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Body dissatisfaction, disordered eating and exercise behaviours: associations with symptoms of REDs in male and female athletes

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ABSTRACT

Objectives Disordered eating and compulsive exercise behaviours are common among athletes and can increase the risk of relative energy deficiency in sport (REDs). Contrarily, the prevalence of muscle dysmorphia and its relationship with REDs are unknown. This cross-sectional study aimed to evaluate associations of all three with REDs symptoms.

Methods Elite and subelite Icelandic athletes (n=83, 67.5% females) answered the Low Energy Availability in Females/Males Questionnaires (LEAF-Q/LEAM-Q), Eating Disorder Examination–Questionnaire Short (EDE-QS), Exercise Addiction Inventory (EAI) and Muscle Dysmorphic Disorder Inventory (MDDI). Body composition was assessed via dual-energy X-ray absorptiometry; resting metabolic rate via indirect calorimetry; and blood samples were drawn for analysis of nutrition and hormonal status. Females were compared based on LEAF-Q total score (≥8 (at risk) vs <8). Simple linear regression was applied to evaluate associations of (a) testosterone with other objective measures and LEAM-Q scores in males; and (b) LEAF-Q/LEAM-Q scores with EDE-QS, EAI and MDDI scores.

Results In total, 8.4% of participants scored above cut-off on EDE-QS, 19.3% on EAI and 13.3% on MDDI. Females with LEAF-Q total score ≥8 had higher median scores on EDE-QS, EAI and MDDI compared with those scoring <8. Testosterone was positively associated with iron and inversely with total iron-binding capacity but was not associated with scoring on any of the administered questionnaires.

Conclusion Drive for muscularity and aesthetic physique may play a role in the complex presentation of REDs. Screening for muscle dysmorphia, in addition to disordered eating and compulsive exercise, could therefore facilitate early detection of REDs.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Relative energy deficiency in sport (REDs) is a complex syndrome, whose causes and manifestations can differ based on factors such as sport and training history, sex and age.

WHAT THIS STUDY ADDS

⇒ Occurrence and severity of disordered eating and exercise behaviours, as well as body dissatisfaction, can vary substantially between athletes.

⇒ Occasional but repeated engagement in disordered eating and/or exercise behaviours may potentially result in REDs and associated consequences, without athletes exceeding screening cut-offs.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ We encourage considerations of multifaceted body image concerns, ie, not only drive for thinness and/or fear of weight gain, in prevention, screening and treatment of REDs.

INTRODUCTION

High-level athletes continuously seek ways to improve their performance. Whether successful or not, substantial focus is often placed on maximising recovery and training adaptations with targeted dietary approaches.[1] Nevertheless, there can be a fine line between dedication and 'win at all costs' mentality. Characteristics such as commitment, toughmindedness and discipline are all crucial for sport performance but can become problematic if athletes' health behaviours are too rigid.[2] Athletic success is underpinned by a fine-tuned balance between training load and nutrition, among other things. When daily energy intake is not in line with exercise energy expenditure, athletes may find themselves in a state of low energy availability (LEA).[3] As defined in a recently updated consensus from the IOC,[4] a problematic (prolonged and/or severe) LEA, either due to intentional or unintentional reasons, is the underlying culprit of relative energy deficiency in sport (REDs). REDs manifests as impaired physiological and/or psychological functioning and can therefore impose several consequences for the ambitious athlete, including impaired training adaptations and overall sport performance.[4,5] Therefore, mitigating the occurrence of REDs via prevention and early detection should be a priority for everyone involved in sports and athletes' well-being.[6]

Eating behaviours occur on a spectrum spanning from optimised nutrition to clinical eating disorders, with disordered eating placed in the middle.[7] Several factors can complicate the training–nutrition balance for athletes and distance them from the optimal state. Among such factors are body image concerns and pressure to perform and/or look a certain way.[8] Although insufficiently addressed in the literature, body image concerns of athletes and non-athletes alike are multifaceted and do not always display as drive for thinness or preoccupation with low body weight.[9] Muscularity concerns and drive for size underlie what has been referred to as muscle dysmorphia.[10] Extreme dietary practices and compulsive exercise are commonly shared symptoms between muscle dysmorphia and restrictive eating disorders, despite the different 'end goals'.[9] Compulsive exercise, which has interchangeably been called exercise addiction, can also occur in the absence of abnormal eating behaviours.[11] Both disordered eating and compulsive exercise are among potential causes of REDs,[12–14] while less is known about the contribution of muscle dysmorphia and other body image facets. Reported prevalence of disordered eating and eating disorders is generally higher in female versus male athletes. Moreover, the risk has been deemed highest in weight-sensitive sports such as endurance, aesthetic and weight-class sports.[7 14 15] Importantly though, most screening tools for eating disorders are primarily focused on drive for thinness, fear of gaining weight and/or body fat.[9 16] This may consequently have resulted in underestimation of prevalence and/or symptoms of body image issues being unrecognised in sports and/or athletes considered at low risk.[4 17] A knowledge gap also exists in the REDs literature itself, as the causes and sequelae of problematic LEA in males, teams and other less-studied sports are far from adequately understood.[18 19] The present study therefore aimed to assess occurrence of disordered eating, compulsive exercise and muscle dysmorphia in high-level male and female athletes from various sports. Secondly, to evaluate associations of all three outcomes with markers and/or symptoms of REDs.

METHODS

Study design and recruitment of participants

Icelandic athletes from various sports were invited to participate in this cross-sectional study. Athletes were eligible if they had reached 15 years of age and were defined by the National Olympic Committee (NOC) as either (a) elite: individuals meeting the elite criteria set by their sport federation, or (b) subelite: individuals currently not defined as elite but with continued training believed to have the potential to excel in their sport. The estimated number of Icelandic athletes meeting the eligibility criteria is around 1000. NOC, through its sport federations, shared the initial invitation via email. Additionally, key ballet schools were asked to share the invite with high-level dancers. Online platforms such as the study website and social media were also used for recruitment. Initially, 218 athletes answered an online questionnaire from July to December 2021. Six respondents did not meet the elite/subelite criteria or only completed part of the questionnaire. Therefore, 212 athletes received invitations to participate in the measurement phase (April–September 2022), of which 87 accepted the invitation. Athletes were categorised into five different sport groups (aesthetic, ball, endurance, power and weight-class sports), based on the approach developed and used in a previous study.[20] Paralympic athletes (n=4) were excluded from the present analysis due to observed deviances in total body bone mineral density (BMD) and some of the blood biomarkers, which are likely attributed more to physical disabilities rather than REDs.[21] Therefore, their data deserve a special consideration and will be reported elsewhere. For athletes over the age of 18 years, completion of the online questionnaire equalled approval for participation in the initial part of the research. For younger athletes, informed consent was acquired from their parents via digital certificates before the online questionnaire was shared with the young athletes. Athletes participating in the measurement phase provided informed consent upon arrival.

Patient and public involvement

In preparation of the study, aims and research protocol were presented and discussed with NOC. Questionnaire selection and translation process were partly based on feedback received from sport science students taking part in piloting of questionnaires.

Equity, diversity and inclusion statement

Regardless of ethnic background, participation was open for athletes from a wide range of sports, with no upper age limit as long as athletes met the inclusion criteria. Invitations were sent to eligible athletes living in all parts of Iceland, urban and rural, although measurements had to be attended in the capital area of Reykjavik.

Data collection procedures

The sex-specific questionnaires in the initial part of the study were distributed via the Qualtrics XM platform. The measurement phase was conducted in two visits. For the first visit, participants underwent assessment of body composition, and a venous blood sample was drawn. They also answered three brief questionnaires. For the second visit, approximately 2 weeks later, resting metabolic rate (RMR) was measured via indirect calorimetry.

Measures

Questionnaires

1. The online questionnaire consisted of the Low Energy Availability in Females Questionnaire (LEAF-Q)[22] and the newer Low Energy Availability in Males Questionnaire (LEAM-Q),[23] in addition to demographic questions. A total score of ≥8 is the established

cut-off for LEAF-Q, indicating a risk of REDs.[22] Scoring of LEAM-Q is currently limited to four questions related to sex drive and morning erections.[23] To allow for comparison between the sexes, females were asked questions from the LEAM-Q that are not included in the LEAF-Q. Scores for LEAM-Q items were calculated according to the scoring key from Lundy *et al*,[23] where higher scores always indicate a worse/more negative outcome.

2. Three brief questionnaires were administered in the measurement phase. The Eating Disorder Examination–Questionnaire Short (EDE-QS)[24] with established cut-off of ≥15[25] was used to screen for symptoms of disordered eating. Compulsive exercise symptoms were assessed using the Exercise Addiction Inventory (EAI).[26] EAI score ≥24 indicates a risk of compulsive exercise, 13–23 some symptoms and 6–12 no symptoms.
3. The Muscle Dysmorphic Disorder Inventory (MDDI)[27] was used to screen for muscle dysmorphia. A cut-off score of ≥39 has been used to discriminate between those at risk of muscle dysmorphia versus not.[28] The internal consistency was good for EDE-QS (Cronbach's α=0.878), EAI (α=0.749) and MDDI (α=0.824).

Detailed information about administered questionnaires can be found in the online supplemental tables 1 and 2. Translation of all questionnaires was conducted according to available guidelines[29]: (a) forward translation from English to Icelandic by two researchers; (b) back-translation by two other researchers who were blinded to the original questionnaire; and (c) discussion between translators/back-translators, and agreement on final versions.

Body composition and anthropometrics

Fasted whole-body dual-energy X-ray absorptiometry (DXA) scans for body composition were performed using GE Lunar iDXA (GE Medical Systems, Belgium). Height was measured to the nearest mm with a stadiometer (Seca model 217; Seca), and body weight to the nearest 0.1 kg with a calibrated scale (Seca model 812; Seca).

Blood sampling

Fasted blood samples were collected in 3.5 mL serum-separating tubes, centrifuged (3500 RPM/10 min) and cooled until analysed in the laboratory. Oestradiol (females), testosterone (males), vitamin B_{12} and 25-OH vitamin D were measured on Cobas 801 analyser (Roche) with electrochemiluminescence-binding assay, using the competition principle. Iron (Fe) was measured on Cobas 702 with colorimetric assay based on the FerroZine method without deproteinisation, and ferritin on Cobas 801 with electrochemiluminescence-binding assay, using the sandwich principle. Unsaturated iron-binding capacity (UIBC) was directly determined with FerroZine, and the sum of serum Fe and UIBC represents the total iron-binding capacity (TIBC). Thyroid-stimulating hormone (TSH) was measured on Cobas 801 with the electrochemiluminescence-binding assay, using the sandwich principle. Alkaline phosphatase (ALP), albumin and magnesium were measured with a colorimetric assay, Immunoglobulin A (IgA) and C reactive protein (CRP) with an immunoturbidimetric assay, creatinine with the enzymatic method and calcium photometrically on Cobas 702. Apart from one female, all had a blood sample taken. One male did not have a valid measure of testosterone. In cases where serum oestradiol concentrations measured below the analytical detection level of the laboratory, the lowest detectable concentration (18 pmol/L) was registered.[30]

Resting metabolic rate

For RMR assessment, participants (n=78, 51 females) arrived at the laboratory in the morning, in a rested and fasted state. They had been instructed to avoid strenuous exercise the day before, and refrain from caffeine, alcohol and stimulating supplements for 12 hours before the visit. Participants rested for 10 min prior to the measurement. Oxygen consumption and carbon dioxide production were measured for 30 min using ventilated hood (Vyntus CPX). The last 20 min of steady state was used for assessment of RMR.[31] A total of 12 participants (5 females) did not arrive in a fasted state, resulting in invalid measures. One additional measure (female) was excluded from the RMR analysis due to technical issues. IOC has listed RMR <30 kcal/kg fat-free mass (FFM)/day as a potential indicator of REDs.[32]

Data analysis

Statistical analyses were conducted using IBM SPSS statistics V.28, with significance set to α<0.05. Continuous variables were summarised as means±SD for parametric data, and medians with IQRs (25th and 75th percentiles) for non-parametric data.

Females were divided into two groups based on their total LEAF-Q score (≥8 (at risk) vs <8). Group comparisons were performed using independent t-test or Mann-Whitney U test as appropriate. Cohen's (d) effect sizes were reported for parametric data, with threshold values set at 0.2 (small), 0.5 (moderate) and 0.8 (large). Wilcoxon effect size ($r=Z/\sqrt{n}$) was calculated for non-parametric data, using thresholds of 0.1, 0.3 and 0.5 for small, moderate and large effects.[33] Simple linear regression with serum testosterone concentrations as the dependent variable and other characteristics as independent variables was conducted for males. For all participants, associations between LEAF-Q/LEAM-Q-derived scores (independent variables) and scores on EDE-QS, EAI and MDDI (dependent variables) were checked with linear regression. Differences between the five sport groups were analysed using one-way analysis of variance, and Bonferroni post-hoc as appropriate. Categorical data were compared using X^2 tests. Internal consistency of EDE-QS, EAI and MDDI was assessed using Cronbach's α.

Table 1 Female participant characteristics presented as medians with IQRs (25th and 75th percentiles) for non-parametric and means±SD for parametric data

Parameter	All (n=56)	Total LEAF-Q ≥8 (n=26)	Total LEAF-Q <8 (n=30)	P value	Effect size*
Age (years)	20.8 (17.9–27.7)	20.2 (17.7–24.5)	22.4 (17.9–32.8)	0.230	0.16
Body weight (kg)	66.5±10.6	66.2±8.6	66.8±12.1	0.829	0.06
DXA FFM (kg)	46.4±4.9	46.4±5.0	46.3±4.8	0.921	0.03
DXA FFM% (FFM/BW)	70.5±7.1	70.4±7.7	70.6±6.5	0.909	0.03
DXA fat%	25.3±7.1	25.1±6.5	25.5±7.7	0.852	0.05
Total body BMD Z-score	1.26±1.0	0.93±1.03	1.53±0.89	0.023	0.63
RMR (kcal)	1630±214	1563±209	1691±204	0.042	0.62
RMR/FFM (kcal/kg)	35.4±3.8	34.5±4.1	36.2±3.3	0.127	0.50
Oestradiol (pmol/L)	191 (93–459)	126 (73–306)	258 (106–553)	0.119	0.21
Ferritin (µg/L)	37.0 (27.0–74.0)	42.0 (31.0–75.5)	33.5 (23.0–72.8)	0.211	0.17
Fe (µmol/L)	16.5±7.0	15.4±4.4	17.4±8.7	0.291	0.28
TIBC (µmol/L)	59.1±9.8	58.2±7.9	60.0±11.3	0.516	0.18
TSH (mU/L)	2.0 (1.5–2.7)	2.1 (1.5–2.7)	2.0 (1.5–2.7)	0.978	0.01
IgA (g/L)	1.7 (1.1–2.3)	1.6 (0.9–2.1)	1.8 (1.3–2.9)	0.160	0.19

P values and effect sizes for comparisons between females with LEAF-Q total score ≥8 vs <8.
*Cohen's (d) effect sizes for parametric and Wilcoxon effect size (r) for non-parametric data.
BMD, bone mineral density; BW, body weight; DXA, dual-energy X-ray absorptiometry; Fe, iron; FFM, fat-free mass; IgA, Immunoglobulin A; LEAF-Q, Low Energy Availability in Females Questionnaire; RMR, resting metabolic rate; TIBC, total iron-binding capacity; TSH, thyroid-stimulating hormone.

RESULTS

Participant characteristics

Characteristics of athletes who completed all parts of the study are presented in tables 1 and 2. The age range was 15–60 years; 23.2% of females and 33.3% of males were <18 years old. Distribution of participants across five sport groups as well as training history is shown in online supplemental tables 3 and 4. Average weekly training hours, as reported by the athletes, were 12.2±4.9 hours and 11.3±3.9 hours for males and females, respectively. Differences in training hours were observed between the sport groups (p<0.001, data not shown), where aesthetic athletes reported greater number of training hours compared with the other four groups. In total, 37.5% (n total=21; LEAF-Q total ≥8 n=11, LEAF-Q total <8 n=10) of the females were currently using hormonal contraceptives. Visual inspection did not indicate age differences for serum testosterone levels in males, but endurance athletes appeared more likely to present relatively low levels (n=7 out of 8 under the median) compared with the other sport groups (online supplemental figure 1).

Symptoms of REDs

LEAF-Q and LEAM-Q

The mean total LEAF-Q score was 7.8±4.6, and 46.4% of female participants had a LEAF-Q total score ≥8 and thus considered at risk of REDs. The LEAM-Q-derived scores on dizziness, fatigue, fitness and energy levels were positively associated with the total LEAF-Q score. No associations were observed between any of the LEAM-Q-derived scores and the LEAF-Q injury score (table 3). In total, 33.3% (n=9) of male athletes had low sex drive according to the LEAM-Q scoring key, and all but one were <18 years. Higher percentage of males <18 vs ≥18 years reported that they 'did not have much interest in sex' (33.3% vs 0%, p<0.001), but no age group differences were observed in responses to the other three sex drive items.

Physiological indicators

Compared with females at low risk, those with total LEAF-Q score ≥8 had lower mean total body BMD Z-scores (table 1). They also had lower RMR, but this difference became non-significant after adjusting for FFM. Of females with valid RMR measurement, three measured <30 kcal/kg FFM/day and thereof, two scored ≥8 (scores: 13 and 14) on total LEAF-Q. No group differences were observed for serum levels of vitamin B_{12}, 25-OH vitamin D, calcium, magnesium, creatinine, CRP and ALP (data not shown). Male testosterone values ranged from 11 to 33 nmol/L (median: 21 nmol/L), but no participant had clinically low levels. No associations were observed between any of the LEAM-Q scores and testosterone. Serum iron was positively and TIBC inversely associated with testosterone concentration in males (table 2). A total of four males had RMR <30 kcal/kg FFM/day, and testosterone levels ranged from 15 to 23 nmol/L in those four.

Disordered eating, compulsive exercise and muscle dysmorphia

Overall, 8.4% (n=6 females (10.7%); one male) of participants scored above the cut-off on EDE-QS, 19.3% (n=11

Table 2 Simple linear regression between male participant characteristics (independent variables) and serum testosterone concentrations as the dependent variable

Independent variables	Values	Dependent variable: serum testosterone (nmol/L)			
	All (n=27)*	β	SE	P value	95% CI for β
Age (years)	24.2 (17.1–30.0)	–0.321	0.100	0.110	–0.371; 0.040
Body weight (kg)	74.4±12.4	0.125	0.099	0.542	–0.143; 0.265
DXA FFM (kg)	61.1±8.6	0.299	0.137	0.138	–0.073; 0.491
DXA FFM% (FFM/BW)	82.6±4.3	0.340	0.268	0.089	–0.078; 1.030
DXA fat%	13.5±4.2	–0.342	0.273	0.087	–1.052; 0.076
Total body BMD Z-score	1.0±1.2	0.052	1.077	0.803	–1.950; 2.494
RMR (kcal)	2030±285	0.259	0.005	0.284	–0.005; 0.015
RMR/FFM (kcal/kg)	33.6±4.9	–0.073	0.287	0.765	–0.694; 0.519
Ferritin (µg/L)	91 (52–146)	–0.085	0.015	0.679	–0.036; 0.024
Fe (µmol/L)	19.2±8.0	0.421	0.137	0.032	0.029; 0.596
TIBC (µmol/L)	53.6±6.9	–0.440	0.158	0.025	–0.703; –0.053
TSH (mU/L)	2.3 (1.5–3.5)	0.187	0.956	0.360	–1.08; 2.864
IgA (g/L)	2.1 (1.3–2.6)	–0.193	1.513	0.345	–4.582; 1.665
Dizziness score†	0.0 [0.0–1.0)	0.125	0.738	0.542	–1.067; 1.979
GI score†	1.0 (0.0–2.0)	0.183	0.915	0.372	–1.056; 2.722
Thermoregulation score†	0.0 (0.0–2.0)	0.240	0.689	0.238	–0.588; 2.256
Fatigue score†	3.0 (1.0–5.0)	0.218	0.330	0.284	–0.320; 1.044
Fitness score†	5.0 (3.0–7.0)	0.224	0.360	0.270	–0.337; 1.148
Sleep score†	3.0 (1.0–7.0)	0.138	0.350	0.502	–0.483; 0.960
Recovery score†	2.0 (1.0–4.0)	0.010	0.563	0.962	–1.135; 1.189
Energy level* score†	3.0 (1.0–4.0)	0.309	0.518	0.125	–0.246; 1.891

Characteristics are presented as medians with IQRs (25th and 75th percentiles) for non-parametric and means±SD for parametric data.
*Characteristics for all male participants (n=27), of which all but one had a valid measure of testosterone.
†Scores derived from the Low Energy Availability in Male Questionnaire.
BMD, bone mineral density; BW, body weight; DXA, dual-energy X-ray absorptiometry; Fe, iron; FFM, fat-free mass; GI, gastrointestinal; IgA, Immunoglobulin A; RMR, resting metabolic rate; TIBC, total iron-binding capacity; TSH, thyroid-stimulating hormone.

females (19.6%), five males) on EAI and 13.3% (n=8 females (14.3%), three males) on MDDI. All but one of the seven athletes who scored above cut-off on EDE-QS also scored above cut-off on either (n=3) or both (n=3) EAI and MDDI (figure 1). Females with LEAF-Q total score ≥8 vs <8 had higher median EDE-QS scores (8.5

Table 3 Simple linear regression between age, LEAM-Q-derived scores (independent variables) and the LEAF-Q scores (dependent variables) for female participants

	LEAF-Q total			LEAF-Q injury score			LEAF-Q GI score			LEAF-Q menstrual score		
Independent variable	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value
Age	–0.117	0.081	0.391	0.147	0.041	0.279	–0.182	0.031	0.181	–0.211	0.046	0.118
Dizziness score*	0.326	0.366	0.014	0.109	0.193	0.422	0.306	0.14	0.022	0.27	0.214	0.044
Thermoregulation score*	0.203	0.307	0.134	0.037	0.157	0.787	0.117	0.118	0.39	0.242	0.175	0.072
Fatigue score*	0.422	0.151	0.001	0.188	0.082	0.165	0.5	0.055	<0.001	0.238	0.093	0.077
Fitness score*	0.485	0.141	<0.001	0.223	0.079	0.098	0.534	0.052	<0.001	0.295	0.089	0.027
Sleep score*	0.239	0.197	0.077	0.04	0.102	0.771	0.342	0.073	0.01	0.154	0.115	0.258
Recovery score*	0.106	0.281	0.438	0.029	0.142	0.832	0.243	0.104	0.071	–0.002	0.163	0.988
Energy level score*	0.386	0.228	0.004	0.068	0.123	0.622	0.496	0.082	<0.001	0.286	0.136	0.035

*Scores derived from LEAM-Q.
GI, gastrointestinal; LEAF-Q, Low Energy Availability in Females Questionnaire; LEAM-Q, Low Energy Availability in Males Questionnaire.

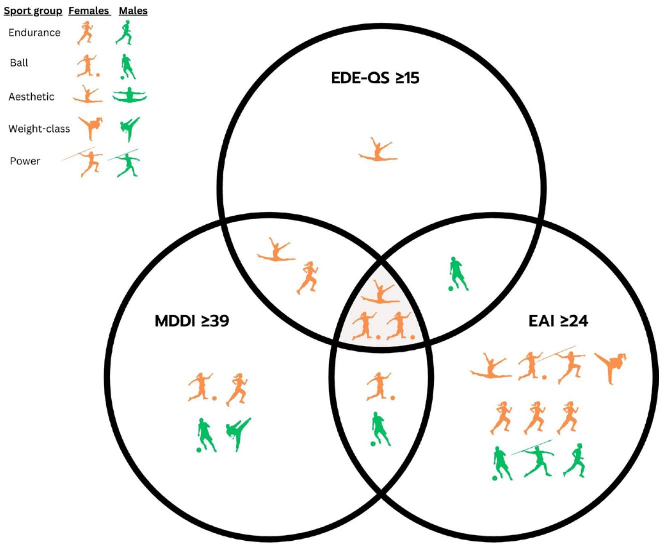

Figure 1 Occurrence and coexistence of disordered eating or eating disorders, compulsive exercise and muscle dysmorphia symptoms in females (orange) and males (green). Icons indicate athletes' sport groups: endurance: middle to long distance running, swimming, cycling, triathlon; ball: football, handball, basketball, volleyball, badminton, table tennis; aesthetic: ballroom dancing, gymnastics, figure skating, ballet; weight-class: powerlifting, Olympic lifting, wrestling, judo, taekwondo, karate, Brazilian jiu jitzu; power: sprinting, throwing and jumping events, alpine skiing. Of all participants (n=83), 7 scored ≥15 on the Eating Disorder Examination–Questionnaire Short (EDE-QS), 16 scored ≥24 on the Exercise Addiction Inventory (EAI) and 11 scored ≥39 on the Muscle Dysmorphic Disorder Inventory (MDDI).

(2.8–11.5) vs 2.5 (0.0–4.8), p=0.004, r=0.38), EAI scores (21.5 (19.8–24.3) vs 19.0 (14.5–21.0), p<0.001, r=0.44) and MDDI scores (31.5 (27.5–37.8) vs 24.0 (21.0–33.0), p=0.020, r=0.31). For female participants, linear regression demonstrated positive associations between most of the LEAF-Q/LEAM-Q-derived scores and scores on the EDE-QS, EAI and MDDI. However, the LEAF-Q injury score was not associated with scores on any of the three brief questionnaires. Dizziness, thermoregulation and fitness scores were positively associated with EAI scores, and fitness and sleep scores were positively associated with MDDI scores in males. No associations were found between serum testosterone levels and male participant scores on EDE-QS, EAI and MDDI (table 4).

Online supplemental figure 2 shows scoring distribution of all participants for items on the EDE-QS. Dissatisfaction with weight or shape was reported by almost 60% of participants, and a similar proportion said their weight or shape had influenced how they think about themselves as persons. Moreover, restrictions on the amount of food eaten, fear of weight gain and desire to lose weight were reported by about 40% of the participants. More severe behaviours, such as fasting for long periods of time, vomiting or taking laxatives, were less frequently reported. Most participants (57–71%) agreed or strongly agreed to four out of six statements on EAI (online supplemental figure 3) and 19.3% said they had conflicts with their family or partner about how much they exercised. Responses to the MDDI are presented in online supplemental figure 4, where a total of 65% reported they sometimes, often or always wished they could get bigger and 42.2% felt they had too much body fat. Other muscularity concerns and body dissatisfaction symptoms were also prevalent.

DISCUSSION

Findings of the present study indicate that disordered eating, compulsive exercise, as well as muscle dysmorphia, can contribute to the risk of REDs. Moreover, females considered at risk of REDs were more likely to report frequent occurrence of symptoms such as physical exhaustion, body pain, lack of energy and motivation compared with those at low risk. Results for males were more subtle, which may be partly explained by the lack of male-specific diagnostic criteria.

REDs symptoms

Females

Almost half of female participants were considered at risk of REDs according to the LEAF-Q scoring.[22] In accordance with the literature,[34] the present study found that this group had lower mean total body BMD Z-scores compared with those at low risk, emphasising REDs' deleterious effects on bone health. Despite moderate effect size for both, only absolute RMR but not RMR/FFM differed significantly between females considered at risk versus low risk of REDs. Further data inspection revealed that two out of three females with RMR <30 kcal/kg FFM/day scored well above the LEAF-Q total cut-off. While RMR/FFM has been suggested as a potential marker of REDs, the evidence is somewhat conflicting.[32] A potential reason for some of the discrepancies encountered in this and similar studies is the sport-specific validity of LEAF-Q and its subscales. While LEAF-Q total, gastrointestinal and menstrual scores were associated with many of the LEAM-Q-derived scores, no associations were found between any of the LEAM-Q derived scores and the LEAF-Q injury score. Accordingly, recent studies have reported that the LEAF-Q injury score lacks specificity when administered in sports other than endurance and aesthetic.[35 36] The injury score is only based on questions regarding number and duration of absences from training or competition in the past year due to unspecified injuries.[22] While overuse injuries are the most common types of injuries among athletes in endurance and other non-contact sports, overuse and acute injuries occur frequently in contact sports.[36] High injury score must therefore be interpreted with caution and in relation to injury type and underlying causes.[35 36] In the present study, athletes' answers to open-ended questions about injury types sustained in the past year were not sufficiently detailed to elaborate further on. Almost 40% of females reported current use of hormonal contraceptives, regardless of REDs risk. Although extending beyond the current study's aims, it

Table 4 Simple linear regression between age, testosterone levels (males) and LEAF-Q/LEAM-Q-derived scores (independent variables) and EDE-QS, EAI and MDDI scores (dependent variables)

		EDE-QS			EAI			MDDI		
Group	**Independent variable**	**β**	**SE**	**P value**	**β**	**SE**	**P value**	**β**	**SE**	**P value**
Females (n=56)	Age	–0.180	0.112	0.184	–0.215	0.074	0.112	–0.303	0.135	0.023
	LEAF-Q total	0.490	0.165	<0.001	0.403	0.115	0.002	0.400	0.216	0.002
	LEAF-Q GI	0.524	0.425	<0.001	0.317	0.313	0.017	0.496	0.537	<0.001
	LEAF-Q injury	–0.010	0.378	0.943	0.144	0.248	0.288	–0.094	0.466	0.489
	LEAF-Q menstrual	0.514	0.283	<0.001	0.366	0.203	0.006	0.449	0.365	<0.001
	Dizziness score*	0.408	0.492	0.002	0.343	0.335	0.010	0.558	0.554	<0.001
	Thermoregulation score*	0.287	0.418	0.032	0.291	0.277	0.029	0.265	0.522	0.049
	Fatigue score*	0.518	0.198	<0.001	0.321	0.145	0.016	0.447	0.257	<0.001
	Fitness score*	0.545	0.188	<0.001	0.375	0.138	0.004	0.498	0.241	<0.001
	Sleep score*	0.431	0.255	<0.001	0.131	0.186	0.337	0.302	0.335	0.024
	Recovery score*	0.465	0.349	<0.001	0.421	0.237	<0.001	0.447	0.437	<0.001
	Energy level score*	0.604	0.273	<0.001	0.323	0.214	0.016	0.502	0.367	<0.001
Males (n=27)	Age	0.062	0.070	0.759	–0.213	0.091	0.287	–0.207	0.146	0.300
	Testosterone (nmol/L)	–0.061	0.138	0.766	0.017	0.184	0.936	0.162	0.277	0.428
	GI score*	0.200	0.607	0.317	0.380	0.762	0.051	0.160	1.308	0.425
	Dizziness score*	0.121	0.488	0.548	0.419	0.593	0.029	0.114	1.045	0.572
	Thermoregulation score*	0.232	0.460	0.245	0.507	0.542	0.007	0.344	0.949	0.079
	Fatigue score*	0.159	0.222	0.428	0.288	0.286	0.145	0.225	0.469	0.260
	Fitness score*	0.255	0.236	0.200	0.383	0.300	0.049	0.507	0.450	0.007
	Sleep score*	0.035	0.235	0.861	0.164	0.308	0.413	0.425	0.454	0.027
	Recovery score*	0.212	0.337	0.288	0.141	0.453	0.484	0.275	0.708	0.164
	Energy level score*	0.156	0.357	0.437	0.042	0.480	0.833	0.218	0.754	0.276

*Scores derived from the LEAM-Q.

EAI, Exercise Addiction Inventory; EDE-QS, Eating Disorder Examination–Questionnaire Short; GI, gastrointestinal; LEAF-Q, Low Energy Availability in Females Questionnaire; LEAM-Q, Low Energy Availability in Males Questionnaire; MDDI, Muscle Dysmorphic Disorder Inventory.

must be acknowledged that contraceptive use may mask menstrual dysfunction, thus limiting the usefulness of menstrual scores.[12] Our results imply that inclusion of items and/or categories derived from the LEAM-Q[23] could potentially detect otherwise overlooked REDs cases among females. However, further work is needed to validate self-reported recovery, fatigue, energy levels and/or other measures against more clinical markers of REDs in females. The recently updated REDs consensus statement[4] and REDs Clinical Assessment Tool V.2 (REDs CAT2)[32] could perhaps guide that work.

Males

One-third of participating males had a low sex drive score according to LEAM-Q, with no apparent relationship between low sex drive and REDs. All but one male with low sex drive score were <18 years old, and majority of them scored low due to not having much interest in sex in general. Therefore, our findings neither support nor refute the proposed utility of sex drive as a self-reported measure[23] when screening for REDs in male athletes.

Clinically to subclinically low testosterone is among the primary indicators included in REDs CAT2.[32] No participant in this study had clinically low levels, but two athletes fell into what has previously been referred to as subclinical 'grey zone' (8–12 nmol/L).[37]

Impaired haematological function is among potential consequences of REDs.[4 32] In accordance with this, we found positive associations between serum iron and testosterone, and inverse associations between TIBC and testosterone. However, neither ferritin nor any of the other objective measures were associated with testosterone. Importantly, low or reduced testosterone can also stem from specific training adaptations (eg, to endurance training) often referred to as exercise-hypogonadal male condition.[38] Accordingly, serum testosterone levels in all but one male categorised as endurance athletes were under the median concentrations of all participants. Whether normative data or reference values of testosterone should be regarded in terms of sport specialisation and training history therefore remains to be clarified.[23 38] Moreover, validation of LEAM-Q has been challenged by the inability of scores other than sex drive to distinguish between males at risk versus low risk of REDs.[23] Those findings were indeed replicated in the present study, with no associations found between calculated LEAM-Q scores and testosterone. Taken together, the results echo the urgent need for further high-quality research on male-specific aetiology of REDs.[18] Notably, despite >170 original research papers on REDs published in the past 5 years, only 20% included male participants.[4]

Disordered eating and muscle dysmorphia

Worldwide, the prevalence of disordered eating and/or eating disorders is estimated to be 6–45% in female and 0–19% in male athletes.[7] In total, 8% of all athletes and 11% of female athletes in the present study had a score above the EDE-QS cut-off, which is consistent with a recent Icelandic study.[39] Females with LEAF-Q total score ≥8 vs <8 had higher median EDE-QS score, which indicates increased likelihood of disordered eating symptoms in females at risk of REDs. Furthermore, apart from the injury score, all LEAF-Q and LEAM-Q-derived scores were positively associated with the EDE-QS score for females. This finding was to be expected, as the effects of both REDs and disordered eating on physiological function and overall well-being have been well described.[4 7] We are therefore in agreement with others that have encouraged screening for disordered eating as complementary to LEAF-Q.[12 22 40]

One male athlete scored above the EDE-QS cut-off, but the small sample size limits our ability to draw conclusions on the prevalence in male athletes. Interestingly though, 13% of all participants scored above the established cut-off on MDDI, with no apparent sex differences. It has previously been suggested that males and athletes from non-weight-sensitive sports may be more concerned about muscularity than thinness or fear of weight gain.[9 16 17] Just like other body image concerns, muscle dysmorphia can interfere with daily activities, social relationships and an individual's overall health.[10] While no associations were observed between LEAM-Q and EDE-QS scores among males in this study, the LEAM-Q fitness and sleep scores were positively associated with MDDI scores. This could be interpreted as a sign that males with considerable muscularity concerns are likely to regularly display symptoms such as physical pain, exhaustion and/or restlessness. Relationships between the self-reported physical symptoms covered by LEAF-Q/LEAM-Q and MDDI were also observed for females. The only exception was the LEAF-Q injury score.

Most participants exceeding the EDE-QS cut-off also scored above the MDDI cut-off. A possible reason for this is that although the instruments screen for two distinct aspects, they both address desire to limit body fat levels and use of exercise to control weight or shape. Others have suggested that athletes' preoccupation with low body weight and willingness to possess an aesthetically toned body are not mutually exclusive.[8] However, six athletes scored above the MDDI cut-off but not EDE-QS. Although larger studies and validation of MDDI in sports other than lifting and bodybuilding are needed, our findings imply that body dissatisfaction in athletes is not a one-size-fits-all. Addressing the broad spectrum of body image concerns could therefore identify otherwise overlooked problems, and thus aid screening of REDs in males and females from various sports and age groups.

Finally, while 1 out of 10 participants scored above the EDE-QS cut-off, a substantially larger proportion regularly engaged in disordered eating behaviours without reaching the cut-off. This is clearly indicated in responses to individual EDE-QS items, which concern drive for thinness, fear of weight gain and engagement in weight-loss practices. As stated by IOC, athletes and/or the team around them may not be concerned about occasional engagement in restrictive behaviours (ie, doing so repeatedly but for relatively short periods of time),[18] but it could potentially result in problematic LEA/REDs and associated health and sport performance consequences.

Compulsive exercise

The EAI questionnaire was used to screen for compulsive exercise, as it has been used in similar studies on REDs,[12] and IOC has listed it among potential instruments for initial screening of REDs.[4 32] An ongoing debate exists on terminology and applicability of tools and cut-offs used to screen for exercise addiction/compulsive exercise behaviours in athletic populations. This debate largely revolves around the fact that exercise addiction/compulsive exercise lacks a clinical diagnosis (as a behavioural disorder) but rather describes an exercise-related dysfunction.[41] Therefore, the less stigmatising term 'compulsive exercise' was used throughout this paper. Almost one out of five participants scored above the EAI cut-off, which indicates a risk of compulsive exercise. Females with LEAF-Q total ≥8 were at higher risk compared with those scoring <8, and this was further demonstrated by positive associations of EAI scores with the LEAF-Q total, GI, menstrual and most of the LEAM-Q-derived scores. Results for males are more complicated to interpret in terms of REDs specifically. However, the LEAM-Q fitness score was positively associated with the EAI score, perhaps indicating that a proportion of participants experience negative physical symptoms due to rigorous training. Thermoregulation and dizziness scores were also associated with EAI scores in males, but weaker. Altogether, our results add to a growing evidence base on how compulsive exercise may contribute to REDs.[11–13] Importantly though, a recent study suggested that the association between compulsive exercise and REDs might be mitigated by the absence of disordered eating,[11] and thus both dietary and training behaviours should be evaluated when screening for REDs. In our study, 10 out of 16 athletes at risk of compulsive exercise did not score above the EDE-QS or MDDI cut-offs. Further development of available screening tools for compulsive exercise will hopefully be provided soon, thereby improving the ability to separate problematic or dysfunctional exercise from normal athletic passion or use of (non-problematic) exercise as an outlet.[42]

Strengths and limitations

A novelty of the present study was the evaluation of muscle dysmorphia symptoms, in addition to disordered eating and compulsive exercise, and its potential relationship with REDs. Therefore, it acknowledges the fact that body image concerns are complex and do not only concern drive for thinness and/or fear of weight gain. We are also not aware of other studies that have administered questions derived from the LEAM-Q in female athlete populations but considered most of them relevant for both sexes. Team sports and other disciplines considered 'low risk' and studies on adolescent athletes are under-represented in the REDs literature. Therefore, the present study included athletes from various sport and age groups, attempting to expand the knowledge on potential age, sex and sport-specific presentation of REDs.

Due to the cross-sectional design, this study mostly presents occurrence of potential REDs symptoms, but no statements on causality can be made. Another limitation is the relatively small sample size and unequal participation of the sexes, and the inclusion of diverse sport groups further complicated data analyses. Despite relentless efforts to invite athletes to participate in the study, our results represent a rather small proportion of the Icelandic elite athlete population, which may have impacted statistical power and generalisability of the results. However, in addition to being time and resource-intensive, studies on high-level athletes rarely include high number of participants due to scarcity of individuals meeting that inclusion criterion.[43] Like previous research on REDs in male athletes, this study is limited by the lack of male-specific criteria.[23] Moreover, validity of questionnaires administered in the study may vary based on sex, age and sport. Another methodological limitation is that bone health assessment only included total body BMD but not site-specific measures. Therefore, no conclusion could be drawn about the prevalence of osteopenia and/or risk of osteoporosis. In addition, as outlined in the recently updated consensus statement from IOC,[4] the REDs literature has grown rapidly in recent years and supported development of REDs CAT2.[32] It is therefore possible that selection of more of the primary and secondary indicators included in REDs CAT2 could have resulted in somewhat different results. RMR measurements are subject to several practical challenges.[32] One such challenge encountered in this study was that despite best efforts in providing both verbal and written instructions regarding preparation for the RMR measurement, 12 athletes arrived in a non-fasted state and therefore did not have a valid measure. Selection bias may also be considered, as athletes interested in the research were perhaps most likely to participate. Being at risk or having REDs may also encourage or discourage participation resulting in underestimation or overestimation of true occurrences.

CONCLUSION

The findings of the study suggest that symptoms of REDs are common among Icelandic athletes from various sports and age groups. Also, drive for muscularity and aesthetic physique may play a role in the complex presentation of REDs. In addition to disordered eating and compulsive exercise, screening for muscle dysmorphia could facilitate early detection of REDs. Finally, the lack of clarity around REDs presentation in male athletes calls for continued work on age, sex and sport-specific screening tools.

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Contributors This study was designed by BV, ASO and SLG. Questionnaires were translated by BV and SLG, and back-translated by ASO and Elisabet Margeirsdottir. BV was responsible for recruitment of participants, and measurements undertaken in the study were performed by her, specialists at the Icelandic Heart Association (DXA and blood sampling) and Sameind laboratory (blood analysis). Data analysis and drafting of the manuscript were conducted by BV, and carefully revised by all authors. The final manuscript was approved by all authors. SLG is the study guarantor.

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