E and Lindinger MI and Lands LC and McKelvie RS and Cederblad G and Jones ML and Heigenhauser GJ
American Journal of Physiology, Endocrinology and Metabolism	St Amand TA and Spriet LL and Jones NL and Heigenhauser GJ
American Journal of Physiology-Regulatory, Integrative and Comparative Physiology	Stubbs RJ and Hughes DA and Johnstone AM and Whybrow S and Horgan GW and King N and Blundell J
Journal of Applied Physiology	Morton JP and Croft L and Bartlett JD and Maclaren DP and Reilly T and Evans L and McArdle a and Drust B
American Journal of Physiology-Regulatory, Integrative and Comparative Physiology	Bartlett JD and Louhelainen J and Iqbal Z and Cochran AJ and Gibala MJ and Gregson W and Close GL and Drust B and Morton JP
International Journal of Sport Nutrition and Exercise Metabolism	Webster, C.C. and van Boom, K.M. and Armino, N. and Larmuth, K. and Noakes, T.D. and Smith, J.A. and Kohn, T.A.
American Journal of Physiology, Endocrinology and Metabolism	Frosig C and Roepstorff C and Brandt N and Maarbjerg SJ and Birk JB and Wojtaszewski JF and Richter EA and Kiens B

Nutrition & Metabolism	Jabekk PT and Moe IA and Meen HD and Tomten SE and HÃ¸stmark AT
European Journal of Applied Physiology	Badenhorst CE and Dawson B and Cox GR and Sim M and Laarakkers CM and Swinkels DW and Peeling P
Acta Scientiarum Polonorum. Technologia Alimentaria	Bykowska-Derda a and Darr R and Czlapka-Matyasik M and Horvath P
Metabolism: Clinical and Experimental	Tamura Y and Watada H and Igarashi Y and Nomiyama T and Onishi T and Takahashi K and Doi S and Katamoto S and Hirose T and Tanaka Y and Kawamori R
International Journal of Sport Nutrition and Exercise Metabolism	Staudacher HM and Carey AL and Cummings NK and Hawley JA and Burke LM
Journal of Applied Physiology	Hansen AK and Fischer CP and Plomgaard P and Andersen JL and Saltin B and Pedersen BK
Medicine and Science in Sports and Exercise	Gejl KD and Thams LB and Hansen M and Rokkedal-Lausch T and Plomgaard P and Nybo L et al.

International Journal of Sport Nutrition and Exercise Metabolism	McKay AKA and Peeling P and Pyne DB and Tee N and Welveart M and Heikura IA and Sharma AP and Whitfield J and Ross ML and van Swelm RPL and Laarakkers CM and Burke LM
Metabolism: Clinical and Experimental	Griffin BA and Skinner ER and Maughan RJ
European Journal of Applied Physiology and Occupational Physiology	Ball D and Greenhaff PL and Maughan RJ
European Journal of Applied Physiology and Occupational Physiology	Langfort J and Zarzeczny R and Pilis W and Nazar K and Kaciuba-UÅ›citko H
International Journal of Exercise Science	Escobar KA and Morales J and Vandusseldorp TA
European Journal of Applied Physiology and Occupational Physiology	Maughan RJ and Greenhaff PL and Gleeson M and Fenn CE and Leiper JB
Journal of Sports Sciences	Hamzah S and Higgins S and Abraham T and Taylor P and Vizbaraite D and Malkova D

Food Science & Nutrition	Wrzosek M and Wozniak J and Wlodarek D
International Journal of Sport Nutrition and Exercise Metabolism	Langfort JL and Zarzeczny R and Nazar K and Kaciuba-Uscilko H
Research In Sports Medicine (Print)	Robins AL and Davies DM and Jones GE
Journal of Exercise Rehabilitation	Rhyu, H.; Cho, S.-Y.
International Journal of Sports Medicine	Costa RJ and Jones GE and Lamb KL and Coleman R and Williams JH
Nutrients	Zajac a and Poprzecki S and Maszczyk a and Czuba M and Michalczyk M and Zydek G
European Journal of Applied Physiology and Occupational Physiology	Pitsiladis YP and Maughan RJ

European Journal of Applied Physiology and Occupational Physiology	Pitsiladis YP and Maughan RJ
Nutrients	Murtaza N and Burke LM and Vlahovich N and Charlesson B and O' Neill H and Ross ML and Campbell KL and Krause L and Morrison M
Metabolism: Clinical and Experimental	Thompson PD and Cullinane EM and Eshleman R and Kantor MA and Herbert PN
Journal of Exercise Rehabilitation	Rhyu HS and Cho SY and Roh HT
Metabolism: Clinical and Experimental	Phinney SD and Bistrian BR and Evans WJ and Gervino E and Blackburn GL
Journal of Sports Sciences	McKay AKA and Pyne DB and Peeling P and Sharma AP and Ross MLR and Burke LM
Journal of Sports Sciences	McKay AKA and Pyne DB and Peeling P and Sharma AP and Ross MLR and Burke LM

European Journal of Applied Physiology	Louis J and Marquet LA and Tiollier E and Bermon S and Hausswirth C and Brisswalter J
Nutrients	Kysel P and Haluzikova D and Dolezalova RP and Lankova I and Lacinova Z and Kasperova BJ and Trnovaska J and Hradkova V and Mraz M and Vilikus Z and Haluzik M
Medicine and Science in Sports and Exercise	Blanchard MA and Jordan G and Desbrow B and MacKinnon LT and Jenkins DG
British Journal of Sports Medicine	Jenkins DG and Hutchins CA and Spillman D
Diabetes	Constantin-Teodosiu, D. and Constantin, D. and Stephens, F. and Laithwaite, D. and Greenhaff, P.L.
the American Journal of Clinical Nutrition	Roy HJ and Lovejoy JC and Keenan MJ and Bray GA and Windhauser MM and Wilson JK
European Journal of Applied Physiology	Van Proeyen K and De Bock K and Hespel P

the Journal of Physiology	Van Proeyen K and Szlufcik K and Nielens H and Pelgrim K and Deldicque L and Hesselink M and Van Veldhoven PP and Hespel P
Medicine and Science in Sports and Exercise	Hulston CJ and Venables MC and Mann CH and Martin C and Philp A and Baar K, et al.
Experimental Physiology	Yeo WK, McGee SL, Carey AL, Paton CD, Garnham AP, Hargreaves M, et al.
Clinical Physiology	Gollnick P and Pernow P and Essen B and Jansson E and Saltin B
the Journal of Sports Medicine and Physical Fitness	Gavin JP and Myers SD and Willems ME
Applied Physiology, Nutrition, and Metabolism	Stoa EM and Nyhus LK and Borresen SC and Nygaard C and Hovet AM and Bratland-Sanda S and Helgerud J and Storen O
European Journal of Applied Physiology and Occupational Physiology	Czarnowski D and Langfort J and Pilis W and Gorski J

Journal of Applied Physiology	Howarth, K.R. and Phillips, S.M. and MacDonald, M.J. and Richards, D. and Moreau, N.A. and Gibala, M.J.
International Journal of Sport Nutrition	Gleeson M and Blannin AK and Walsh NP and Bishop NC and Clark AM
European Journal of Applied Physiology	Johnson NA and van Overbeek D and Chapman PG and Thompson MW and Sachinwalla T and George J
Medicine and Science in Sports and Exercise	Burke LM and Hawley JA and Angus DJ et al
Medicine and Science in Sports and Exercise	Stepto NK and Carey AL and Staudacher HM and Cummings NK and Burke LM and Hawley JA
Journal of Applied Physiology	Churchley EG and Coffey VG and Pedersen DJ and Shield A and Carey KA and Cameron-Smith D and Hawley JA
the Journal of Physiology	Blomstrand E and Saltin B

Journal of Applied Physiology	Yeo WK and Paton CD and Garnham AP and Burke LM and Carey AL and Hawley JA
FASEB Journal	Keller C and Steensberg A and Pilegaard H, et al
Journal of Physiology	Pilegaard H and Keller C and Steensberg A et al.
Journal of Physiology	Pilegaard H and Keller C and Steensberg A et al.
Applied Physiology, Nutrition, and Metabolism	Steinberg GR and Watt MJ and McGee SL, et al
European Journal of Applied Physiology and Occupational Physiology	Helie R and Lavoie JM and Cousineau D
European Journal of Applied Physiology	Klapcinska B and Sadowska-Krepa E and Manowska B and Pilis W and Sobczak a and Danch A

Applied Physiology, Nutrition, and Metabolism	Lima-Silva AE and Pires FO and Bertuzzi R and Silva-Cavalcante MD and Oliveira RS and Kiss MA and Bishop D
Journal of Applied Physiology	Duhamel TA and Green HJ and Perco JG and Ouyang J
Metabolism	Margolis LM and Wilson MA andvWhitney CC and Carrigan CT and Murphy NE and Hatch AM and Montain SJ and Pasiakos SM
Experimental Physiology	Hearris MA and Owens DJ and Strauss JA and Shepherd SO and Sharples AP and Morton JP and Louis JB
Journal of Applied Physiology	Creer a and Gallagher P and Slivka D and Jemiolo B and Fink W and Trappe S
Journal of Applied Physiology	Hargreaves M and McConell G and Proietto J
Journal of the International Society of Sports Nutrition	Margolis LM and Wilson MA and Whitney CC and Carrigan CT and Murphy NE and Hatch-McChesney a and Pasiakos SM

Journal of Applied Physiology	Johnson NA and Stannard SR and Mehalski K and Trenell MI and Sachinwalla T and Thompson CH and Thompson MW
Psychophysiology	Lima-Silva AE and Pires FO and Bertuzzi RC and Lira FS and Casarini D and Kiss MA
American Journal of Physiology, Endocrinology and Metabolism	Zderic TW and Schenk S and Davidson CJ and Byerley LO and Coyle EF
Sports (Basel, Switzerland)	Kephart WC and Pledge CD and Roberson PA and Mumford PW and Romero MA and Mobley CB and Martin JS and Young KC and Lowery RP and Wilson JM and Huggins KW and Roberts MD
American Journal of Physiology-Regulatory, Integrative and Comparative Physiology	Lindinger MI and Spriet LL and Hultman E and Putman T and McKelvie RS and Lands LC and Jones NL and Heigenhauser GJ
International Journal of Sport Nutrition and Exercise Metabolism	Bishop NC and Walsh NP and Haines DL and Richards EE and Gleeson M
International Journal of Sport Nutrition and Exercise Metabolism	Bishop NC and Walsh NP and Haines DL and Richards EE and Gleeson M

Applied Physiology, Nutrition, and Metabolism	Gregory R Steinberg, Matthew J Watt, Sean L McGee, Stanley Chan, Mark Hargreaves , Mark A Febbraio, David Stapleton, and Bruce E Kemp
American Journal of Physiology, Endocrinology and Metabolism	Jackman ML and Gibala MJ and Hultman E and Graham TE
Journal of Strength and Conditioning Research	Souglis AG and Chryssanthopoulos CI and Travlos AK and Zorzou AE and Gissis IT and Papadopoulos CN and Sotiropoulos AA
Experimental Physiology	Ball D and Maughan RJ
European Journal of Applied Physiology and Occupational Physiology	Greenhaff PL and Gleeson M and Maughan RJ
Nutrients	O'Brien L and Collins K and Webb R and Davies I and Doran D and Amirabdollahian F
European Journal of Applied Physiology and Occupational Physiology	Greenhaff PL and Leiper JB and Ball D and Maughan RJ

European Journal of Applied Physiology and Occupational Physiology	Maassen N and Busse MW
FASEB Journal	Chan MH and McGee SL and Watt MJ and Hargreaves M and Febbraio MA
Journal of Applied Physiology	Starling RD and Trappe TA and Parcell AC and Kerr CG and Fink WJ and Costill DL
European Journal of Applied Physiology	Psilander N and Frank P and Flockhart M and Sahlin K
Journal of Applied Physiology	Hearris MA and Hammond KM and Seaborne RA and Stocks B and Shepherd SO and Philp A and Sharples AP and Morton JP and Louis JB
European Journal of Sport Science	Podlogar T and Free B and Wallis GA
Medicine and Science in Sports and Exercise	Gillen JB and West DWD and Williamson EP and Fung HJW and Moore DR

American Journal of Physiology, Endocrinology and Metabolism	Roepstorff C and Halberg N and Hillig T and Saha AK and Ruderman NB and Wojtaszewski JF and Richter EA and Kiens B
International Journal of Sport Nutrition and Exercise Metabolism	Waterworth SP and Spencer CC and Porter AL and Morton JP
the Journal of Physiology	Hammond KM and Sale C and Fraser W and Tang J and Shepherd SO and Strauss JA and Close GL and Cocks M and Louis J and Pugh J and Stewart C and Sharples AP and Morton JP
the Journal of Physiology	Roepstorff C and Vistisen B and Donsmark M and Nielsen JN and Galbo H and Green KA and Hardie DG and Wojtaszewski JF and Richter EA and Kiens B
American Journal of Physiology, Endocrinology and Metabolism	Schrauwen P and van Marken Lichtenbelt WD and Saris WH and Westerterp KR
Journal of the American College of Nutrition	Paris HL and Fulton TJ and Wilhite DP and Baranauskas MN and Chapman RF and Mickleborough TD
European Journal of Applied Physiology and Occupational Physiology	Casey a and Short AH and Curtis S and Greenhaff PL

International Journal of Sports Physiology and Performance	Russo I and Della Gatta PA and Garnham a and Porter J and Burke LM and Costa RJS
European Journal of Applied Physiology	Skein M and Duffield R and Kelly BT and Marino FE
International Journal of Sports Physiology and Performance	Webster CC and Swart J and Noakes TD and Smith JA
Journal of Applied Physiology	Ainslie PN and Abbas K and Campbell IT and Frayn KN and Harvie M and Keegan MA and MacLaren DP and Macdonald IA and Paramesh K and Reilly T
Journal of Strength and Conditioning Research	Leveritt M and Abernethy P
Journal of Sports Medicine and Physical Fitness	Van Zant RS and Conway JM and Seale JL
Journal of Strength and Conditioning Research	Sawyer JC and Wood RJ and Davidson PW and Collins SM and Matthews TD andGregory SM and Paolone WJ

Journal of Strength and Conditioning Research	Wilson JM and Lowery RP and Roberts MD and Sharp MH and Joy JM and Shields KA and Part J and Volek IJS and D'Agostino D
Journal of Applied Physiology	Camera DM and West DWD and Burd NA and Phillips SM and Garnham AP and Hawley JA and Coffey VG
Annals of Sports Medicine and Research	Skemp K. and Stehly M and Baumann D
Medicine and Science in Sports and Exercise	McKay AKA and Peeling P and Pyne DB and Tee N and Whitfield J and Sharma AP and Heikura I and Burke LM
Frontiers in Nutrition	Cipryan L and Dostal T and Litschmannova M and Hofmann P and Maffetone PB and Laursen PB
European Journal of Applied Physiology	Johnson NA and Stannard SR and Chapman PG and Thompson MW
Plos One	Bennett S and Tiollier E and Brocherie F and Owens DJ and Morton JP and Louis J

European Journal of Sport Science	Salokannel MM and Hakulien OM and Ahtianen JP
European Journal of Sport Science	Salokannel MM and Hakulien OM and Ahtianen JP

CHO STRATEGY	THEME
P-CHO	Indirect Associations
MvH	Indirect Associations
LCHF	Indirect Associations
MvH	Performance
P-CHO	Indirect Associations
MvH	Indirect Associations

MvH	Performance
LCHF	Performance
LCHF	Indirect Associations
LCHF	Performance
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations

MvH	Indirect Associations
MvH	Performance
P-CHO	Indirect Associations
LCHF	Performance
MvH	Performance
LCHF	Performance
LCHF	Indirect Associations

LCHF	Indirect Associations
P-CHO	Performance
LCHF	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Performance
LCHF	Indirect Associations

P-CHO	Indirect Associations
LCHF	Performance
LCHF	Performance
LCHF	Performance
LCHF	Performance
P-CHO	Performance
LCHF	Indirect Associations

LCHF	Performance
P-CHO	Indirect Associations
LCHF	Performance
P-CHO	Performance
LCHF	Performance
P-CHO	Performance
LCHF	Performance

P-CHO	Indirect Associations
P-CHO	Indirect Associations
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Indirect Associations
LCHF	Indirect Associations
P-CHO	Performance

LCHF	Performance
LCHF	Performance
LCHF	Performance
LCHF	Indirect Associations
MvH	Performance
MvH	Performance
MvH	Performance

LCHF	Performance
LCHF	Performance
LCHF	Performance
LCHF	Indirect Associations
LCHF	Performance
LCHF	Indirect Associations
MvH	Performance

LCHF	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Performance

MvH	Performance
MvH	Performance
LCHF	Performance
LCHF	Performance
LCHF	Performance
MvH	Indirect Associations
LCHF	Performance

LCHF	Performance
LCHF	Indirect Associations
LCHF	Performance
LCHF	Performance
MvH	Indirect Associations
MvH	Performance
MvH	Performance

MvH	Performance
MvH	Performance
LCHF	Performance
MvH	Performance
LCHF	Performance
LCHF	Indirect Associations
LCHF	Performance

LCHF	Performance
MvH	Performance
LCHF	Performance
MvH	Indirect Associations
P-CHO	Indirect Associations
MvH	Performance
LCHF	Performance

LCHF	Indirect Associations
LCHF	Performance
LCHF	Performance
LCHF	Performance
P-CHO	Performance
MvH	Performance
P-CHO	Indirect Associations

LCHF	Performance
LCHF	Indirect Associations
MvH	Indirect Associations
LCHF	Indirect Associations
MvH	Indirect Associations
P-CHO	Performance
LCHF	Indirect Associations

LCHF	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
LCHF	Performance
LCHF	Performance
LCHF	Indirect Associations
MvH	Performance

LCHF	Indirect Associations
LCHF	Performance
LCHF	Indirect Associations
P-CHO	Performance
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LCHF	Performance
LCHF	Performance

LCHF	Performance
P-CHO	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
LCHF	Indirect Associations
MvH	Performance
LCHF	Indirect Associations

LCHF	Performance
MvH	Indirect Associations
LCHF	Performance
MvH	Performance
P-CHO	Indirect Associations
LCHF	Indirect Associations
LCHF	Performance

LCHF	Performance
LCHF	Performance
LCHF	Performance
LCHF	Performance
MvH	Indirect Associations
P-CHO	Performance
LCHF	Performance

LCHF	Indirect Associations
LCHF	indirect Associations
LCHF	Performance
MvH	Indirect Associations
P-CHO	Performance
LCHF	Indirect Associations
LCHF	Performance

LCHF	Performance
MvH	Indirect Associations
LCHF	Indirect Associations
LCHF	Performance
MvH	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations

P-CHO	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Performance
P-CHO	Indirect Associations
P-CHO	Indirect Associations
LCHF	Performance

LCHF	Performance
LCHF	Indirect Associations
MvH	Indirect Associations
P-CHO	Performance
P-CHO	Indirect Associations
LCHF	Indirect Associations
LCHF	Indirect Associations

LCHF	Indirect Associations
MvH	Indirect Associations
LCHF	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Performance

MvH	Indirect Associations
LCHF	Indirect Associations
LCHF	Performance
LCHF	Performance
MvH	Performance
LCHF	Indirect Associations
MvH	Performance

LCHF	Indirect Associations
LCHF	Indirect Associations
LCHF	Performance
LCHF	Performance
MvH	Indirect Associations
LCHF	Performance
MvH	Performance

MvH	Performance
P-CHO	Indirect Associations
LCHF	Indirect Associations
LCHF	Indirect Associations
LCHF	Performance
LCHF	Indirect Associations
P-CHO	Indirect Associations

P-CHO	Performance
LCHF	Performance
MvH	Indirect Associations
LCHF	Performance
LCHF	Indirect Associations
LCHF	Indirect Associations
P-CHO	Indirect Associations

P-CHO	Performance
P-CHO	Performance
P-CHO	Performance
P-CHO	Indirect Associations
P-CHO	Indirect Associations
LCHF	Indirect Associations
LCHF	Indirect Associations

P-CHO	Indirect Associations
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LCHF	Indirect Associations
LCHF	Performance
LCHF	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations

P-CHO	Performance
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
LCHF	Indirect Associations

LCHF	Performance
LCHF	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations

P-CHO	Indirect Associations
LCHF	Performance
P-CHO	Indirect Associations
LCHF	Performance
P-CHO	Indirect Associations
P-CHO	Indirect Associations
P-CHO	Indirect Associations

P-CHO	Indirect Associations
P-CHO	Performance
LCHF	Performance
MvH	Performance
LCHF	Indirect Associations
MvH	Performance
LCHF	Indirect Associations

P-CHO	Performance
P-CHO	Indirect Associations
LCHF	Performance
P-CHO	Indirect Associations
P-CHO	Performance
P-CHO	Performance
P-CHO	Indirect Associations

P-CHO	Indirect Associations
P-CHO	Performance
P-CHO	Indirect Associations
P-CHO	Indirect Associations
LCHF	Indirect Associations
P-CHO	Performance
LCHF	Performance

P-CHO	Performance
P-CHO	Performance
P-CHO	Performance
LCHF	Indirect Associations
LCHF	Performance
MvH	Performance
LCHF	Performance

LCHF	Performance
P-CHO	Indirect Associations
LCHF	Indirect Associations
LCHF	Indirect Associations
LCHF	Performance
LCHF	Performance
P-CHO	Performance

P-CHO Indirect Associations

P-CHO Performance

POPULATION	ATHLETIC CALIBRE
Males Only	Unclassified
Males Only	Tier 4
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 1
Females Only	Unclassified

Males Only	Unclassified
Mixed cohort	Tier 2
Mixed cohort	Tier 0
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 1
Males Only	Tier 1

Males Only	Tier 2
Males Only	Tier 2
Males Only	Unclassified
Females Only	Tier 2
Females Only	Tier 2
Males Only	Tier 2
Males Only	Unclassified

Males Only	Tier 2
Males Only	Unclassified
Mixed cohort	Tier 3
Mixed cohort	Tier 4
Males Only	Unclassified
Males Only	Tier 1
Mixed cohort	Tier 4

Males Only	Tier 2
Mixed cohort	Tier 4
Males Only	Tier 2
Males Only	Tier 4
Males Only	Unclassified
MvFdes	Unclassified
Females Only	Tier 2

Males Only	Tier 3
Males Only	Tier 4
Males Only	Tier 2
Males Only	Tier 1
Males Only	Tier 5
Males Only	Tier 4
Males Only	Tier 2

Males Only	Tier 4
Males Only	Unclassified
Mixed cohort	Tier 4
Mixed cohort	Tier 4
Mixed cohort	Tier 4
Males Only	Unclassified
Mixed cohort	Tier 4

Mixed cohort	Tier 4
Males Only	Tier 2
Males Only	Unclassified
Males Only	Tier 1
Males Only	Tier 3
Males Only	Unclassified
Mixed cohort	Tier 3

Males Only	Tier 0
Males Only	Unclassified
Males Only	Tier 2
MvFdes	Tier 2
Males Only	Tier 2
Females Only	Unclassified
Males Only	Tier 3

Males Only	Unclassified
Mixed cohort	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Mixed cohort	Tier 2
Males Only	Unclassified

Females Only	Tier 1
Males Only	Tier 2
Mixed cohort	Tier 0
Males Only	Tier 1
Males Only	Tier 1
Males Only	Tier 4
Females Only	Unclassified

Females Only	Unclassified
Females Only	Unclassified
Males Only	Tier 3
Males Only	Tier 2
Males Only	Unclassified
Males Only	Tier 4
Males Only	Tier 4

Males Only	Tier 2
Males Only	Tier 3
Males Only	Tier 3
MvFsub	Tier 2
Males Only	Tier 4
Mixed cohort	Tier 2
Males Only	Tier 3

Males Only	Unclassified
Mixed cohort	Tier 2
Females Only	Unclassified
Males Only	Unclassified
Males Only	Tier 2
Mixed cohort	Unclassified
Males Only	Tier 2

Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 3
Males Only	Tier 2
Males Only	Tier 2
Males Only	Tier 2
Males Only	Tier 3

Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 0
Males Only	Unclassified
Mixed cohort	Tier 2
Males Only	Tier 2
Males Only	Tier 2

Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 2
Males Only	Tier 2
Mixed cohort	Tier 2
Males Only	Tier 2

Males Only	Unclassified
Males Only	Tier 1
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 1
Mixed cohort	Tier 1
Mixed cohort	Unclassified

Males Only	Unclassified
Males Only	Tier 0
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Females Only	Unclassified

Males Only	Unclassified
Males Only	Tier 1
Males Only	Unclassified
Mixed cohort	Tier 2
Mixed cohort	Unclassified
Males Only	Unclassified
Males Only	Unclassified

MvFdes	Tier 2
Males Only	Tier 2
Mixed cohort	Tier 2
Males Only	Tier 3
Males Only	Tier 1
Males Only	Tier 4
Males Only	Tier 4

Males Only	Unclassified
Males Only	Tier 1
Mixed cohort	Tier 1
Males Only	Unclassified
Mixed cohort	Tier 1
Males Only	Unclassified
Males Only	Unclassified

Males Only	Tier 1
Mixed cohort	Unclassified
Males Only	Unclassified
Males Only	Tier 2
MvFsub	Tier 3
Males Only	Tier 4
Mixed cohort	Unclassified

Males Only	Tier 2
Males Only	Unclassified
Mixed cohort	Tier 2
Males Only	Tier 2
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified

Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 2
Males Only	Unclassified

Females Only	Unclassified
Males Only	Unclassified
Males Only	Tier 1
Males Only	Tier 2
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 3

Males Only	Tier 4
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Mixed cohort	Tier 1
Males Only	Unclassified
Males Only	Tier 2

Males Only	Tier 1
Males Only	Unclassified
Males Only	Tier 2
Males Only	Tier 2
Males Only	Tier 2
Males Only	Tier 2
Males Only	Unclassified

Males Only	Unclassified
Males Only	Tier 4
Males Only	Tier 2
Males Only	Tier 2
Males Only	Unclassified
Mixed cohort	Tier 4
Mixed cohort	Tier 4

Males Only	Tier 2
Males Only	Tier 1
Males Only	Tier 2
Males Only	Unclassified
Males Only	Unclassified
Males Only	Comparison study- tier 1 (n=11) vs tier 0 (n=6)
Males Only	Unclassified

Males Only	Tier 1
Males Only	Tier 2
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Females Only	Tier 1
Males Only	Unclassified

Males Only	Tier 1
Males Only	Unclassified
Males Only	Tier 1
Males Only	Unclassified
Males Only	Tier 2
Males Only	Tier 1
Males Only	Unclassified

Males Only	Tier 2
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 1
Males Only	Unclassified
Females Only	Unclassified

Males Only	Unclassified
Females Only	Tier 0
Males Only	Unclassified
Males Only	Tier 2
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified

Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Mixed cohort	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified

Males Only	Tier 1
Mixed cohort	Unclassified
Males Only	Tier 3
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 2
Males Only	Unclassified

Males Only	Unclassified
Males Only	Unclassified
Males Only	Unclassified
Males Only	Tier 3
Males Only	Unclassified
Mixed cohort	Tier 1
Males Only	Tier 1

Males Only	Tier 1
Males Only	Tier 1
Males Only	Unclassified
Males Only	Tier 1
Mixed cohort	Tier 0
Males Only	Unclassified
Males Only	Unclassified

Males Only	Tier 2
Males Only	Tier 2
Males Only	Tier 4
Males Only	Unclassified
Mixed cohort	Unclassified
Males Only	Tier 1
MvFdes	Tier 1

Males Only	Tier 1
Males Only	Tier 1
Females Only	Unclassified
Males Only	Tier 4
Mixed cohort	Unclassified
Males Only	Unclassified
Mixed cohort	Tier 2

Mixed cohort	Unclassified
Mixed cohort	Unclassified

MENSTRUAL STATUS	Menstrual Grade
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded

N/A	N/A
Unclassified	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded
MC	Ungraded
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
Unclassified	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A

N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
MC	Ungraded

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
Unclassified	N/A
Unclassified	N/A
Unclassified	N/A
N/A	N/A
Unclassified	N/A

Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A

N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
Mixed	Ungraded
N/A	N/A

N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A

MC	Ungraded
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded

Mixed	Ungraded
MC	Ungraded
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded
N/A	N/A
Unclassified	N/A
N/A	N/A

N/A	N/A
Unclassified	N/A
MC	Ungraded
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
Unclassified	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded

N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
MC	Ungraded
N/A	N/A
N/A	N/A

MC	Ungraded
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A

N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
Unclassified	N/A

N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
Unclassified	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
MC	Ungraded

N/A	N/A
Mixed	0.5= Ungraded; 0.5= Bronze
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
N/A	N/A

N/A	N/A
N/A	N/A
N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
Unclassified	N/A

N/A	N/A
N/A	N/A
Unclassified	N/A
N/A	N/A
MC	Ungraded
N/A	N/A
Unclassified	N/A

Unclassified	N/A
Unclassified	N/A

Supplementary Table 1 Ranking system to assess studies with female participants as per the standardized protocol of Smith et al., 2022

Tier	MC studies	Hormonal Contraceptive Studies: Oral contraceptive pill	Hormonal Contraceptive Studies: Other	Menstrual irregularities studies
Gold	Participants are eumenorrheic: 1. have MC lengths ≥21 days and ≤35 days resulting in nine or more consecutive periods per year 2. evidence of LH surge 3. correct hormonal profile (from blood sample analysis) 4. no HC use 3 months prior to recruitment MC characteristics are tracked for ≥2 months prior to testing	OCP use ≥3 months prior to recruitment (i.e., length of usage), with the type (e.g., mono, bi, or triphasic; combined or progesterone only and formulation [name and concentration of exogenous hormones]) stated Stipulate and consider OCP taking (i.e., active OCP) days and OCP free (i.e., inactive/placebo OCP) days One brand/type of OCP per group of participants	HC use ≥3 months prior to recruitment (i.e., length of usage), with the type (e.g., implants, injections, intrauterine devices/coils that are hormone releasing and NOT copper-based, vaginal rings, contraceptive transdermal patches), and formulation (e.g., combined or progesterone only; names and concentration of exogenous hormones) stated One type of HC per group of participants	Condition diagnosed by medical professional as part of the study Length of condition stated

Tier	MC studies	Hormonal Contraceptive Studies: Oral contraceptive pill	Hormonal Contraceptive Studies: Other	Menstrual irregularities studies
	Outcome measures are repeated in a second cycle			
Silver	Participants are naturally menstruating with ovulatory cycles: 1. they experience menstruation, with MC lengths ≥ 21 days and ≤ 35 days 2. confirmed ovulation (LH) but without correct hormonal profile 3. prior HC use not stated or less than 3 months prior to recruitment	Two of three stated: OCP length of usage, type, and formulation Do/do not stipulate and consider OCP-taking (i.e., active OCP) days and OCP-free (i.e., inactive/placebo OCP) days One or more than one brand/type of OCP per group of participants	Two of three stated: HC length of usage, type, and formulation One or more than one type of HC per group of participants	Condition diagnosed by medical professional not as part of the study—self-reported or via medical records Length of condition stated/not stated

Tier	MC studies	Hormonal Contraceptive Studies: Oral contraceptive pill	Hormonal Contraceptive Studies: Other	Menstrual irregularities studies
	MC characteristics are tracked for 1 month prior to testing Outcome measures not repeated in a second cycle			
Bronze	Participants are naturally menstruating: 1. they experience menstruation, with MC lengths ≥21 days and ≤35 days 2. without confirmed ovulation and correct hormonal profile 3. prior HC use not stated or <3 months prior to recruitment	One of three stated: OCP length of usage, type, and formulation Do not stipulate and consider OCP taking (i.e., active OCP) days and OCP free (i.e., inactive/placebo OCP) days More than one brand/type of OCP per group of participants	One of three stated: HC length of usage, type, formulation More than one type of HC per group of participants	Self-reported condition without medical diagnosis OR not specified if/how the condition was diagnosed Length of condition not stated

Tier	MC studies	Hormonal Contraceptive Studies: Oral contraceptive pill	Hormonal Contraceptive Studies: Other	Menstrual irregularities studies
	No tracking of MC characteristics prior to testing			
Ungraded	Insufficient detail to award a gold, silver, or bronze	Insufficient detail to award a gold, silver, or bronze	Insufficient detail to award a gold, silver, or bronze	Insufficient detail to award a gold, silver, or bronze

Note. HC = hormonal contraception; LH = luteinizing hormone; MC = menstrual cycle; OCP = oral contraceptive pill.