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REVIEW ARTICLE

Physiological and Nutritional Considerations for Elite Squash: A Systematic Review

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Abstract

Purpose To systematically review all the physiological and nutritional research conducted in squash to guide practitioners and researchers on how best to interpret the data, while identifying gaps in the literature to determine future directions of research within squash.

Methods Following PRISMA guidelines, studies investigating an aspect of physiology or nutrition within squash were identified using scientific databases CINAHL, MEDLINE, PUBMED, and SPORTDiscus, from March 2022 to October 2023.

Results Of the 1208 studies identified, 35 met the inclusion criteria across a variety of physiological and nutritional topics, such as the physiological demands of squash, anthropometric and physiological characteristics of squash players, squash-specific performance tests, training demands of squash, nutritional requirements of squash, hydration demands of squash, nutrition knowledge of squash players, and nutritional supplements for squash players. Ten studies had poor methodological quality, 19 as fair, four as good, and two as excellent. Seventeen out of 35 studies included were undertaken post the 2009 rule change, and 14 studies were conducted on either elite or world class players. Twenty-nine of the studies involved male players, with 15 involving female players.

Conclusion Much of the physiological and nutritional literature is of low quality and outdated. We present future research focuses throughout the review, such as quantifying the game characteristics of male and female players, the energy expenditures during a training and competition microcycle, and the efficacy of certain nutritional supplements. These efforts aim to create sport specific guidelines and advance evidence-based practice within squash.

Keywords Sports physiology · Sports nutrition · Racket sports · Squash · High intensity intermittent sport

Introduction

Squash is classified as one of four major racket sports along with badminton, tennis, and table-tennis [50]. It was first played at Harrow school in 1865, originating from a combination of the traditional racket sports, including real tennis and racquets [105]. Squash is unique to other major racket sports as players compete in the same area of the court, with the simplest rules being that the ball must be struck before bouncing twice and hit the front wall, landing above the tin line (bottom out of court line) and below the front wall and side wall lines [106]. There are 123 national squash federations and 50,000 courts worldwide [107]. Squash is currently included in the Pan-American Games, Asian Games, Pacific Games, Commonwealth Games, and World Games programmes [107]. It was also showcased at the 2018 Youth Olympic Games and has recently gained inclusion into the Los Angeles 2028 Summer Olympic Games programme [68]. The Professional Squash Association is the global governing body for men's and women's professional squash around the world. It has over 1400 registered players and runs more than 600 competitions around the world each year [72]. At the elite level, squash is a high intensity intermittent sport which requires a blend of physical, technical, psychological, and tactical capabilities [43]. Elite male matches are reported to last a mean match duration of 54 minutes, with players covering a mean distance of 1848 m throughout a match [63]. Squash is characterised by sport-specific

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movements which are highly dynamic and acyclic in nature, such as 3–6 metre sprints, lunges, and changes of direction [98].

Elite male squash has been reported to elicit a mean energy expenditure of 4933 ± 620 kJ/h, a mean heart rate of 92% ± 3% of heart rate maximum (HR_{max}) and a mean respiratory exchange ratio (RER) of 0.94 ± 0.06 [33], demonstrating the high intensity nature of the sport. However, in 2009, the World Squash Federation and Professional Squash Association standardised the rules for professional players, changing the scoring system from the 9 point-on serve (POS9) to an 11 point-a-rally (PAR11), while also lowering the tin line from 48.3 to 43.2 cm. This has been reported to alter the physical demands and shot characteristics of the sport, reducing the duration of rallies (pre rule changes = 15.0 ± 5 s, post rule changes = 13.2 ± 16 s), while increasing the number of shots per rally (pre rule changes = 11 ± 16; post rule changes = 13 ± 19) [63]. An interpretation of this data could be that players have changed their shot strategies to become more attacking because of the lowered tin height, as conveyed by the shorter rally durations. It can be debated that much of the research undertaken in squash is outdated due to these rule changes. Consequently, the purpose of this review was to evaluate the current physiological and nutritional literature on squash. This investigation will contribute to the current knowledge of squash by synthesising literature and have a positive impact on applied practice by presenting guidance for scientists, coaches, and players, whilst identifying gaps in knowledge to guide future research directions within squash.

Methods

Protocol and Registration

This review was conducted in accordance with the contemporary guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [69] and was prospectively registered on the Registry of Systematic Reviews & Meta-Analyses (registration number 1328) [79].

Eligibility Criteria

Original research such as randomised control trials, observational and cross-sectional studies using squash players, which are published in peer reviewed journals, were included in the review. Excluded items included abstracts, conference posters, review articles and unpublished theses. All 'standards' of squash performance (e.g. beginner, recreational, collegiate, national, elite and world class etc.) were included. Only studies written in English were included. Studies were required to investigate an aspect of nutrition (e.g. nutrition knowledge, dietary analysis, effects of a nutritional substance on squash performance) or physiology (e.g. energetic demands, training load, performance test, physiological profiling etc.) relating to squash. The underpinning biochemical and physiological demands of squash inform nutritional recommendations, hence these two subject areas were combined in this review.

Search Strategy

Studies that investigated an aspect of nutrition or physiology relating to squash were identified through the following databases: CINAHL (EBSCO), MEDLINE (EBSCO), PUBMED, and SPORTDiscus (EBSCO). A literature search was conducted every month, upon inception (March 2022) until the end date (October 2023), to retrieve newly published articles. The search strategy combined the terms ("squash sport [MeSH Terms]") AND ("squash[Title]"). Additionally, citation chaining (where another source cites another source) was also performed after the literature search using identified studies to discover other relevant research articles. After conducting the search strategy, duplicate studies were removed using Refworks bibliography software (ProQuest). Two independent reviewers (OT and NM) assessed reviewed the titles, abstracts, and descriptors of identified studies to determine eligibility. Full texts of studies that satisfied the inclusion criteria were reviewed before being selected. If there were any disagreements in this process, a third reviewer (MR) was conferred with (Fig. 1).

Data Extraction

Data extraction was conducted by the first author (OT) into an Excel (V 16.58, Microsoft) data extraction form. Extracted information included but not exclusive of; (1) participant and study characteristics (authors, age, sex, stature, body mass, sample size, playing standard); (2) type of intervention (randomised control trial, observational, cross-sectional); (3) measurement of intervention (test procedure, frequency, duration etc.); (4) means and standard deviations (SDs) for outcome measures of the intervention (e.g. nutrition knowledge score, energy expenditure, RER, time etc.).

Assessment of Methodological Quality

The PEDro scale was used to assess the methodological quality of studies (Pedro [70]. The scale rates the quality of clinical trials [16] and is commonly used across physiotherapy, health, medical research, and sport [26]. The scale has been shown to be a valid and reliable tool to distinguish between studies with low and high methodological quality

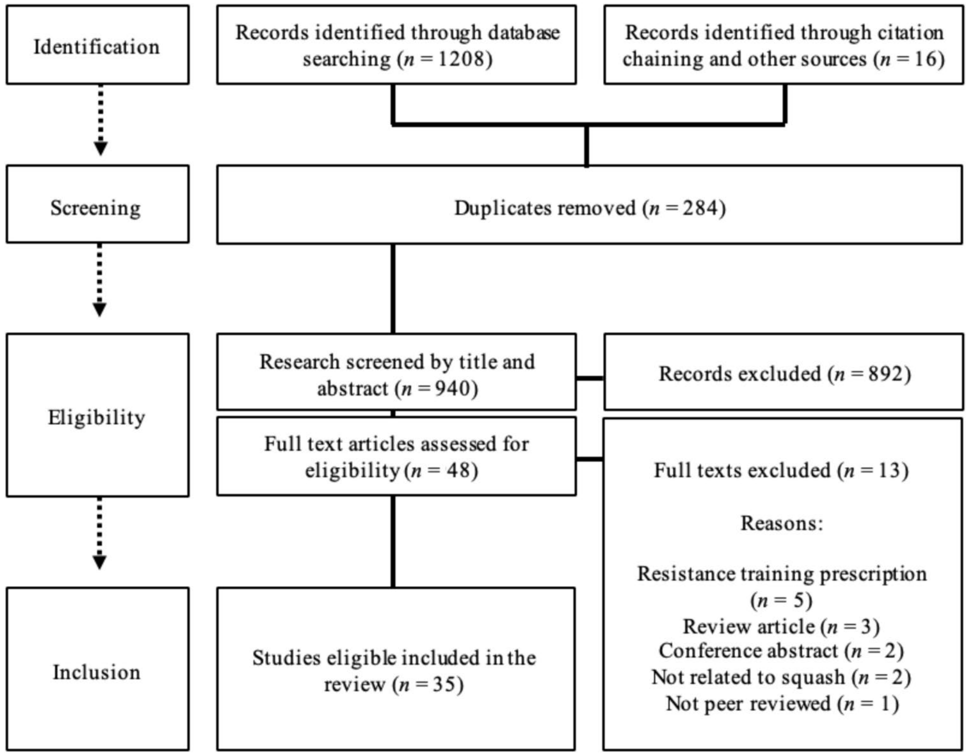

Fig. 1 PRISMA flow chart displaying the study selection process

[16]. Although the scale was originally intended for physiotherapy and clinical trials, it is considered comparable to other methodological quality scales [16]. The scale consists of 11 items, assessing external validity (item 1), internal validity (items 2 to 9), and statistical reporting (items 10 and 11). Each item is rated 1 or 0 (yes or no), depending on whether the criterion is satisfied in the study [26]. Items 2–11 scores are collated to provide a score between 0 and 10. Studies with a greater methodological quality have a higher score. Scores of less than 4 are considered 'poor', 5–6 are considered 'fair', 6–8 are considered 'good' and 9–10 are considered 'excellent' [30]. The PEDro scale has exhibited 'excellent' inter-rater reliability for clinical trials (intraclass correlation coefficient [*ICC*] = 0.91) [36]. The assessment of methodological quality was conducted by two reviewers (OT and NM). A third reviewer (MR) was conferred with if there were any disagreements.

Results

Overall, 35 studies were considered to have met the inclusion criteria and were included in the review (see Fig. 1). Table 1 displays the study characteristics, aims, methodology, results, key findings and PEDro quality rating of the reviewed studies. Many of the studies conducted in squash had poor (10) or fair (19) methodological quality, with only four being considered good and two being considered excellent. Only 14/35 studies were conducted on elite or world class players. Twenty-nine of the studies involved male players, with 15 studies involving female players, while four studies did not specify the sex of the player(s). Overall, 78% of players included in studies were male, while 22% were female. Studies that did not report the sex of the player(s) were not included in the percentage calculation. Only 17/35 studies reviewed were published during or after the 2009 rule change.

Physiological Demands of Squash

Thirteen studies have quantified a physiological demand of squash, with four studies published during or after the 2009 rule change, and four studies including either elite or world class players. The physiological demands of junior squash players have been quantified through heart rate and blood lactate concentrations during match play [54]. In recreational players, the energetic demands [60], heart rate response [7, 9, 10, 11, 52, 60], blood lactate concentrations [7], blood pressure response [10, 13], and rectal temperature during squash match play [10] have been quantified, as well as the metabolic responses [12, 52] and alterations in neuromuscular function post squash match play (Girard et al. 2008). In elite players, a game analysis has quantifyied physiological responses during match play among male players [33].

Table 1 Study characteristics, aims, methodology, results, key findings and PEDro quality rating

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Beaudin et al. [7] (Canada)	2	10 (M)	29.4	Quantify whether squash is an appropriate exercise to promote and/or maintain cardiovascular fitness Assess blood lactate levels post squash	45-min squash match	↑ Blood lactate $HR_{max} = 185 \pm 12.5$ beats/min Mean HR = 155 ± 8.2 beats/min	Squash exhibits heart rate responses which elicit aerobic training effects Squash does not produce high blood lactate concentrations	3/10 = Poor
Blanksby et al., [9] (Australia)	1–3	Sedentary = 25 (M) active = 25 (M) "A" grade = 25 (M)	Sedentary ≤ 40 active ≤ 40 "A" grade = N/A	Quantify the physiological strain of squash at different playing standards using heart rate	30-min squash match	↓ HR among middle aged active players ↔ HR between sedentary and "A" grade players	Middle aged active and "A" grade players work within tolerable limits while playing squash Middle aged sedentary players exposed themselves to a high world load and therefore players should begin slowly and allow for ample recovery time in between rallies	2/10 = Poor

Table 1 (continued)

References (Country/Area)	Participant standard tier	N (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Blanksby et al., [10] (Australia)	1–3	Sedentary = 9 (M); active = 9 (M) “A” grade = 9 (M)	Sedentary = 44.8 active = 44.2 “A” grade = 25.8	To quantify the alterations in blood pressure and rectal temperature experienced by sedentary, active and "A"-grade male squash players during a simulated match play.	30-min squash match	↑ Rectal temperature ↑ Systolic blood pressure ↓ Diastolic blood pressure	Despite squash requiring individuals to exercise at a vigorous intensity, rectal temperatures did not reach dangerous levels (37 °C to 39 °C) Blood pressure increased and anyone with already elevated blood pressure should seek medical advice before playing squash	2/10 = Poor
Bottoms et al., [11] (Scotland)	2–3	16 (M)	31 ± 6	To quantify the effects of carbohydrate ingestion on skill maintenance following short duration exercise simulating the demands of squash play in squash players	Participants participated in three trials (familiarisation, CHO trial, and PLA trial) Players completed a reaction test, maximal voluntary activation fatigue test, squash skill test, and on court shuttle running and ghosting tests	↔ Skill maintenance ↑ Visual reaction time ↔ Maximal voluntary contraction pre and post exercise	Carbohydrate ingestion during squash may maintain skill levels after fatiguing exercise due to elevated blood glucose levels	10/10 = Excellent

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Brady et al., [12] (Ireland)	2	10 (M)	49	Quantify players heart rate and metabolic response during a competitive squash match and during a ITT to compare whether metabolic changes ensued during these exercise bouts	There were two testing sessions: competitive squash match and ITT; phlebotomy and assessment of heart rate were performed immediately pre-exercise, immediately post-exercise (< 1 min), 5 minutes post-exercise, and 30 min post-exercise	↑ Mean HR post-match ↑ Plasma noradrenaline post-match ↑ Plasma LA^+ immediately post-match ↑ Blood glucose post-match ↓ Plasma potassium post-match ↑ Serum free fatty acids post-match ↔ Plasma adrenaline ↔ Haematocrit	Individuals with coronary heart disease should not partake in squash	4/10 = Fair
Brigden et al., [13] (England)	2	4 (M) 1 (F)	30	Quantify blood pressure changes while partaking in squash	Squash match (time not specified)	↑ Systolic blood pressure ↑ Mean HR	Participating in squash may be a risk for individuals with pre-existing diseases	3/10 = Poor
Chin et al., [17] (Hong Kong, China)	4	10 (Not specified)	20.7 ± 2.5	To quantify the physiological profiles of elite squash players and provide baseline data for coaches, players, and practitioners to compare against	A battery of tests including: body composition test (skinfolds); pulmonary function test; continuous running test; squash-specific field test; muscular strength test (isokinetic dynamometer); and flexibility test (sit and reach test)	Stature = 172.6 ± 4.3 cm Body mass = 67.7 ± 6.9 kg Body fat % = 7.4% ± 3.4% VO_{2max} = 61.7 ± 3.4 mL/kg/min Alactic power index = 15.5 ± 1.8 W/kg Sit and reach test = 38.5 ± 6.2 cm	Players have a low body fat %, average flexibility, and high aerobic and anaerobic capabilities	3/10 = Poor

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Girard et al., [35] (France)	3–5	7 (M)	24.9 ± 4.1	Develop a squash-specific fitness test; Compare physiological responses recorded during the IST with an ITT	Two testing sessions: ITT whereby participants completed an incremental treadmill test to exhaustion and field testing whereby participants completed a IST	↑ in VO_{2max} IST vs. ITT ↑ in competition ranking correlated with Te in ST ($r = -0.96$; $P < 0.001$)	The ST allowed for higher maximal values to be achieved The ranking of players strongly correlated with Te of the IST	6/10 = Good
Girard et al., [33] (France)	3–5	7 (M)	24.9 ± 4.1	Quantify the energetic demands of elite male squash simulated match play	Two testing sessions: Squash-specific fitness test to quantify VO_{2max} and a best of three squash match simulating	Mean $EEVO_2$ = 4933 ± 620 kJ/h Mean VO_2 = 54.4 ± 4.8 mL/min/kg Mean HR = 177 ± 10 beats/min Mean RER = 0.94 ± 0.06 Mean LA^+ = 8.3 ± 3.4 mmol/L	Elite male squash is largely a high intensity aerobic activity, while placing high demands on the anaerobic energy systems Coaches should aim to control the various energetic pathways to optimise the prescription of a conditioning session	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Girard et al., [34] (France)	2	10 (M)	32.2 ± 7.3	Quantify the alterations of neuromuscular function after simulated squash match play	Players completed a 1-hour simulated squash match play against another player. Post squash match neuromuscular test sessions occurred (maximal voluntary contractions and electromyographic signals)	↓ MVC post squash match ↓ Peak torque post squash match	1-hour simulated squash match play induces central fatigue as well as an alteration in excitation contraction coupling Training neural factors (increased reflex excitability), structural (hypertrophy) and biochemical may delay central fatigue and increase fatigue resistance	4/10 = Fair
Gouttebarge et al., [37] (Netherlands)	4	6 (F)	31 ± 8	Develop a squash specific fitness test that encompasses the physiological demands and quantify it's face and convergent validity	Two testing sessions: TT whereby participants completed an incremental treadmill test to exhaustion and field testing whereby participants completed a ST	↑ VO_{2max} TT vs. ST ↑ HR_{max} ST vs. TT ↔ LA^+	The ST had a good level of validity in comparison to the TT The ST may be preferable for practitioners as it requires minimal equipment	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	N (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
James et al., [42] (Malaysia)	4	6 (M) 2 (F)	20.3 ± 2.1	Validate and quantify the retest reliability of a squash-specific exercise test which calculates a maximal performance score as well as physiological markers such as VO_{2max}, lactate thresholds and oxygen cost in a squash-specific context	Three testing sessions: TT whereby participants completed an incremental treadmill test to exhaustion and a field testing whereby participants completed a ST in two separate trials to assess reliability of the ST	↑ VO_{2max} TT vs. ST ↑ HR_{max} ST vs. TT ↑ LA^+ TT vs. ST ↑ RPE TT vs. ST	The ST is suitable to quantify squash specific performance, alongside physiological assessments such as HR, LA^+, and VO_2 to quantify adaptations to training	6/10 = Good
James et al., [39] (Malaysia)	4	11 (M) 4 (F)	20 ± 3	Quantify the training intensities and loads of group, ghosting, feeding, matchplay and conditioning sessions across a 2-week in-season microcycle	During a two week in season period, players wore 100-Hz triaxial accelerometer/global positioning system and heart rate monitor during on court (group, feeding, ghosting and match play) and off-court (conditioning) sessions	Time > 90% maximum HR: ↓ Feeding ↔ Among other sessions Relative playerload: ↑ Conditioning ↔ Ghosting and matchplay Highest playerload: ↑ Conditioning ↑ Group (in comparison to other on court sessions) RPE: ↑ Group	Group sessions provide the highest training loads and have a key role within the training process Findings of the study help facilitate planning or adjustment of frequency, volume and intensity of sessions to reach the desired physiological result	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
James et al., [39] (Malaysia)	4	11 (M) 4 (F)	19.1 ± 2.5	Investigate the relationships between training load approaches in elite squash players, during a 2-week microcycle	Throughout 134 on-court sessions and 32 off-court 'conditioning' sessions among players: External load (playerload) was captured using a tri-axial accelerometer Internal load was quantified via HR, sRPE and dRPE-Legs; dRPE-Breathing Heart rate was utilised to quantify Banister's, Edward's and TEAM TRIMPs	Playerload was 'moderately correlated' with: TRIMP-Bannister TRIMP-Edwards Moderate correlation between s RPE and Playerload Association of sRPE was 'large' with TRIMP-Banister Association of sRPE was 'very large' with TRIMP-Edwards Association of sRPE was 'moderate' with TRIMP-TEAM sRPE-Legs and dRPE-Breathing had nearly perfect correlations with sRPE and each other	Quantifying the internal and external load of elite players is recommended to understand the physical demands of squash Isolating an individual squash training session and interpreting the data from it may underestimate or overestimate the physical stress a player is enduring	4/10 = Fair
James et al., [41] (Malaysia)	4	21 (M) 10 (F)	Males = 20 ± 4 Females = 18 ± 5	Quantify the physiological attributes of elite squash players and determine which characteristics correlate with squash performance	Participants completed: ASSPPT; RSA; COD; 5m sprint test; squat jump; countermovement jump; anthropometric profiling	Higher ranked players performed significantly better on: ↑ ASSPPT final lap ↑ 4 mmol/L lap of ASSPPT ↑ COD ASPPT 'very large' correlation with: 4 mmol/L lap of ASSPPT ASSPPT 'large' correlations with: COD RSA Sum-of-7 skinfolds VO_{2max}	Quantifying players RSA, COD, body composition and cardiovascular fitness are pertinent when profiling elite squash players	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Kingsley et al., [47] (Wales)	2	8 (M)	16.2 ± 0.8	Develop a squash simulation protocol which replicates the physiological demands of elite junior squash	Participants completed: A squash match against a player of a similar standard; IST; SSPT	Between squash match and SSP: ↔ HR_{max} ↔ Mean HR ↔ RPE ↑ LA^{+} post-match in SSPT	The SSPT mirrored the physiological demands of an elite junior squash match and is a suitable field-based test to quantify physiological responses to elite junior squash The SSP can be applied to quantify the efficacy of interventions such as ergogenic aids	5/10 = Fair
Lombard et al., [51] (South Africa)	2	10 (M)	23.4 ± 3.5	Determine the relationship between players physiological characteristics and their squash performance and club ranking	Participants completed: Static stork stand balance test; Dynamic star excursion stand balance test; Illinois agility test; Standard ruler drop response time test; 10 m acceleration test	Correlation between ranking and performance in the star excursion stand balance test	Some physiological characteristics may be more essential than for optimal squash performance	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Lynch et al., [52] (Ireland)	2	10 (M)	52	Are the physiological and metabolic responses of squash exaggerated or accentuated when squash matches are performed in close proximity	Players underwent three matches in 36 hours	↑ Mean HR post-match ↔ Plasma noradrenaline post-match ↑ Plasma LA^+ immediately post-match ↓ Plasma K^+ post-match ↑ Serum free fatty acids post-match	Squash has several physiological risk factors which could contribute to an underlying coronary heart disease and sudden cardiac death	4/10 = Fair
MacGowan et al., [53]	2	12 (Not specified)	24	Effects of several fluid replacement strategies post-match play on metabolic responses	Each player played 5 games of squash and then consumed: No fluid replacement; 500 mL distilled water; 500 mL weak electrolyte solution; 500 mL glucose solution; 500 mL glucose/electrolyte 'sports' drink Metabolic responses assessed 5-, 15-, 30-, and 60-min post exercise: Lactate; free fatty acids; glucose; potassium; sodium; urine osmolarity	↑ blood glucose levels when consuming 500 mL glucose solution & 500 mL glucose/electrolyte 'sports' drink	Fluid replacements may increase blood glucose levels but not electrolyte levels	6/10 = Good

Table 1 (continued)

References (Country/Area)	Participant standard tier	N (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Madjumdar et al., [54] (India)	2	33 (M) 9 (F)	15–19 years old	Quantify the physiological demands of squash through heart rate and lactate during matchplay	Four on court drill sessions (ghosting, court run, shuttle run, box sprint) and one matchplay session were monitored with blood lactate levels being taken	Between sexes: ↔ HR ↔ Blood LA^+ Blood LA^+: ↓ Matchplay in comparison to other sessions	Higher blood LA^+ in on court drills suggest they may not be appropriate to optimise training adaptations for matchplay	4/10 = Fair
Micklewright and Papapdopoulou [58] (England)	1–3	11 (M) 10 (F)	M = 20.4 ± 3 F = 22.1 ± 5.7	Develop a reliable and valid squash specific incremental test (SSIT) Create a conversion table to estimate VO_{2max} from the SSIT time to fatigue	Players underwent an ITT before completing a IST test twice, separated by at least 72 hours between tests	Positive intraclass correlation between two SSIT and time to fatigue Positive correlation between SSIT performance and VO_{2max} Regression equations found the IST to be a valid and reliable tool to quantify VO_{2max}	The IST can be used to quantify the maximal aerobic capacity of squash players	4/10 = Fair
Montpetit et al., [60] (Canada)	2	16 (M)	27.1 ± 5.2	Quantify the aerobic energy costs of recreational squash	EE was collected during three separate occasions using the Douglas Bag Technique	EE = 600 kcal/h Squash played at 57 % of VO_{2max}	Thirty minutes of squash would be appropriate as an exercise session to develop and maintain fitness due to the intensity level and energy expenditure of squash	3/10 = Poor

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Raman et al., [75] (New Zealand)	2–3	9 (M)	24 ± 8	Quantify whether a high carbohydrate diet prior to a simulated squash match altered physical performance	Players completed a simulated squash match on two separate occasions after consuming either a high CHO or calorie matched low CHO diet	High CHO trial: ↑ RER ↑ Time to completion ↑ Blood glucose ↑ LA^+	High CHO prior to simulated squash match increases carbohydrate oxidation rate and maintenance of higher blood glucose levels. This is associated with optimised physical performance	8/10 = Good
Romer et al., [81] (England)	3	9 (M)	21.3 ± 0.3	Quantify the effects of creatine monohydrate supplementation on high intensity, intermittent exercise performance in competitive squash players	Players underwent a ghosting protocol in a double blinded crossover design whereby they consumed either creatine monohydrate or maltodextrin with a 4-week washout period in-between	Creatine Monohydrate: ↑ Mean set sprint time	Creatine Monohydrate supplementation improves squash-specific exercise performance in squash players	10/10 = Excellent

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Rosimus [82] (England)	4	1 (F)	19	Case study quantifying the effect of a nutritional intervention on body composition, vitamin D status and physical performance	Player underwent a 6 week moderate energy restricted diet (70%–78% of 2300 Kcals)	After 6-week intervention: ↓ Sum of 8 skinfolds ↑ Lean mass to fat mass ratio ↑ 25 hydroxyvitamin D3 ↑ Ferritin ↑ Eosinophils ↑ Triglycerides ↑ Reactive strength index ↑ On court repeated speed	A structured dietary calorie restricted intervention in conjunction with a strength and conditioning programme is an appropriate way to optimise body composition and physical performance characteristics of an elite squash player	2/10 = Poor
Steininger & Wodick [88] (Germany)	2	7 (M) 6 (F)	Junior players	Quantify the anaerobic threshold and VO_{2max} during a laboratory-based test and a squash-specific field test	Participants completed an IST test before undergoing an ITT	Low correlation between ranking and ITT High correlation between ranking and IST	Physiological characteristics obtained from field-based tests are more valid for estimating squash specific fitness in comparison to laboratory based tests	3/10 = Poor

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Turner et al., [94] (England)	3–5	37 (M) 40 (F)	24 ± 5	Assess the nutrition knowledge of elite squash players Investigate the factors which may influence an elite squash players nutrition knowledge Assess the association between age and world ranking on nutrition knowledge Quantify whether players standard of relevant education and main source of nutrition knowledge influence nutrition knowledge	Quantify players nutrition knowledge via the NSKQ alongside additional questions to determine influencing factors	Nutrition knowledge: Players had average nutrition knowledge (56% ± 12%) ↔ M vs. F Influencing factors: ↔ World ranking and NSKQ score ↔ Age and NSKQ score ↑ Relevant undergraduate degree ↑ Nutrition information from a registered nutritionist	Elite squash players should aim to increase their nutrition knowledge by consulting with a sports nutritionist	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Turner et al., [95] (England)	4–5	7 (M) 7 (F)	25 ± 5 (M) 25 ± 4 (F)	Quantify the fluid balance and sweat [Na^+] of elite squash players during a training session alongside their hydration practices	Players fluid balance was taken during a training session Hydration practices (fluid and sodium intake) were calculated via a self-reported food diary until the players next session Sweat [Na^+] was quantified post session through Pilocarpine Iontophoresis Players perceived seat rate and sweat [Na^+] concentration were taken during sweat [Na^+] collection	Mean fluid balance = – 1.22% ± 1.22% Mean sweat rate = 1.11 ± 0.56 L/h Mean sweat [Na^+] = 46 ± 12 mmol/L ↑ Males sweat rate in comparison to females ↑ Increased rehydration practices when have 21 hours 30 min in comparison to 2 hours 30 min	There is variability in players hydration demands and the data highlights the need to quantify and individualise players hydration strategies as well as training prescription to ensure players can optimally rehydrate	4/10 = Fair
Ventura-Comes [97] (Spain)	3–4	International: 10 (M) 4 (F) National: 20 (M) 8 (F)	International: 25 ± 6.2 National: 35.6 ± 14.2	Quantify the consumption of nutritional supplements by national and international level squash players	Players were sent a validated telematic survey to quantify their nutritional supplement consumption	↑ Supplementation in international players ↑ Advice regarding supplementation in international players	International level players show a higher level of sup-plementation in comparison to national level players	3/10 = Poor

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Ventura-Comes [96] (Spain)	3–4	International: 10 (M) 4 (F) National: 20 (M) 8 (F)	International: 25 ± 6.2 National: 35.6 ± 14.2	Quantify the dietary habits of national and international squash players via a validated food frequency questionnaire	Players completed a validated food frequency questionnaire with differences being compared between national and international players	International players: ↑ Bread ↑ Nuts No differences in: ↔ Meat ↔ Fish ↔ Fruit ↔ Vegetables ↔ Pulses ↔ Potato ↔ Pasta ↔ Rice ↔ Soft drinks ↔ Sweets ↔ Snacks	National and international players may over consume protein and under consume carbohydrates Players do not obtain their nutrition advice from a sport dietitian	3/10 = Poor
Wilkinson et al., [103] (England)	2	8 squash players (not specified) 8 runners (not specified)	30 ± 11.2	Examine the validity of an IST by determining the endurance capability and VO_{2max} of trained squash players in comparison to distance runners using an IST and ITT protocol	SG and RG underwent the ITT and IST in a counterbalanced order, separated by at least 48 hours	Comparisons between SG vs. RG in IST: ↑ SG time to exhaustion ↔ VO_{2max} ↔ HR_{max} Comparisons between SG vs. RG in ITT: ↑ RG time to exhaustion ↑ RG VO_{2max} ↔ HR_{max}	The ST is a valid means to assess VO_{2max} of squash players	5/10 = Fair
Wilkinson et al., [103] (England)	2	8 (not specified)	29.6 ± 9.4	Examine the reproducibility of assessments from a squash-specific fitness test	Participants performed a IST twice, separated by at least 7 days	Time: LOA = 14; TEM = 27 VO_{2max}: LOA = 0.2; TEM = 2.4 HR_{max}: LOA -2; TEM = 2 Economy: LOA = –3.9; TEM = 1.6	The ST produces reproducible assessments for the assessment of endurance capabilities in squash players	4/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	N (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Wilkinson et al., [103] (England)	2	10 squash players (M) 10 non-squash players (M)	Squash players = 23 ± 4 Non-squash players = 24 ± 3)	Examine the validity of a squash-specific test designed to assess change-of-direction speed	SP and NSP underwent two trials of the SSCODT and two trials of the IAR. Each trial was separated by at least 24 hours	Performance results: ↔ in time to completion between SP and NSP in IAR ↑ SP in SSCODT Reproducibility of performance in ST among SSCODT: TEM = 0.13 s CI = 0.09–0.21 s	The SSCODT is a valid and reliable field-based assessment for squash players which produces more accurate assessments when compared to an equivalent nonspecific field test	4/10 = Fair
Wilkinson et al., [104] (England)	2	8 squash players (M) 8 soccer players (M)	Squash players = 25 ± 5 Soccer players = 22 ± 3	Examine the validity and reproducibility of a squash-specific test designed to assess multiple sprint ability	SP and SoP underwent two trials of the SSMST and two trials of the BST. Each trial was separated by at least 24 hours	Performance results: ↔ in time to completion between SP and SoP in BST ↑ SP in ST Reproducibility of performance in ST among SqP: TEM = 6 s CI = 4–13 s *ICC r* = 0.97	The ST is a valid and reliable field-based assessment for squash players to assess multiple sprint ability	5/10 = Fair

Table 1 (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (Years)	Study aim(s)	Methods	Results	Key finding(s)	PEDro quality rating
Wilkinson et al., [102] (England)	3–5	20 (M) 11 (F)	M = 26 ± 2 F = 25 ± 2	Compare performance on a battery of fitness tests among elite-standard squash players on different tiers of a national performance program (senior, transition, and TASS) Investigate possible relationships among test scores and player rank in such players Identify fitness factors that relate to squash-specific multiple-sprint ability in this standard of player	During one session, players completed a battery of fitness tests; countermovement jump, drop jump, squash-specific test of change-of-direction (COD), squash-specific test of multiple-sprint (SSMST), and multistage fitness test (MFT)	Countermovement jump height: ↔ Between senior vs. transition players ↑ Male vs. female Squash-specific change of direction speed: ↑ Senior vs. TASS (i.e. faster) ↔ Senior vs. transition players ↑ Male vs. female Squash-specific multiple sprint ability: ↑ Senior vs. transition ↑ Senior vs. TASS ↔ Transition vs. TASS players ↑ Male vs. female Fastest multiple sprint: ↑ Senior vs. transition ↑ Senior vs. TASS ↔ Between transition vs. TASS players ↑ Male vs. female Endurance fitness: ↔ Senior vs. transition vs. TASS players ↑ Male vs. female Correlations between test score and player rank: ↑ Fastest sprint in SSMST with increased world ranking	Lower-body-explosive capabilities and multiple-sprint ability are important performance variables for elite squash ability	4/10 = Fair

↑ indicates significant increase ($P < 0.05$); ↓ indicates significant decrease ($P < 0.05$); ↔ indicates no significant differences ($P > 0.05$). Participant standard tier [57], Tier 0 = sedentary, Tier 1 = Recreationally active, Tier 2 = Trained/developmental, Tier 3 = Highly trained/national level, Tier 4 = Elite/international level, Tier 5 = World class; *HR* Heart rate, HR_{max} Heart rate maximum, *CHO* Carbohydrate, *PLA* Placebo, VO_{2max} Maximal rate of oxygen consumption, *ITT* Incremental treadmill test, *IST* Incremental squash test, *Te* Time to exhaustion, $EEVO_2$ Energy expenditure, VO_2 rate of oxygen consumption, *RER* Respiratory exchange ratio, *MVC* Maximal voluntary contraction, LA^+ lactate concentration, *RPE* Rating of perceived exertion, *sRPE* Session rating of perceived exertion, *dRPE* differential rating of perceived exertion, *ASSPPT* aerobic squash-specific physical performance test, *RSA* Repeated sprint ability, *COD* Change of direction test, *SSPT* Squash simulation protocol test, K^+ Potassium, *NSKQ* nutrition for sport knowledge questionnaire, [Na^+] Sweat sodium rate, *SG* squash group, *RG* Running group, *LOA* Limits of agreement, *TEM* technical error of measurement, *SP* squash players, *NSP* non-squash players, *SSCODT* Squash-specific change of direction test, *IAR* Illinois agility run, *CI* confidence interval, *ICC* intraclass correlation coefficient, *SoP* soccer players, *SSMST* Squash-specific multiple sprint test, *TASS* talented athlete scholarship scheme

Table 2. Anthropometric characteristics of squash players

References (Country/Area)	Participant standard tier	*N* (sex)	Age (years)	Stature (cm)	Body mass (kg)	body fat (%)	Method of body fat % calculation
Beaudin et al., [7] (Canada)	2	10 (M)	29.4		77.4	10.3	Not disclosed
Bottoms et al., [11] (Scotland)	3	16 (M)	31 ± 6	178 ± 2	80.1 ± 12		
Chin et al., [17] (Hong Kong, China)	4	10 (Not specified)	20.7 ± 2.5	172 ± 4.3	67.7 ± 6.9	7.4 ± 3.4	Sum of 3 skinfold thickness
Girard et al., [35] (France)	3–5	7 (M)	24.9 ± 4.1	177 ± 5.9	72.1 ± 6.1		
Girard et al., [33] (France)	3–5	7 (M)	24.9 ± 4.1	177 ± 5.9	72.1 ± 6.1		
Girard et al., [34] (France)	2	10 (M)	32.2 ± 7.3	179 ± 4.5	74.2 ± 5.5		
Gouttebarge et al., [37] (Netherlands)	4	6 (F)	31 ± 8	170 ± 8.3	59.5 ± 5.7		
James et al., [42] (Malaysia)	4	6 (M) 2 (F)	20.3 ± 2.1	171 ± 7	64.7 ± 6.3		
James et al., [40] (Malaysia)	4	11 (M) 4 (F)	M = 20 ± 3 F = 19 ± 1	M = 172 ± 8 F = 158 ± 4	M = 66 ± 5 F = 52 ± 5		
James et al., [41] (Malaysia)	4	21 (M) 10 (F)	M = 20 ± 4 F = 18 ± 5	M = 173 ± 6 F = 160 ± 4	M = 65 ± 6 F = 55.7 ± 5	M = 9 ± 2 F = 19 ± 5	Sum of 7 skinfolds thickness
Kingsley et al., [47] (Wales)	2	8 (M)	16.2 ± 0.8	176 ± 6	61.3 ± 6		
MacGowan et al., [53] (Ireland)	Not specified	12 (Not specified)	24	178	77.5		
Madjumdar et al., [54] (India)	2	33 (M) 9 (F)	M = 18 ± 2 F = 16 ± 1	M = 168 ± 6 F = 165 ± 6	M = 57.9 ± 8 F = 61.6 ± 5.3	M = 15.1 ± 7.9 F = 25.9 ± 6.5	Sum of 4 skinfolds thickness
Micklewright and Papadopoulou [58] (England)	1-3	11 (M) 10 (F)	M = 20.4 ± 3 F = 22.1 ± 5.7	M = 179 ± 4 F = 166 ± 10	M = 73.8 ± 7.5 F = 60.3 ± 5.5		
Montpetit et al., [60] (Canada)	1	16 (M)	27 ± 5		70.5 ± 8.2		
Raman et al., [75] (New Zealand)	2–3	9 (M)	24 ± 8	180 ± 1	76.9 ± 6.8		
Romer et al., [81] (England)	3	9 (M)	21.3 ± 0.3	177 ± 4	73.3 ± 3.3	15.2 ± 1.4	Sum of 4 skinfolds thickness
Rosimus [82] (England)	4	1 (F)	19	178	80.9	22	Sum of 8 skinfolds thickness
Turner et al., [95] (England)	4 & 5	7 (M) 7 (F)	M = 25 ± 5 F = 25 ± 4	M = 184 ± 2 F = 169 ± 7	M = 78.9 ± 7.3 F = 63.7 ± 8.6		

Table 2. (continued)

References (Country/Area)	Participant standard tier	*N* (sex)	Age (years)	Stature (cm)	Body mass (kg)	body fat (%)	Method of body fat % calculation
Ventura-Comes [97] (Spain)	4 (I) and 3 (N)	Tier 4 = 10 (M); 4 (F) Tier 3 = 20 (M); 8 (F)	Tier 4 = 25 ± 6.2 Tier 3 = 35.6 ± 14.2	Tier 4 = 180 ± 1 Tier 3 = 170 ± 1	Tier 4 = 72.1 ± 10.1 Tier 3 = 68.3 ± 11.4		
Ventura-Comes [96] (Spain)	4 (I) & 3 (N)	Tier 4 = 10 (M); 4 (F) Tier 3 = 20 (M); 8 (F)	Tier 4 = 25 ± 6.2 Tier 3 = 35.6 ± 14.2	Tier 4 = 178 ± 1 Tier 3 = 173 ± 1	Tier 4 = 72.1 ± 10.1 Tier 3 = 68.3 ± 11.4		
Wilkinson et al., [101] (England)	2	8 (not specified)	30 ± 11	180 ± 4	81.3 ± 10.2		
Wilkinson et al., [101] (England)	2	8 (not specified)	30 ± 9	177 ± 5	69.4 ± 6.7		
Wilkinson et al., [101] (England)	2	10 (M)	23 ± 4	180 ± 5	79.7 ± 5.3		
Wilkinson et al., [104] (England)	2	8 (M)	25 ± 5	177 ± 4	72.8 ± 7.8		
Wilkinson et al., [100] (England)	3–5	Senior = 7 (M); 5 (F) Transitional = 3 (M); 4 (F) TASS = 9 (M); 3 (F)	Senior (M) = 26 ± 2 Senior (F) = 25 ± 2 Transitional (M) = 22 ± 1 Transitional (F) = 21 ± 1 TASS (M) = 20 ± 1 TASS (F) = 20 ± 1		Senior (M) = 79.5 ± 6 Senior (F) = 62.5 ± 3.1 Transitional (M) = 69.9 ± 2.8 Transitional (F) = 58.4 ± 1.7 TASS (M) = 69.5 ± 6.8 TASS (F) = 66.2 ± 9.1		

Participant standard tier [57], Tier 0 = sedentary; Tier 1 = Recreationally active; Tier 2 = Trained/Developmental; Tier 3 = Highly Trained/National Level; Tier 4 = Elite/International Level; Tier 5 = World Class; *TASS* talented athlete scholarship scheme

Anthropometric Characteristics of Squash Players

Twenty-six studies included an anthropometric characteristic (Table 2), with 12 studies published after the 2009 rule change, as well as 13 including either elite (tier 4) or world class (tier 5) players.

Physiological Characteristics of Squash Players

Nineteen studies have quantified a physiological characteristic of squash players (Table 3), with nine of these studies being published after the 2009 rule change, and six of the studies including either elite (tier 4) or world class (tier 5) players.

Squash-Specific Performance Tests

Table 4 outlines the characteristics of the squash-specific performance tests. Ten studies have created squash-specific performance tests to quantify a variety of physiological and technical capabilities, such as change of direction speed [103], multiple sprint ability [104], and players endurance capacity [17, 35, 37, 42, 47, 58, 88, 103].

Training Demands of Squash

Two studies have quantified the training demands of squash players. Research has quantified the training intensities and training loads of elite squash players during a 2-week in-season microcycle [39] and investigated the relationships between training load approaches in elite squash players, during a 2-week microcycle [39].

Table 3 Physiological characteristics of squash players

References (Country/Area)	Participant standard	*N* (sex)	Aerobic characteristics				Anaerobic characteristics	
			VO_{2max} (mL/kg/min)	Maximum heart rate (beats/min)	Lactate threshold (% VO_{2max})	Test method	SSCODT (s)	SSMST (s)
Beaudin et al., [7] (Canada)	2	10 (M)	45	185 ± 13		ICT		
Bottoms et al., [11] (Scotland)	3	16 (M)	62.9	188 ± 8		ITT		
Chin et al., [17] (Hong Kong, China)	3	10 (Not specified)	61.7 ± 3.4	191 ± 7	80.1 ± 4.9	ITT		
Girard et al., [35] (France)	3–5	7 (M)	ITT = 54.9 ± 2.5 IST = 63.6 ± 3.0	ITT = 195 ± 9 IST = 193 ± 8	ITT = 92 ± 5.6 IST = 90.5 ± 3.5	ITT IST		
Girard et al., [33] (France)	3–5	7 (M)	63.6 ± 3	193 ± 8		IST		
Gouttebarge et al., [37] (Netherlands)	4	6 (F)	ITT = 49.1 ± 5.2 IST = 48.9 ± 5.3	ITT = 185 ± 14 IST = 187 ± 16		ITT IST		
James et al., [42] (Malaysia)	4	6 (M) 2 (F)	ITT = 48.8 ± 5 IST = 46.2 ± 4.1	ITT = 195 ± 7 IST = 200 ± 7		ITT IST		
James et al., [41] (Malaysia)	4	21 (M) 10 (F)	47.7 ± 5.3			IST	M = 9.21 ± 0.57 F = 10.46 ± 0.68	M = 221.0 ± 11.0 F = 250.6 ± 12.6
Kingsley et al., [47] (Wales)	2	8 (M)		198 ± 9		IST		
Madjumdar et al., [54] (India)	2	33 (M) 9 (F)	M = 55.3 ± 4 F = 46.2 ± 4	M = 189 ± 7 F = 190 ± 12		ITT		
Micklewright and Papapdopoulou [58] (England)	1–3	11 (M) 10 (F)	(M) = 58.2 ± 6.7 (F) = 42.1 ± 6.3			ITT		
Montpetit et al., [60] (Canada)	1	16 (M)	55 ± 6	186 ± 8				
Romer et al., [81] (England)	3	9 (M)	61.9 ± 2.1					
Steininger & Wodick [88] (Germany)	2	7 (M) 6 (F)	58.5 ± 8.1	195 ± 6		ITT		
Wilkinson et al., [103] (England)	2	8 (not specified)	ITT = 49.6 ± 7.3 IST = 52.2 ± 7.1	ITT = 191 ± 13 IST = 190 ± 7		ITT IST		
Wilkinson et al., [103] (England)	2	8 (not specified)	50.8 ± 6.5	189 ± 10		IST		

Table 3 (continued)

References (Country/Area)	Participant standard	*N* (sex)	Aerobic characteristics				Anaerobic characteristics	
			VO_{2max} (mL/kg/min)	Maximum heart rate (beats/min)	Lactate threshold (% VO_{2max})	Test method	SSCODT (s)	SSMST (s)
Wilkinson et al., [103] (England)	2	8 (not specified)					10.90 ± 0.44	
Wilkinson et al., [104] (England)	2	8 (M)	56.8 ± 5.5			Not specified		232 ± 32
Wilkinson et al., [100] (England)	3–5	Senior = 7 (M); 5 (F) Transitional = 3 (M); 4 (F) TASS = 9 (M); 3 (F)	Senior (M) = 56.2 ± 2.1 Senior (F) = 49.3 ± 3.2 Transitional (M) = 59.4 ± 2.9 Transitional (F) = 49.3 ± 3.3 TASS (M) = 55.3 ± 5.3 TASS (F) = 48.3 ± 3.8			IRT	Senior (M) = 8.8 ± 0.44 Senior (F) = 9.02 ± 0.32 Transitional (M) = 9.15 ± 0.57 Transitional (F) = 9.34 ± 1.03 TASS (M) = 9.35 ± 0.64 TASS (F) = 10.45 ± 0.55	Senior (M) = 203 ± 9 Senior (F) = 213 ± 6 Transitional (M) = 213 ± 3 Transitional (F) = 235 ± 19 TASS (M) = 219 ± 14 TASS (F) = 245 ± 13

Participant standard tier [57], Tier 0 = Sedentary, Tier 1 = Recreationally active, Tier 2 = Trained/Developmental, Tier 3 = Highly Trained/National Level, Tier 4 = Elite/International Level, Tier 5 = World Class; *TASS* talented athlete scholarship scheme, *ICT* Incremental Cycle Test, *ITT* Incremental Treadmill Test, *IST* incremental squash test, *IRT* incremental running test, *SSCODT* squash-specific change of direction test, *SSMST* squash-specific multiple-sprint test, *TASS* talented athlete scholarship scheme

Nutritional Requirements of Squash

Four studies have measured a nutritional requirement of squash. Research has quantified the energy expenditure and respiratory exchange ratio of elite match play in male players [33], whether a high carbohydrate diet prior to a simulated squash match on physical performance [75], the effect of a nutritional intervention on body composition, vitamin D status and physical performance in an elite female player [82], and the dietary habits of national and international squash players via a validated food frequency questionnaire [96].

Hydration Demands of Squash

Two studies have quantified a hydration demand of squash. Previous research has quantified the of several fluid replacement strategies post-match play on metabolic responses [53] and the fluid balance, sweat [Na^+] and hydration practices of elite players during a training session [95].

Nutrition Knowledge of Squash Players

One study has quantified the nutrition knowledge of squash players, with Turner et al., [94] quantifying the nutrition knowledge of elite players via the Nutrition for Sport Knowledge Questionnaire [92, 93].

Nutritional Supplements for Squash

Three studies have quantified a nutritional supplement for squash. Research has quantified the effects of a carbohydrate containing fluid on squash-specific skill maintenance [11], the results of creatine monohydrate supplementation on squash-specific performance [81], the supplementation consumption of international level Spanish squash players [97], and the supplementation knowledge of elite squash players [94].

Discussion

The aim of this review was to evaluate the current physiological and nutritional literature regarding squash to guide practitioners, coaches, and players on how best to interpret

Table 4. Characteristics of Squash-Specific Performance Tests

References (Country/Area)	Participant tier standard	*N* (sex)	Test capability measure	Reliability and validity data	Technical requirement to test?	Test overview
Chin et al., [17] (Hong Kong, China)	4	10 (not specified)	Endurance capacity	No	Graded squash test whereby player must 'ghost' to an area of the court (when a corresponding lightbulb flashes) and perform a squash swing to hit a static squash ball	The IST's utilisation should be used with caution as it hasn't been validated
Girard et al., [35] (France)	5	7 (M)	Endurance capacity	IST Intra-rater reliability Time to exhaustion = 1085 ± 267 vs. 1099 ± 195 s ($P = > 0.05$); $CV = 0.9\%$ HR_{max} =192.2 ± 4.5 vs. 187.5 ± 6.1 beats/min ($P = > 0.05$); $CV = 1.8\%$ IST vs. ITT VO_2 = 57.6 ± 3.9 vs. 50.5 ± 4.3 mL/kg/min ($P \leq 0.01$)	Graded incremental test whereby the player must 'ghost' to one of six areas on the court denoted by audio and visual feedback in a random order	Players were able to attain a greater VO_2 in the IST in comparison to the ITT, potentially due to the squash specific technical demands of the squash test making it potentially more appropriate than a non-specific endurance capacity test The test requires squash specific movements such as 'ghosting' over marked areas The random order of the IST may make the test more squash specific as the player is having to react to a stimulus. However, squash players utilise many visual cues to anticipate an opponent's shot and therefore fixed visual cues may be negligible The IST was shown to have good intra-rater reliability
Gouttebarge et al., [37] (Netherlands)	4	6 (F)	Endurance capacity	(IST vs. ITT) VO_{2max} = 48.9 ± 5.3 mL/kg/min vs. 49.1 ± 5.2 mL/kg/min; r = 0.9 ($P \leq 0.05$) HR_{max} = 187 ± 16 beats/min vs. 185 ± 14 beats/min; r = 0.99 ($P \leq 0.01$)	Graded incremental test whereby the player must 'ghost' to one of six areas on the court denoted by audio feedback in a fixed order	The IST is shown to have a good level of validity in comparison to ITT The test requires squash specific movements such as 'ghosting' over marked areas

Table 4. (continued)

References (Country/Area)	Participant tier standard	N (sex)	Test capability measure	Reliability and validity data	Technical requirement to test?	Test overview
James et al., [42] (Malaysia)	4	6 (M) 2 (F)	Endurance capacity	IST vs. ITT VO_2 = 46.2 ± 4.1 mL/kg/min vs. 48.8 ± 5 mL/kg/min Mean bias = 2.5 mL/kg/min TEE = 3.3 mL/kg/min TEE (CV%) = 7 LOA = − 3.5:8.6 mL/kg/min $r = 0.79$ $d = 0.56$ IST Intra-rater reliability VO_2 = 47.7 ± 5.4 mL/kg/min vs. 46.2 ± 6.8 mL/kg/min Mean bias = 1 mL/kg/min TEE = 1.5 mL/kg/min TEE (CV%) = 3.2 LOA = − 3.2:5.1 mL/kg/min $r = 0.95$ $d = 0.25$	Graded incremental test whereby the player must move to one of six areas on the court denoted by audio feedback in a fixed order	The IST is a modification of Gouttebarge et al., [37]. Squash-specific 'ghosting' and movements (e.g. running backwards to the centre of the court) were removed from the IST as well as increasing shuttle distances by ~10% to account for this The IST good intra-rater reliability and good agreement between the IST and ITT in performance and physiological markers. The IST is therefore an appropriate tool to determine squash-specific endurance capacity
Kingsley et al., [47] (Wales)	2	8 (M)	Endurance capacity	No	Graded incremental test whereby the player must ghost to one of eight areas on the court denoted by audio feedback in a fixed order	The IST's utilisation should be used with caution as it hasn't been validated
Micklewright & Papapdopoulou [58] (England)	1–3	11 (M) 10 (F)	Endurance capacity	IST validity with ITT $r = 0.92$ (P <0.001) IST Intra-rater reliability Time = 569 ± 139 s vs. 478 ± 107 s; $r = 0.99$ ($P = 0.001$) CV = 2.7% LOA = 2.7–3.9	Graded incremental test whereby the player must run towards and place a foot in one of four areas (front right, front left, back right, back left) on the court denoted by audio feedback in a random order. Players were required to hold a racket to increase specificity	IST had good validity in comparison to ITT IST had good intra-rater reliability Caution to be applied as IST did not directly measure VO_2 with a regression analysis being used to calculate this May not be specific to elite squash players as the IST was validated in novice to national level players
Steininger & Wodick, [88] (Germany)	2	7 (M) 6 (F)	Endurance capacity	No	Graded squash test whereby player must ghost to are of the court (when corresponding lightbulb flashes) and perform a squash swing to hit a static squash ball	The IST's utilisation should be used with caution as it hasn't been validated

Table 4. (continued)

References (Country/Area)	Participant tier standard	N (sex)	Test capability measure	Reliability and validity data	Technical requirement to test?	Test overview
Wilkinson et al., (2009*a*); Wilkinson et al., [103] (England)	2	8 (not specified)	Endurance capacity	IST validity vs. ITT RER = 1.23 ± 0.8 vs. 1.31 ± 0.1 (P = 0.15); post-test L^+ = 9.0 ± 1.3 mmol/L vs. 9.8 ± 2.4 mmol/L (P = 0.25); final VO_2 increase = 1.02 ± 0.8 mL/kg/min vs. 0.71 ± 0.7 mL/kg/min (P = 0.43) IST Intra-rater reliability Time = 692 ± 148 vs. 715 ± 168 s; LOA = 14 ± 62 s; TE = 27% ± 4% VO_{2max} = 50.8 ± 6.5 mL/kg/min vs. 51.2 ± 6.9 mL/kg/min; LOA = 0.2 ± 5.1 mL/kg/min; TE = 2.4% ± 4.7%	Graded incremental test whereby the player must ghost to one of six areas on the court denoted by audio feedback in a random order	IST had good validity in comparison to ITT IST had good intra-rater reliability The random order of the IST makes it more squash specific as the player is having to react to a stimulus May not be specific to elite squash players as the IST was validated in recreational level players
Wilkinson et al., [103] (England)	2	8 (not specified)	Change of direction speed	SSCODT Intra-rater reliability TEM = 0.13 s CI = 0.09 s – 0.21 s Correlations between SSCODT and IAR r = 0.77, P <.01	Time trial test whereby player has to perform lateral movements over short distances to mimic the squash-specific movement patterns	SSCODT had good intra-rater reliability and correlated with IAR SSCODT test discrimanted between squash and non-squash players suggesting its squash-specific nature May not be specific to elite squash players as the SSCODT was validated in recreational level players
Wilkinson et al., [104] (England)	2	8 (M)	Multiple sprint ability	TEM = 6 s *CI* = 4 – 13 s *ICC* r = 0.97	Time trial test whereby player has to perform lateral movements over short distances to mimic the squash-specific movement patterns	SSMST had good intra-rater reliability and correlated with Bakers Test SSMST test discrimanted between squash and non-squash players suggesting its squash-specific nature May not be specific to elite squash players as the SSMST was validated in recreational level players

Standard tier [57], Tier 0 = sedentary, Tier 1 = Recreationally active, Tier 2 = Trained/developmental, Tier 3 = Highly trained/national level, Tier 4 = Elite/international level, Tier 5 = World class; 'Ghost' or 'ghosting' = Technical squash term whereby player performs a squash swimming shot without hitting a ball; HR_{max} heart rate maximum, VO_{2max} maximal rate of oxygen consumption, *ITT* incremental treadmill test, *IST* incremental squash test, VO_2 rate of oxygen consumption, *RER* Respiratory exchange ratio, LA^+ lactate concentration, *LOA* limits of agreement, *TEM* technical error of measurement, *TEE* typical error of the estimate, *TEE CV%* Typical error of the estimated expressed as coefficient of variation, *SSCODT* squash-specific change of direction test, *IAR* illinois agility run, *CI* confidence interval, *ICC* intraclass correlation coefficient, *SSMST* squash-specific multiple sprint test the contemporary data, while identifying gaps in the literature to inform future research directions within squash. To our knowledge, this is the first systematic review to examine the physiological and nutritional literature within squash.

The main findings were (1) there are 35 studies which met the inclusion criteria across a diversity of topics, such as the physiological demands of squash, anthropometric characteristics of squash players, the physiological characteristics of squash players, squash-specific performance tests, the training demands of squash, the nutritional requirements of squash, the hydration demands of squash, the nutrition knowledge of squash players, and nutritional supplements for squash players; (2) many of the studies conducted in squash have poor (10) or fair (19) methodological quality, with only four conveying good and two conveying excellent methodological quality. This is due to many of the studies conducted in squash being observational in design (32), rather than double blinded crossover design studies; (3) only 14/35 studies were conducted using elite or world class players; (4) 17/35 studies reviewed are published during or after the 2009 rule change. Consequently, the following sections will critically appraise the contemporary physiological and nutritional literature within squash.

Physiological Demands of Squash

Girard et al., [33] quantified the physiological responses during match play in elite male squash players. They reported a mean VO_2 of 54.4 ± 4.8 mL/kg/min or 92% ± 3% of VO_{2max} and mean heart rate of 177 ± 10 beats/min or 92% ± 3% HR_{max} during match play. They also reported a mean minute ventilation (VE) of 102.6 ± 12.1 L/min, a breathing frequency of 47.9 ± 4.8 breaths/min and mean blood lactate value of 8.3 ± 3.4 mmol/L. Players spent 24% ± 9% and 69% ± 18% above > 90% of their VO_{2max} and HR_{max} respectively, while spending 14% ± 23% and 32% ± 25% above >95% of their VO_{2max} and heart rate maximum, respectively. These data convey that a high demand is placed on aerobic metabolism with some contribution from anaerobic glycolysis during match play, as exhibited through high blood lactate concentrations, an oxygen uptake response near VO_{2max}, and heart rate response near HR_{max}.

Much of the literature conducted on the physiological demands of squash match play is not relevant to elite players, as it has been undertaken in junior [54], or recreational players [7, 9, 10, 12, 34, 52, 60]. For example, Montpetit et al. [60] reported a mean heart rate of 147 ± 18 beats/min (72 ± 13% heart rate maximum) during match play, considerably less than Girard et al. [33]. This may be due to the disparity in playing levels between the players, and inability for recreational athletes to maintain high workloads for extended periods of time due to a lower lactate threshold [44].

Murray et al. [63] reported that the rule changes in 2009 have altered the physical demands of elite squash. Consequently, players, coaches and conditioning coaches should interpret the data with caution as it may be outdated due to rule changes. This rule change may affect the physiological demands of match play, and practitioners should consider this when proposing training prescription.

Future research should aim to quantify the physiological responses during match play in elite players with the altered rule changes to determine whether rule changes have affected the physiological responses during match play. Girard et al. [33] only quantified the physiological responses of elite male players, and the physiological responses during match play of elite female players have never been quantified. Therefore, future research should also quantify the physiological responses during match play of elite female players to compare their differences with male players and to develop exercise prescription guidance specific for elite female players.

Future research should also aim to quantify muscle and blood metabolites in elite squash match play among male and female players. Squash matches can last > 90 minutes, with high intensity intermittent exercise lasting around this duration being shown to completely deplete muscle glycogen stores in individual muscle fibers, reducing high intensity performance [49]. Quantifying muscle and blood metabolites in elite squash match play among male and female players would enable the ability to make specific nutritional recommendations based on the substrate utilisation during match play [2]. Future research should also aim to quantify the locomotor demands of elite squash, such as the total distance covered and amount of high intensity movements, accelerations and decelerations. This data would help provide information on how to better condition players to the demands of elite squash.

Professional squash matches are played in a variety of different environmental conditions, such as hot and humid environments, as well as at altitude [74]. These environmental conditions may alter the physiological demands and ball velocity and therefore future research should aim to quantify whether any differences are experienced in a variety of different environmental conditions.

Anthropometrical Characteristics of Squash Players

Anthropometrical characteristics (stature, body mass, body fat %) are essential for quantifying an individual's body composition [99]. Body composition is a key performance variable [1], and low amounts of fat mass alongside an appropriate amount of lean mass may be beneficial for players to execute squash-specific movements, and move efficiently around the court [22].

There appears to be diversity in the anthropometrical characteristics of elite squash players. Turner et al. [95] quantified the stature and body mass of elite or world class English players, reporting a mean stature of 184 ± 2 cm and body mass of 78.9 ± 7.3 kg among male players, and a mean stature of 169 ± 7 cm and body mass of 63.7 ± 8.6 kg among female players. In comparison, elite Malaysian squash players were shown to be smaller and lighter, with James et al., [41] reporting a mean stature and body mass of 173 ± 6 cm and 65 ± 6 kg among male players, and a mean stature and body mass of 160 ± 4 cm and 55.7 ± 5 kg among female players. Players from different regions may have physical differences due to their geographic ancestry, which could influence performance, in combination with differences in playing styles and/or playing standard.

Quantifying the stature and body mass of an individual only portrays a small aspect of body composition in comparison to multi component models [99]. To date, six studies have quantified the body fat % of squash players. Elite players appear to have a lower body fat % than sub-elite players. Chin et al., [17] reported that elite Hong Kong players had a body fat % of 7.4% ± 3.4%, in comparison to Romer et al. [81] who found sub-elite players had a body fat % of 15.2% ± 1.4%.

Elite female squash players have been shown to have a greater body fat percentage (19% ± 5%) in comparison to elite male players (9% ± 2%) [41]. This is consistent with epidemiological studies indicating that females have a greater amount of adipose tissue, equating to approximately 10% more body fat than male counterparts [45], due to the female sex hormone oestrogen [67].

All six studies that provided a methodology for quantifing body fat % (see Table 2) have utilised the skinfolds thickness method [46]. However, there were differences in the number of sites taken for skinfold thickness, and therefore caution should be applied when comparing results across studies [55]. Another limitation of skinfold thickness is that converting the data into a doubly indirect method, such as a body fat %, adds a layer of complexity [46]. There are over 100 formulae for converting the sum of skinfold thickness to body fat % [46], which are often created from varying populations and protocols [46]. Therefore, it is hard to make comparisons between studies, as no study presented the formulae utilised to convert their data.

Future research should aim to quantify the anthropometrical characteristics of elite male and female squash players, among a variety of different ethnicities. This would quantify the body composition of elite squash players and any differences related to sex and ethnicity. If body fat % is of interest, then Dual-Energy X-Ray Absorptiometry (DXA) is a valid and reliable tool [46, 65], provided that the methodology follows a standardised protocol [64]. If sum of eight skinfolds is of interest, then skinfolds callipers are a valid and reliable tool [46].

Physiological Characteristics of Squash Players

Elite squash matches are variable in length and are reported to have a mean match duration of 59 ± 20 min, ranging from 39 min to 89 min [43]. However, anecdotally, matches can be considerably shorter (<25 min) and longer (>100 min) depending on the playing conditions, playing styles of the players, and tactics employed. Elite squash players are reported to have a VO_{2max} ranging from 46.2 to 63.6 mL/kg/min (Table 3). Some of the data presented should be interpreted with caution, as some studies did not differentiate data between sexes [17, 41, 42], with Wilkinson et al., [100] reporting that elite male players outperformed elite female players in all physiological characteristics. Research has shown that VO_{2max} is not correlated with world ranking [17, 41, 100]. Consequently, while elite squash players may be required to have a developed aerobic system at a threshold level to ensure that their performance isn't inhibited, enabling them to sustain long match durations [43], and optimise recovery from one rally to the next (Tomlin & Wegner [91], this isn't a differential physiological characteristic at elite level.

Squash is a high intensity intermittent sport whereby elite male match play is performed at a mean VO_2 of 54.4 ± 4.8 mL/kg/min or 92% ± 3% of VO_{2max}. Consequently, a high lactate threshold is required to ensure players can sustain high intensity exercise for a continued period [33]. Girard et al., [35] reported that elite male players have a lactate threshold of 92% ± 5.6% of VO_{2max}. This is greater than data previously conveyed by Chin et al. [17], who reported a lactate threshold of 80.1% ± 4.9% among players. This ~10% difference in lactate threshold could be due to differences in playing ability (tier 3 vs. tier 4–5) or an indication of how squash has become more glycolytic and requires players to perform at an intensity closer to their VO_{2max} for longer periods of match play.

More recently, high intensity and high intensity intermittent characteristics have also been quantified among elite players to mimic the demands of match play [33]. Wilkinson et al. [100] reported that among male and female players, squash-specific multiple-sprint ability (SSMST), fastest sprint from the SSMST and change of direction speed correlated with a players world ranking. Consequently, the ability to produce high amounts of force and translate this into squash specific movements for extended periods of time is a key performance indicator for elite male and female squash players [100].

Future research should aim to quantify the physiological characteristics of elite squash players. It is difficult to compare between studies as they have been performed on players of differing standard and a variety of tests (e.g. incremental treadmill test or incremental squash test) to quantify variables. Data collected is also based on relatively sporadic samples, often with the same players from a select group of countries/area (e.g. England, Malaysia). Therefore, future research should also aim to quantify the physiological characteristics from a variety of different samples of players. This would enable a richer analysis of the physiological characteristics of elite players and determine how different playing standards and styles influence the physiological characteristics of players. Murray et al. [63] reported that the intensity of match play is increasing, however, much of the data collected is prior to the 2009 rule change (e.g. lactate threshold [35]), and key data is missing, such as the lactate threshold of elite female players.

Squash-Specific Performance Tests

Sport-specific tests increase construct validity [23] and as a result, research has focused on creating squash-specific performance tests to quantify a variety of squash-specific physiological and technical capabilities. Three studies with a squash-specific endurance test did not report any data regarding the validity, reliability, and/or sensitivity of the performance tests [17, 47, 88], so their utilisation should be approached with caution. All studies that did report validity, reliability and/or sensitivity data demonstrated high sensitivity and reproducibility [35, 37, 42, 58, 103].

Wilkinson et al. [103] developed a squash-specific change of direction speed test (SSCODT) to assess players' speed to change direction. The SSCODT did not include straight-line sprints but rather a variety of lateral movements over short distances, to mimic the squash-specific movement patterns exhibited in squash [98]. Therefore, the SSCODT may be more appropriate in a testing battery than a non-specific field-based change of direction test like the Illinois agility run (IAR). However, the study was conducted on recreational male squash players and to determine its ability to screen elite male and female squash players change of direction speed, future research should aim to determine whether similar results can be observed in elite male and female players.

Wilkinson et al. [104] devised a squash-specific multiple sprint test (SSMST) to quantify players' repeated sprint ability. The SSMST mimicked the squash-specific movement patterns [98] such as short, dynamic lateral movements, with no straight lines, making it more appropriate than a non-specific field-based test such as the Baker's sprint test. The SSMST produced higher physiological responses in comparison to the Baker's sprint test, however, blood lactate concentrations are lower than exhibited during match play [33] = 8.3 ± 3.4 mmol/L). This could be due to Wilkinson et al. [104] testing recreational squash players. As previously discussed (see sect. "Physiological Demands of Squash"), recreational players may not be able to reach the high intensities observed in elite squash. Consequently, future research should aim to investigate whether similar results are observed in an elite male and female population.

Five squash-specific endurance tests have been developed and validated [35, 58], [37, 42, 103]. Three squash-specific endurance tests were conducted on elite or world class players and therefore may be more suitable for an elite population [35, 37, 42]. Girard et al. [35] utilised audio and visual feedback, displaying where to move throughout the test. This is in contrast to other tests, which have used just audio feedback [37, 42]. While squash players respond to both audio and visual cues during match play, it could be debated that responding to visual cues in a fixed position during an incremental test is questionable and doesn't enhance the squash-specificity of the test [58]. Rather, during match play, players respond to cues such as body positions of the opponent, and the travel direction of the ball. The squash-specific endurance test designed by Girard et al., [35] also requires specialist computer software to project images onto a wall using a projector, making it difficult for its administration in the field as it requires specialist equipment [42]. There are also some variations in the requirement for 'ghosting' strokes and squash-specific movements between the three tests. Girard et al. [35] and Gouttebarge et al. [37] included squash-specific 'ghosting' strokes in their tests, whereas James et al. [42] did not. James et al. [42] collected pilot data prior to data collection and found squash-specific 'ghosting' strokes were shown to exhibit high levels of variation at maximal stages, while limiting some players' ability to achieve a maximal effort due to possessing a slower stroke speed [42]. Girard et al. [35] and Gouttebarge et al. [37] also required players to complete squash-specific movements throughout the test, similar to how players would move during match play (such as backward running when moving back to the centre of the court). James et al. [42] excluded the requirement for squash-specific movements, as from the pilot data collected, players were not able to maintain the intensity of the later test stages when performing squash-specific movements, despite not reaching maximal fatigue. This is most likely due to the reductions in speed when running backwards. Consequently, the squash-specific endurance test by James et al. [42] may be the most appropriate to quantify endurance capabilities of elite squash players. The test is validated in elite players, is easy to utilise in the field, and has undergone rigorous pilot testing to ensure that a true VO_{2max} value has been achieved, rather than confounded by squash-specific movements.

Training Demands of Squash

James et al., [39] reported that group sessions were the longest in duration (79 ± 12 min) in comparison to feeding (55 ± 15 min), ghosting (35 ± 15 min), match play (46 ± 17 min), and conditioning sessions (37 ± 9 min) throughout a 2-week microcycle in elite squash players. Group sessions were shown to elicit the greatest sRPE (5793 ± 1477 scores) and most high intensity movements (189 ± 88 > 3.5 m/s), playing a key role in preparing players for competition due to their likely effect on aerobic fitness [39]. Group sessions may have elicited the greatest sRPE and most high intensity movements due to the duration of group sessions in comparison to other sessions, enabling for more load and movements to occur. For example, match play sessions were shown to have a greater mean heart rate (Match play = 81% ± 6% HR_{max} vs group = 76% ± 5% HR_{max}) and greater time > 90% heart rate maximum (Match play = 10 ± 10 min vs. group = 7 ± 10 min) but were shorter in duration. To this extent, conditioning sessions were shown to have the greatest RPE (77 ± 16 scores) and player load (519 ± 153 scores) but were only 37 ± 9 min in duration. James et al. [39] reported that there was minimal agreement between internal and external load metrics during the 2-week microcycle and collecting the data in isolation (i.e. just internal) may underestimate or overestimate the amount of stress a player is feeling. Consequently, it is important to collect a variety of internal and external load metrics to determine the amount of stress a player is undergoing throughout a microcycle, rather than in isolation. Different cohorts of elite squash players may also train differently (e.g. greater duration in match play sessions), altering the training load. Future research should aim to quantify the training load across various cohorts of elite squash players throughout a microcycle to allow for comparisons differences between groups.

Competition Demands of Squash

No current research has quantified the competition demands of squash. Elite squash matches during competition are played in proximity (~8–48 hours in-between matches), with players required to potentially compete in 1–6 matches in as many days during PSA World Series events. Research in tennis [27–29], soccer [3, 4], Brinkmans et al. [14, 62], and rugby league [61] has quantified the player load during competition. Future research should aim to quantify the cumulative player load during elite squash competition to determine the internal and external load players experience.

Squash match play has been shown to alter neuromuscular function in recreational players through the development of peripheral fatigue [34], which may reduce physical performance in subsequent matches [48]. Therefore, future research should aim to investigate whether similar alterations in neuromuscular function occur in elite male and female players after match play. Peripheral fatigue may be less prevalent in elite players, due to their training to condition their body to the rigours of competition [31, 34, 39]. Research in soccer has also quantified the muscle damage, inflammatory, immune and performance responses following matches in proximity [59] to create specific physiological [66] and nutritional recovery strategies [76]. Future research should aim to do the same in elite male and female squash players during competition so specific physiological and nutritional recovery strategies can be devised and assess whether logistical changes, such as match intervals, should be altered by the World Squash Federation and Professional Squash Association to maintain high match quality throughout competitions.

Nutritional Requirements of Squash

Girard et al. [33] quantified the energy requirements during match play in elite male squash players. They reported a mean energy expenditure of 4933 ± 620 kJ/h and RER of 0.94 ± 0.06. This is considerably more than recreational squash players, who exhibited an energy expenditure of 2850 kJ/h during match play [60]. As previously discussed (see section "Physiological Demands of Squash"), recreational players may not be able to reach the high intensities observed in elite squash. Similarly, elite male tennis players were shown to expend significantly less (2718 ± 438 kJ/h) during match play [77]. This could be due to the increased intensity during match play in squash and differences in total playing time between squash (70% ± 5%, [33] and tennis (20%–30%) [85]. Consequently, nutritional strategies should be individualised to the demands of squash, as generic nutritional guidelines may not be relevant due to differences in energy requirements.

Future research should aim to quantify the energy expenditures of elite squash players throughout a training microcycle to create specific nutritional guidelines during training, as had been done in other racket [77] and high intensity intermittent sports [18]. As highlighted by Turner et al. [94], players' dietary intakes should also be reported alongside energy expenditure to quantify whether their current dietary habits are optimal. This has been previously conducted in other racket [27, 29, 83], and high intensity intermittent sports [3, 14, 20, 21, 24, 25, 38, 61, 62, 84, 86]. Similarly, the energy expenditures during a competition period should be quantified to create specific nutritional guidelines during competition [18, 77].

Raman et al. [75] explored whether a high carbohydrate diet prior to a simulated squash match altered physical performance in recreational to national standard players. Players consumed either a high carbohydrate diet (H-CHO) (11.1 g/kg) or a calorie matched low carbohydrate diet (L-CHO) (2.1 g/kg) 48 hours prior to a simulated squash match. They reported that players completed five games of a simulated match in a significantly faster time (2340 ± 189 s) in the H-CHO condition in comparison to the L-CHO condition (2416 ± 128 s). Respiratory exchange ratio (0.80 vs. 0.76), blood glucose and blood lactate concentrations were also significantly higher in the H-CHO condition in comparison to the L-CHO condition. Consequently, consuming a high carbohydrate diet prior to may increase physical performance during squash by increasing carbohydrate oxidation rates and maintaining higher blood glucose concentrations.

Rosimus [82] quantified the effects of a 6-week nutritional intervention on body composition, vitamin D status and physical performance on an elite female squash player. Preintervention energy intake was estimate at 2511 ± 568 kcal/day with carbohydrate, protein and fat intake being approximately 365 ± 121 g/day, 114 ± 29.5 g/day, and 86 ± 7.4 g/day, respectively. During the intervention, dietary assessment revealed a daily energy intake of 1501 ± 150 kcal/day, with a carbohydrate, protein, and fat intake of approximately 169 ± 35 g/day, 82 ± 40.9 g/day, and 55 ± 23.2 g/day, respectively. The intervention targeted a structured energy restriction of 500–700 kcal/day so may not be representative of a player's optimal energy intake to adequately fuel and recover from training sessions. The player achieved a body mass loss of 2.9 kg (80.9 to 78 kg) during the intervention and saw a reduction in sum of eight skinfolds (127 mm to 107 mm) and increase in lean mass (61.8 kg to 63.5 kg). The player's squash-specific physiological characteristics improved with an increase in reactive strength index (3.10 to 3.25) and a reduction in the time to complete both an on-court speed test (9.15 s to 8.62 s) and repeated on-court speed tests (206 to 194 s). Consequently, the study highlights that a gradual energy deficit can optimise body composition and physical performance in an elite squash player.

Ventura-Comes et al. [96] reported the dietary habits of national level Spanish squash players. They reported that players may under consume carbohydrate rich foods such as bread, pasta, rice, and potatoes in comparison to contemporary guidelines [15]. The data collected by Ventura-Comes [96] was quantified via a food frequency questionnaire as previously suggested by Turner et al. [94], this should be interpreted with caution as food frequency questionnaires have been conveyed to display poor validity and reliability [90] in comparison to other methods such as 24-h dietary recall, snap 'N' send method and weighed food diaries [8, 19]. Current carbohydrate guidelines may not be appropriate for elite squash players. Quantifying the energy expenditures of elite squash players throughout a training microcycle would help determine whether these guidelines are appropriate. Players' dietary habits should also be quantified using more accurate and reliable technique,s such as weighed food diaries or the snap 'N' send method [8, 19]. This would also determine the macronutrient and micronutrient intake of elite squash players, which has not yet been quantified.

Hydration Demands of Squash

MacGowan et al. [53] investigated the effects of consuming different post-match fluids: no fluid replacement, 500 mL of water; an electrolyte solution; a glucose solution; or a glucose/electrolyte 'sports' drink on metabolic responses, such as lactate, free fatty acids, glucose, potassium, sodium, and plasma osmolality in recreational players. They found that the glucose containing drinks significantly elevated blood glucose levels but did not influence potassium or sodium levels, stating that there is no benefit to consuming a fluid replacement other than water during short intense sports including squash. A key limitation of this study is that they did not report the fluid balance during the squash match, or whether players consumed any electrolytes during the squash match. Sweat rates and sweat [Na^+] are highly individualised [6], it's possible that the players had low sweat [Na^+] rates, but this was not quantified.

Turner et al. [95] quantified the fluid balance and sweat [Na^+] of elite squash players during a training session, alongside their hydration practices. They found that elite squash players had a mean fluid balance of − 1.22% ± 1.22% throughout the session, exhibiting a mean sweat rate of 1.11 ± 0.56 L/h and a mean sweat [Na^+] of 46 ± 12 mmol/L. Male players were shown to have significantly higher sweat rates than female players, hypothesised to be due to the female sex hormones estrogen and progesterone [32, 78]. Seven players had 21 hours 30 mins until their next training session whereas the other seven players had 2 hours 30 mins until their next training session. There was a significant difference in fluid and sodium intake post session between the two groups, the players who had 21 hours 30 mins until their next training session were able to optimally rehydrate in comparison to players who had 2 hrs 30 mins until their next training session, who were not able to. Turner et al., [95] concluded that sweat rates and sweat [Na^+] are highly variable and there is a need to individualise players hydration strategy alongside training prescription to ensure players optimally rehydrate. As suggested by Turner et al. [95], future research should aim to quantify the sweat rates of elite squash players during hot conditions and compare them with moderate environmental conditions (temperature = 17–24 °C, humidity 40%–60%). Elite players compete in hot environments, such as the 2022 Professional Squash

Association World Championships, held outdoors in Cairo, Egypt [73]. This research would help players determine whether differing hydration strategies are appropriate when competing in hot and humid environmental conditions. Future research should also aim to quantify the sweat rates of players during match play. Research has shown that elite squash match play may be performed at a higher intensity to training sessions [31, 33, 40], with exercise intensity being an intraindividual factor in individuals sweat rates [5]. Previous research has quantified the thermoregulatory responses of recreational players, whereby players' core temperature increased from 37 to 39 °C during 39 minutes of match play [10]. Due to the hot and humid environmental conditions that elite squash players compete in, future research should also aim to quantify the thermoregulatory responses of elite squash like core temperature. Anecdotally, many elite squash matches at the 2022 Professional Squash Association World Championships in Cairo, whereby temperature exceeded 30 °C and matches lasted longer than 60 minutes, might put athletes at risk of heat stress unless appropriate interventions are applied [71]. Other sports, such as soccer, have drinks and cooling breaks, and it may be beneficial for squash to implement similar strategies if severe thermoregulatory demands are experienced.

Nutrition Knowledge of Squash Players

Turner et al. [94] reported that elite squash players had 'average' nutrition knowledge as measured via the Nutrition for Sport Knowledge Questionnaire [92, 93]. There were no significant differences in nutrition knowledge between male and female players. Age and world ranking were shown to have a weak positive effect on nutrition knowledge. It was reported that older players may have more time to accumulate knowledge and understanding of nutrition, while players with higher world rankings may be able to pay for a nutrition consultant or may have an optimised performance due to more appropriate dietary habits due to greater nutrition knowledge [94]. Players with a relevant undergraduate degree had better nutrition knowledge than those who had no relevant education, as many may have studied a nutrition module as part of their course [94]. Players who consulted with a sports nutritionist were shown to have better nutrition knowledge than those who obtained nutrition information from the internet or a sport scientist, with the authors concluding that players should consult with a sports nutritionist to increase their nutrition knowledge [94].

Future research should assess the effectiveness of a nutrition education intervention in increasing the nutrition knowledge of elite squash players [89]. Future research should also investigate the dietary habits of elite squash players to determine whether a greater nutrition knowledge translates to more optimal dietary habits [87].

Nutritional Supplements for Squash Players

Supplements may be beneficial for squash players to address nutritional deficiencies, augment training adaptations, and optimise performance during competition [56]. Current research on supplements within squash has explored the effects of carbohydrate containing fluids on squash-specific skill maintenance [11], the effects of creatine monohydrate supplementation on squash-specific performance [81], the supplementation consumption patterns of international-level Spanish squash players [97], and the supplementation knowledge of elite squash players [94]. Turner et al. [94] reported that elite squash players had poor supplementation knowledge via the Nutrition for Sport Knowledge Questionnaire [92, 93]. Despite this, research suggests that squash players do consume supplements, with Ventura-Comes et al. [97] reporting 100% of international-level Spanish squash players consumed some form of supplement. Players were shown to consume supplements with lower efficacy, such as flax seed oil, glutamine, and branch chain amino acids, in comparison to ones with higher efficacy like beta-alanine, creatine, and sodium bicarbonate [56].

Bottoms et al. [11] quantified the effects of a 6.4% carbohydrate drink solution on skill maintenance, cognitive function, and maximal voluntary contraction fatigue test, before and after a squash-specific fatigue protocol in recreational squash players. Carbohydrate supplementation during exercise has been reported to delay the onset of fatigue through sparing muscle glycogen stores, preventing hypoglycemia, and reducing the impairment of excitation contraction coupling during exercise [80]. They reported that a 6.4% carbohydrate drink had no significant effect on skill maintenance, although significantly more shots landed in the scoring zone during the skill test. Carbohydrate ingestion also had a significant effect on visual reaction time. Consequently, carbohydrate ingestion may help maintain skill level and reaction time during squash play.

Romer et al. [81] reported that a creatine monohydrate supplementation protocol of 4 servings of 0.075 g/kg for 5 days increased squash-specific high intensity intermittent performance. During a squash-specific ghosting protocol, creatine monohydrate supplementation significantly increased mean set sprint time in comparison to a control group (maltodextrin) by 3.2% ± 0.8% ($P = 0.004$). A potential limitation of the study is that Romer et al. [81] did not use a validated squash-specific performance test and therefore it is difficult to ascertain whether improvements in mean set sprint time were due to a familiarization effect [23].

As previously discussed by Turner et al., [94], future research should aim to assess the efficacy of supplements on squash-specific performance to create consensus for an appropriate supplementation protocol for squash players similar to other racket (Ranchrodas et al. [77] and high intensity intermittent sports [18]. Beta-alanine, sodium bicarbonate, caffeine, and nitrate supplementation may be beneficial for elite squash players either acutely or chronically during training and/or competition [56].

Conclusions

This is the first systematic review to synthesise the physiological and nutritional research conducted in the sport of squash. Current research within squash has focused on a variety of areas, such as the physiological demands of squash to match play, the training load during a two-week microcycle, the sweat [Na^+] rates of elite players, the nutritional knowledge of elite players and the effects of carbohydrate and creatine supplementation on squash-specific performance. Squash is a high intensity intermittent sport that places high demands on aerobic metabolism during matches, as conveyed by high percentages of VO_{2max} and HR_{max}. Similarly, elite squash matches place high nutritional demands on players due to high energy expenditures. Consequently, generic nutritional guidelines may not be applicable, as energy expenditures were shown to differ from other racket sports.

Many of the studies conducted in squash had poor (10) or fair (19) methodological quality and only 14/35 studies are conducted on elite or world class players. Therefore, it is hard for practitioners and coaches to make accurate recommendations to optimise training, nutrition and recovery, as much of the scientific literature is based on recreational players and poor methodology (e.g. unblinded, no control group etc.). Much of the key literature to provide physiological and nutritional recommendations is lacking or outdated (pre 2009 rule change). The 2009 rule change is also reported to change the physical demands of the sport [63], and to this extent 17/35 studies reviewed are published during or after the 2009 rule change.

The present study identifies several future directions to advance research and evidence-based practice in squash. These include quantifying the physiological demands of elite female match play, examining muscle and blood metabolites during match play, and calculating energy expenditures and dietary intakes of players during training microcycles and competition periods. Such research would enable the development of sport-specific recovery and nutritional guidelines, similar to those in other racket [77] and high intermittent sports [18, 66, 76]. This would help practitioners, coaches, and players optimise training, fuelling and recovery guidelines, which can ultimately improve performance.

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Declarations

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References

1. Ackland TR, Lohman TG, Sundgot-Borgen J, Maughan RJ, Meyer NL, Stewart AD, Müller W. Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. medical commission. Sports Med. 2012;42(3):227–49. https://doi.org/10.2165/11597140-000000000-00000.
2. Ament W, Verkerke GJ. Exercise and fatigue. Sports Med. 2009;39(5):389–422. https://doi.org/10.2165/00007256-200939050-00005.
3. Anderson L, Close GL, Morgans R, Hambly C, Speakman JR, Drust B, Morton JP. Assessment of energy expenditure of a professional goalkeeper from the english premier league

using the doubly labeled water method. Int J Sports Phys Perf. 2019;14(5):1–684. https://doi.org/10.1123/ijspp.2018-0520.

4. Anderson L, Orme P, Naughton RJ, Close GL, Milsom J, Rydings D, Morton JP. Energy intake and expenditure of professional soccer players of the english premier league: evidence of carbohydrate periodization. Int J Sport Nut Exer Metab. 2017;27(3):228–38. https://doi.org/10.1123/ijsnem.2016-0259.
5. Baker LB. Sweating rate and sweat sodium concentration in athletes: a review of methodology and Intra/Interindividual variability. Sports Med. 2017;47:111–28.
6. Barnes KA, Anderson ML, Stofan JR, Dalrymple KJ, Reimel AJ, Roberts TJ, Baker LB. Normative data for sweating rate, sweat sodium concentration, and sweat sodium loss in athletes: an update and analysis by sport. J Sports Sci. 2019;37(20):2356–66. https://doi.org/10.1080/02640414.2019.1633159.
7. Beaudin P, Zapiec C, Montgomery D. Heart rate response and lactic acid concentration in squash players. Res Q. 1978;49(4):406–12. https://doi.org/10.1080/10671315.1978.10615553.
8. Bingham SA, Gill C, Welch A, Day K, Cassidy A, Khaw KT, Day NE. Comparison of dietary assessment methods in nutritional epidemiology: weighed records v. 24 h recalls, food-frequency questionnaires and estimated-diet records. Br J Nutr. 1994;72(4):619–43. https://doi.org/10.1079/BJN19940064.
9. Blanksby BA, Elliott BC, Bloomfield J. Telemetered heart rate responses of middle-aged sedentary males, middle aged active males and "A" grade male squash players. Med J Aus. 1973;2(10):477–81. https://doi.org/10.5694/j.1326-5377.1973.tb128870.x.
10. Blanksby BA, Elliott BC, Davis KH, Mercer MD. Blood pressure and rectal temperature responses of middle-aged sedentary, middle-aged active and "A"-grade competitive male squash players. Bri J Sports Med. 1980;14(2–3):133–8. https://doi.org/10.1136/bjsm.14.2-3.133.
11. Bottoms LM, Hunter AM, Galloway SR. Effects of carbohydrate ingestion on skill maintenance in squash players. Eur J Sport Sci. 2006;6(3):187–95. https://doi.org/10.1080/17461390600804455.
12. Brady HR, Kinirons M, Lynch T, Ohman EM, Tormey W, O'Malley KM, Horgan JH. Heart rate and metabolic response to competitive squash in veteran players: Identification of risk factors for sudden cardiac death. Eur Heart J. 1989;10(11):1029–35. https://doi.org/10.1093/oxfordjournals.eurheartj.a059415.
13. Brigden GS, Hughes LO, Broadhurst P, Raftery EB. Blood pressure changes during the game of squash. Eur Heart J. 1992;13(8):1084–7. https://doi.org/10.1093/oxfordjournals.eurheartj.a060318.
14. Brinkmans NJ, Iedema N, Plasqui G, Wouters L, Saris WM, van Loon LC, van Dijk J. Energy expenditure and dietary intake in professional football players in the dutch premier league: implications for nutritional counselling. J Sport Sci. 2011;37(24):2759–67. https://doi.org/10.1080/02640414.2019.1576256.
15. Burke LM, Hawley JA, Wong SS, Jeukendrup AE. Carbohydrates for training and competition. J Sports Sci. 2011;29:17–27. https://doi.org/10.1080/02640414.2011.585473.
16. Cashin AG, McAuley JH. Clinimetrics: physiotherapy evidence database (PEDro) scale. J Physiother. 1995;66(1):59. https://doi.org/10.1016/j.jphys.2019.08.005.
17. Chin MK, Steininger K, So RC, Clark CR, Wong AS. Physiological profiles and sport specific fitness of asian elite squash players. Br J Sports Med. 1995;29(3):158–64. https://doi.org/10.1136/bjsm.29.3.158.
18. Collins J, Maughan RJ, Gleeson M, Bilsborough J, Jeukendrup A, Morton JP, McCall A. UEFA expert group statement on nutrition in elite football. Current evidence to inform practical recommendations and guide future research. Br J Sports Med. 2021;55(8):416. https://doi.org/10.1136/bjsports-2019-101961.
19. Costello N, Deighton K, Dyson J, Mckenna J, Jones B. Snap-N-send: a valid and reliable method for assessing the energy intake of elite adolescent athletes. Eur J Sport Sci. 2017;17(8):1044–55. https://doi.org/10.1080/17461391.2017.1337815.
20. Costello N, Deighton K, Preston T, Matu J, Rowe J, Jones B. Are professional young rugby league players eating enough? energy intake, expenditure and balance during a pre-season. Eur J Sport Sci. 2019;19(1):123–32. https://doi.org/10.1080/17461391.2018.1527950.
21. Costello N, Deighton K, Preston T, Matu J, Rowe J, Sawczuk T, Jones B. Collision activity during training increases total energy expenditure measured via doubly labelled water. Eur J App Phys. 2018;118(6):1169–77. https://doi.org/10.1007/s00421-018-3846-7.
22. Cronin J, Mcnair P, Marshall R. Lunge performance and its determinants. J Sports Sci. 2003;21(1):49–57. https://doi.org/10.1080/0264041031000070958.
23. Currell K, Jeukendrup AE. Validity, reliability and sensitivity of measures of sporting performance. Sports Med. 2008;38(4):297–316. https://doi.org/10.2165/00007256-200838040-00003.
24. Dasa MS, Friborg O, Kristoffersen M, Pettersen G, Plasqui G, Sundgot-Borgen J, Rosenvinge JH. Energy expenditure, dietary intake and energy availability in female professional football players. BMJ Open Sport Exer Med. 2023;9(1):e001553. https://doi.org/10.1136/bmjsem-2023-001553.
25. Ebine N, Rafamantanantsoa HH, Nayuki Y, Yamanaka K, Tashima K, Ono T, Jones PH. Measurement of total energy expenditure by the doubly labelled water method in professional soccer player. J Sport Sci. 2002;20(5):391–7. https://doi.org/10.1080/026404102317366645.
26. Elkins MR, Moseley AM, Sherrington C, Herbert RD, Maher CG. Growth in the physiotherapy evidence database (PEDro) and use of the PEDro scale. Br J Sports Med. 2013;47(4):188–9. https://doi.org/10.1136/bjsports-2012-091804.
27. Ellis DG, Speakman J, Hambly C, Cockram A, Morton JP, Close GL, Donovan TF. Case-study: energy expenditure of a world class male wheelchair tennis player during training, grand slam and british open tournaments measured by doubly labelled water. Int J Sports Sci Coach. 2023;19(2):57–63. https://doi.org/10.1177/17479541231169033.
28. Ellis DG, Speakman J, Hambly C, Morton JP, Close GL, Donovan TF. An observational case series measuring the energy expenditure of elite tennis players during competition and training by using doubly labeled water. Int J Sports Physiol Perform. 2023;18(5):547–52.
29. Ellis DG, Speakman J, Hambly C, Morton JP, Close GL, Lewindon D, Donovan TF. Energy expenditure of a male and female tennis player during association of tennis professionals/women's tennis association and grand slam events measured by doubly labeled water. Med Sci Sports Exer. 2021;53(12):2628–34. https://doi.org/10.1249/MSS.0000000000002745.
30. Foley NC, Bhogal SK, Teasell RW, Bureau Y, Speechley MR. Estimates of quality and reliability with the physiotherapy evidence-based database scale to assess the methodology of randomized controlled trials of pharmacological and nonpharmacological interventions. Phys Ther. 2006;86(6):817–24. https://doi.org/10.1093/ptj/86.6.817.
31. Gibson N, Bell P, Clyne A, Lobban G, Aitken L, Gibbon K. Physical preparation for elite-level squash players: monitoring, assessment, and training practices for the strength and conditioning coach. Strength Cond J. 2019;41(3):51–62. https://doi.org/10.1519/SSC.0000000000000449.
32. Giersch GW, Charkoudian N, Stearns RL, Casa DJ. Fluid balance and hydration considerations for women: review and future directions. Sports Med. 2020;50(2):253–61. https://doi.org/10.1007/s40279-019-01206-6.

33. Girard O, Chevalier R, Habrard M, Sciberras P, Hot P, Millet GP. Game analysis and energy requirements of elite squash. J Strength Cond Res. 2007;21(3):909.
34. Girard O, Micallef JP, Noual J, Millet GP. Alteration of neuromuscular function in squash. J Sci Med Sport. 2010;13(1):172–7. https://doi.org/10.1016/j.jsams.2008.11.002.
35. Girard O, Sciberras P, Habrard M, Hot P, Chevalier R, Millet GP. Specific incremental test in elite squash players. Br J Sports Med. 2005;39(12):921–6.
36. Gonzalez GZ, MoseleyAM MCG, Nascimento DP, Costa LM, Costa LO. Methodologic quality and statistical reporting of physical therapy randomized controlled trials relevant to musculoskeletal conditions. Arc Phys Med Rehab. 2018;99(1):129–36. https://doi.org/10.1016/j.apmr.2017.08.485.
37. Gouttebarge V, Moen M, Boschman JS, Kantebeen M. Squash-specific exercise test for elite squash players: development and validity. Eur J Sports Exerc sci. 2013;2:1–6.
38. Hannon MP, Parker LF, Carney DJ, Mckeown J, Speakman JR, Hambly C, Morton JP. Energy requirements of male academy soccer players from the english premier league. Med Sci Sport Exer. 2021;53(1):200–10. https://doi.org/10.1249/MSS.0000000000002443.
39. James C, Dhawan A, Jones T, Girard O. Quantifying training demands of a 2-week in-season squash microcycle. Int J Sports Phys Perform. 2021;16(6):779.
40. James C, Dhawan A, Jones T, Pok C, Yeo V, Girard O. Minimal agreement between internal and external training load metrics across a 2-wk training microcycle in elite squash. J Sports Sci Med. 2021;20(1):101.
41. James C, Jones T, Farra S. Physiological and performance correlates of squash physical performance. J Sports Sci Med. 2022;21(1):82–90.
42. James C, Tenllado Vallejo F, Kantebeen M, Farra S. Validity and reliability of an on-court fitness test for assessing and monitoring aerobic fitness in squash. J Strength Cond Res. 2019;33(5):1400–7. https://doi.org/10.1519/JSC.0000000000002465.
43. Jones TW, Williams BK, Kilgallen C, Horobeanu C, Shillabeer BC, Murray A, Cardinale MA. Review of the performance requirements of squash. Int J Sports Sci Coach. 2018;13(6):1223–32. https://doi.org/10.1177/1747954118792492.
44. Joyner MJ, Coyle EF. Endurance exercise performance: the physiology of champions. J Phys. 2008;586(1):35–44.
45. Karastergiou K, Smith SR, Greenberg AS, Fried SK. Sex differences in human adipose tissues - the biology of pear shape. Biol Sex Differ. 2012;2012(3):13. https://doi.org/10.1186/2042-6410-3-13.
46. Kasper AM, Langan-Evans C, Hudson JF, Brownlee TE, Harper LD, Naughton RJ, Close GL. Come back skinfolds, all is forgiven: a narrative review of the efficacy of common body composition methods in applied sports practice. Nutrients. 2021;13(4):1075. https://doi.org/10.3390/nu13041075.
47. Kingsley M, James N, Kilduff L, Dietzig RE, Dietzig B. An exercise protocol that simulates the activity patterns of elite junior squash. J Sports Sci. 2006;24(12):1291–6.
48. Kirkendall DT. Mechanisms of peripheral fatigue. Med Sci Sports Exerc. 1990;22(4):444–9.
49. Krustrup P, Mohr M, Steensberg A, Bencke J, Kjair M, Bangsbo J. Muscle and blood metabolites during a soccer game: implications for sprint performance. Med Sci Sports Exerc. 2006;38(6):1165–74. https://doi.org/10.1249/01.mss.0000222845.89262.cd.
50. Lees A. Science and the major racket sports: a review. J Sports Sci. 2003;21(9):707–32. https://doi.org/10.1080/0264041031000140275.
51. Lombard AJ, Shaw I, Shaw BS, Watkin SJ, Schoeman HJ, Shaw I, Coetzer EW. Role of physical fitness parameters in squash performance. Af J Phys Health Edu Rec Dance. 2014;20:55–962.
52. Lynch T, Kinirons MT, O'Callaghan D, Ismail S, Brady HR, Horgan JH. Metabolic changes during serial squash matches in older men. Can J Sport Sci. 1992;17:110–3.
53. MacGowan GA, Ryan R, O'Donovan D, Tempany K, Kinsella A, Horgan JH. Fluid replacements after squash: an analysis of the effects of several fluid regimens on exercise-related metabolic changes. Cardiology. 1994;84(4–5):356–64. https://doi.org/10.1159/000176423.
54. Majumdar P, Mandal M, Yadav D. The effectiveness of training routine with reference to the physiological demand of squash match play. Int J App Sports Sci. 2009;21:28–44.
55. Martin AD, Ross WD, Drinkwater DT, Clarys JP. Prediction of body fat by skinfold caliper: assumptions and cadaver evidence. Int J Obes. 1985;1(Supple 1):31–9.
56. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer D, Peeling P, Phillips SM, Engebretsen L. IOC consensus statement: dietary supplements and the high-performance athlete. Br J Sports Med. 2018;52(7):439–55. https://doi.org/10.1136/bjsports-2018-099027.
57. McKay AA, Stellingwerff T, Smith ES, Martin DT, Mujika I, Goosey-Tolfrey V, Burke LM. Defining training and performance caliber: a participant classification framework. Int J Sports Phys Perf. 2002;17(2):317–31. https://doi.org/10.1123/ijspp.2021-0451.
58. Micklewright D, Papapdopoulou E. A new squash specific incremental field test. Int J Sports Med. 2008;29(9):758.
59. Mohr M, Draganidis D, Chatzinikolaou A, Barbero-Álvarez JC, Castagna C, Douroudos I, Fatouros IG. Muscle damage, inflammatory, immune and performance responses to three football games in 1 week in competitive male players. Eur J Appl Physiol. 2016;116(1):179–93. https://doi.org/10.1007/s00421-015-3245-2.
60. Montpetit RR, Beauchamp L, Léger L. Energy requirement of squash and racquetball. Phys Sports Med. 1987;15(8):106–9.
61. Morehen JC, Bradley WJ, Clarke J, Twist C, Hambly C, Speakman JR, Close GL. The assessment of total energy expenditure during a 14-day in-season period of professional rugby league players using the doubly labelled water method. Int J Sport Nut Exer Metab. 2016;26(5):464–72. https://doi.org/10.1123/ijsnem.2015-0335.
62. Morehen JC, Rosimus C, Cavanagh BP, Hambly C, Speakman JR, Elliott-Sale K, Morton JP. Energy expenditure of female international standard soccer players: a doubly labeled water investigation. Med Sci Sport Exer. 2022;54(5):769–79. https://doi.org/10.1249/MSS.0000000000002850.
63. Murray S, James N, Hughes MD, Perš J, Mandeljc R, Vučković G. Effects of rule changes on physical demands and shot characteristics of elite-standard men's squash and implications for training. J Sports Sci. 2016;34(23):2170–4. https://doi.org/10.1080/02640414.2016.1216155.
64. Nana A, Slater GJ, Hopkins WG, Halson SL, Martin DT, West NP, Burke LM. Importance of standardized DXA protocol for assessing physique changes in athletes. Int J Sport Nut Exer Met. 2016;26(3):259–67. https://doi.org/10.1123/ijsnem.2013-0111.
65. Nana A, Slater GJ, Stewart AD, Burke LM. Methodology review: Using dual-energy X-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people. Int J Sport Nut Exer Met. 2015;25(2):198–215. https://doi.org/10.1123/ijsnem.2013-0228.
66. Nédélec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G. Recovery in soccer: part II—recovery strategies. Sports Med. 2013;43(1):9–22. https://doi.org/10.1007/s40279-012-0002-0.

67. Okura T, Koda M, Ando F, Niino N, Ohta S, Shimokata H. Association of polymorphisms in the estrogen receptor α gene with body fat distribution. Int J Ob. 2003;27(9):1020–7. https://doi.org/10.1038/sj.ijo.0802378.
68. Olympics. IOC Session approves LA28's proposal for five additional sports. 2023. https://olympics.com/ioc/news/ioc-session-approves-la28-s-proposal-for-five-additional-sports. Accessed 20 Oct 2023.
69. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Moher D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Int J Sur. 2021;88:105905. https://doi.org/10.1016/j.ijsu.2021.105906.
70. Physiotherapy Evidence Database. PEDro Scale. 2022. https://pedro.org.au/english/resources/pedro-scale/. Accessed 15 Mar 2022.
71. Périard J, Eijsvogels T, Daanen H. Exercise under heat stress: Thermoregulation, hydration, performance implications, and mitigation strategies. Physiol rev. 2021;101(4):1873–979. https://doi.org/10.1152/physrev.00038.2020.
72. Professional Squash Association. PSA squash tour. 2022. https://www.psaworldtour.com. Accessed 16 Mar 2022.
73. Professional Squash Association. PSA World Championsips. 2023. https://www.psaworldtour.com/tournament/cib-psa-world-championships-cairo-2022/. Accessed 16 Jan 2023.
74. Professional Squash Association. PSA Tournamets. 2024. https://www.psaworldtour.com/tournaments/. Accessed 1 June 2024.
75. Raman A, Macdermid PW, Mündel T, Mann M, Stannard SR. The effects of carbohydrate loading 48 hours before a simulated squash match. Int J Sports Nut Exerc Metab. 2014;24(2):157.
76. Ranchordas MK, Dawson JT, Russell M. Practical nutritional recovery strategies for elite soccer players when limited time separates repeated matches. J Int Soc Sports Nutr. 2017. https://doi.org/10.1186/s12970-017-0193-8.
77. Ranchordas MK, Rogersion D, Ruddock A, Killer SC, Winter EM. Nutrition for tennis: practical recommendations. J Sports Sci Med. 2013;12(2):211–24.
78. Rodriguez-Giustiniani P, Rodriguez-Sanchez N, Galloway SR. Fluid and electrolyte balance considerations for female athletes. Eur J Sport Sci. 2022;22(5):697–708. https://doi.org/10.1080/17461391.2021.1939428.
79. Research Registry. Registry of systematic reviews & meta-analyses. 2022. https://www.researchregistry.com. Accessed 18 Apr 2022.
80. Rollo I, Gonzalez JT, Fuchs CJ, van Loon LC, Williams C. Primary, secondary, and tertiary effects of carbohydrate ingestion during exercise. Sports Med. 2020;50(11):1863–71. https://doi.org/10.1007/s40279-020-01343-3.
81. Romer LM, Barrington JP, Jeukendrup AE. Effects of oral creatine supplementation on high intensity, intermittent exercise performance in competitive squash players. Int J Sports Med. 2001;22(8):546–52. https://doi.org/10.1055/s-2001-18520.
82. Rosimus C. Case study: the effect of nutritional intervention on body composition and physical performance of a female squash player. Int J Sport Nut Exerc Metab. 2018;28(3):279–83. https://doi.org/10.1123/ijsnem.2017-0069.
83. Sagayama H, Hamaguchi G, Toguchi M, Ichikawa M, Yamada Y, Ebine N, Tanaka H. Energy requirement assessment in japanese table tennis players using the doubly labeled water method. Int J Sport Nut Exer Metab. 2017;27(5):421–8. https://doi.org/10.1123/ijsnem.2017-0022.
84. Silva AM, Santos DA, Matias CN, Minderico CS, Schoeller DA, Sardinha LB. Total energy expenditure assessment in elite junior basketball players: a validation study using doubly labeled water. J Str Cond Res. 2013;27(7):1920–7. https://doi.org/10.1519/JSC.0b013e31827361eb.
85. Smekal G, Von Duvillard SP, Rihacek C, Pokan R, Hofmann P, Baron R, Bachl N. A physiological profile of tennis match play. Med Sci Sports Exer. 2001;33(6):999–1005. https://doi.org/10.1097/00005768-200106000-00020.
86. Smith DR, King RJ, Duckworth LC, Sutton L, Preston T, O'Hara JP, Jones B. Energy expenditure of rugby players during a 14-day in-season period, measured using doubly labelled water. Eur J App Phys. 2018;118(3):647–56. https://doi.org/10.1007/s00421-018-3804-4.
87. Spronk I, Kullen C, Burdon C, O'Connor H. Relationship between nutrition knowledge and dietary intake. Br J Nutr. 2014;111(10):1713–26. https://doi.org/10.1017/S0007114514000087.
88. Steininger K, Wodick RE. Sports-specific fitness testing in squash. Br J Sports Med. 1987;21(2):23.
89. Tam R, Beck KL, Manore MM, Gifford J, Flood VM, O'Connor H. Effectiveness of education interventions designed to improve nutrition knowledge in athletes: a systematic review. Sports Med. 2019;49(11):1769–86. https://doi.org/10.1007/s40279-019-01157-y.
90. Thompson FE, Subar AF. Dietary assessment methodology. In: Nutrition in the prevention and treatment of disease. London: Elsevier; 2017. pp. 5–48.
91. Tomlin DL, Wenger HA. The relationship between aerobic fitness and recovery from high intensity intermittent exercise. Sports Med. 2001;31(1):1–11. https://doi.org/10.2165/00007256-200131010-00001.
92. Trakman GL, Brown F, Forsyth A, Belski R. Modifications to the nutrition for sport knowledge questionnaire (NSQK) and abridged nutrition for sport knowledge questionnaire (ANSKQ). J Int Soc Sports Nut. 2019;16(1):26. https://doi.org/10.1186/s12970-019-0293-8.
93. Trakman GL, Forsyth A, Hoye R, Belski R. The nutrition for sport knowledge questionnaire (NSKQ): development and validation using classical test theory and rasch analysis. J Int Soc Sports Nutr. 2017;14:26. https://doi.org/10.1186/s12970-017-0182-y.
94. Turner O, Mitchell N, Ruddock A, Purvis A, Ranchordas MK. Elite squash players nutrition knowledge and influencing factors. J Int Soc Sports. 2021;18(1):1.
95. Turner O, Mitchell N, Ruddock A, Purvis A, Ranchordas MK. Fluid balance, sodium losses and hydration practices of elite squash players during training. Nutrients. 2023;15(7):1749. https://doi.org/10.3390/nu15071749.
96. Ventura-Comes A, Martínez-Sanz JM, Sánchez-Oliver AJ, Domínguez R. Analysis of foods habits in squash players. J Phys Ed Sport. 2019;19:1300–7. https://doi.org/10.7752/jpes.2019.s4189.
97. Ventura-Comes A, Sánchez-Oliver AJ, Martínez-Sanz JM, Domínguez R. Analysis of nutritional supplements consumption by squash players. Nutrients. 2018;10(10):1341. https://doi.org/10.3390/nu10101341.
98. Vučković G, Dežman B, Erčulj F, Kovačič S, Perš J. Comparative movement analysis of winning and losing players in men's elite squash. Kinesiol Slov. 2003;9:74–84.
99. Wang J, Thornton JC, Kolesnik S, Pierson RN Jr. Anthropometry in body composition: an overview. Ann N Y Acad Sci. 2001;904:317–26. https://doi.org/10.1111/j.1749-6632.2000.tb06474.x.
100. Wilkinson M, Cooke M, Murray S, Thompson KG, St Clair Gibson A, Winter EM. Physiological correlates of multiple-sprint ability and performance in international-standard squash players. J Strength Cond Res. 2012;26(2):540–7. https://doi.org/10.1519/JSC.0b013e318220ddbb.
101. Wilkinson M, Leedale-Brown D, Winter EM. Reproducibility of physiological and performance measures from a squash-specific fitness test. Int J Sports Phys Perf. 2009;4(1):41.

102. Wilkinson M, Leedale-Brown D, Winter EM. Validity of a squash-specific test of change-of-direction speed. Int J Sports Phys Perf. 2009;4(2):176–85. https://doi.org/10.1123/ijspp.4.2.176.
103. Wilkinson M, Leedale-Brown D, Winter EM. Validity of a squash-specific fitness test. Int J Sports Phys Perf. 2009;4(1):29–40. https://doi.org/10.1123/ijspp.4.1.29.
104. Wilkinson M, McCord A, Winter EM. Validity of a squash-specific test of multiple-sprint ability. J Strength Cond Res. 2010;24(12):3381–6. https://doi.org/10.1519/JSC.0b013e3181f56056.
105. World Squash Federation. A sport with history. 2022. https://www.worldsquash.org/a-sport-with-history/. Accessed 16 Mar 2022.
106. World Squash Federation. World squash singles rules. 2022. https://www.worldsquash.org/wp-content/uploads/2021/12/201127_Rules-of-Singles-Squash-2020-V2.pdf. Accessed 16 Mar 2022.
107. World Squash Federation. Info about WSF. 2022. https://www.worldsquash.org/wsf-information/. Accessed 16 Mar 2022.