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The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad

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ABSTRACT

Background Low energy availability (EA) in female athletes with or without an eating disorder (ED) increases the risk of oligomenorrhoea/functional hypothalamic amenorrhoea and impaired bone health, a syndrome called the female athlete triad (*Triad*). There are validated psychometric instruments developed to detect disordered eating behaviour (DE), but no validated screening tool to detect persistent low EA and *Triad* conditions, with or without DE/ED, is available.

Aim The aim of this observational study was to develop and test a screening tool designed to identify female athletes at risk for the *Triad*.

Methods Female athletes (n=84) with 18–39 years of age and training ≥5 times/week filled out the Low Energy Availability in Females Questionnaire (LEAF-Q), which comprised questions regarding injuries and gastrointestinal and reproductive function. Reliability and internal consistency were evaluated in a subsample of female dancers and endurance athletes (n=37). Discriminant as well as concurrent validity was evaluated by testing self-reported data against measured current EA, menstrual function and bone health in endurance athletes from sports such as long distance running and triathlon (n=45).

Results The 25-item LEAF-Q produced an acceptable sensitivity (78%) and specificity (90%) in order to correctly classify current EA and/or reproductive function and/or bone health.

Conclusions The LEAF-Q is brief and easy to administer, and relevant as a complement to existing validated DE screening instruments, when screening female athletes at risk for the *Triad*, in order to enable early detection and intervention.

INTRODUCTION

When energy intake is restricted or inadequate, the amount of energy available for basic physiological functions, such as reproductive function, becomes insufficient.[1 2] Therefore, persistent low energy availability (EA), with or without an eating disorder (ED) present, may pose a significant health risk to female athletes. There are validated screening tools for the detection of disordered eating behaviour (DE) in athletes including the *Athletic Milieu Direct Questionnaire* (AMDQ),[3] the *Female Athlete Screening Tool* (FAST)[4] and the *American Physiological Screening Test for eating disorders among Female College Athletes* (PST).[5] The prevalence of low EA is assumed to be high in female athletes,[1] but there are no screening tools based on self-reported physiological symptoms of low EA. It is, therefore, relevant to develop an instrument that can be routinely and widely used for screening female athletes to identify individuals at risk of the female athlete triad (*Triad*).

EA <125 kJ/kg fat-free mass (FFM) over more than 5 days has been shown to reduce blood glucose and leptin levels, to suppress the pulsatility of gonadotropin-releasing hormone and hypothalamic-pituitary axis hormones, like luteal hormone (LH) and triiodothyronine (T_3), and to elevate cortisol as well as to increase bone resorption markers in eumenorrheic sedentary women.[6 7] If maintained for a longer period, low EA can cause functional hypothalamic amenorrhoea (FHA),[2 8] and FHA has been shown to have a high predictive value when screening for ED among female athletes.[9] Low levels of oestrogen increase the risk for stress fractures and osteoporosis,[1 10] and results from a study on young female athletes indicate that restricted eating behaviour and FHA may also increase the risk for muscular and joint overload.[11] Orthostatic hypotension is common among patients with ED,[5 10] and the sensation of dizziness when rising from a supine to a standing position could, therefore, be a symptom of low EA. Reduced T_3 and T_4 have been reported in athletes with FHA[12 13] and in patients with ED.[14] Hypothyroidism can result in an increased cold sensitivity and could, therefore, be a symptom of low EA. Persistent low EA could have immunosuppressive consequences, and therefore increase the risk for infections in athletes.[15] Irregular meal patterns and high fibre intake are commonly reported among female athletes dieting or with DE[1] and can cause a variety of different gastrointestinal symptoms such as bloating and constipation.[5 16]

The aim of this study was to develop a screening tool, the Low Energy Availability in Females Questionnaire (LEAF-Q) designed to identify female athletes at risk for the *Triad* and evaluate reliability, internal consistency and discriminants as well as concurrent validity.

METHOD

A total of 84 female athletes from Sweden and Denmark, recruited through the national federations of endurance sport, competitive endurance sport clubs and professional dancers were included in the validation of the LEAF-Q. Participants included were women between 18–39 years of age, who trained ≥5 times/week. Dancing and endurance sports such as long-distance running and triathlon were chosen as representatives for leanness-demanding sports, with an increased risk

for the *Triad*.[17 18] The study had two parts. In part one, the reliability of the LEAF-Q was assessed using endurance athletes and dancers (n=37). In part two, the self-reported symptoms, reported on the LEAF-Q, were verified in another group of endurance athletes (n=45) using clinical assessments. The exclusion criteria were pregnancy, chronic illness, use of forms of contraceptives other than oral, for example, hormonal coil, not being willing to stop with oral contraceptives (OC) for at least 6 weeks prior to investigation or injuries preventing the athlete from training ≥2 weeks. A total of 47 participants participated in the clinical verification of self-reported symptoms; two dropped out and 45 were included in the analysis. Permission to undertake the study was provided by relevant regional ethics committees in Sweden and Denmark (no 2011/576 and H-4-2011-096). Physiological symptoms in the literature frequently associated with long-term low EA and/or other *Triad* conditions were included as variables in the LEAF-Q after being verified as especially relevant by a collective clinical expertise in endocrinology, sports nutrition, medicine and gastroenterology.

Internal consistency and reliability

The first version of the LEAF-Q included 29 items distributed on five main variables (injuries, dizziness, cold sensitivity, gastrointestinal function and menstrual dysfunction (MD), including questions regarding the use of OC). Since these endurance athletes and dancers (n=37) were of English, Swedish and Danish origin, the LEAF-Q was, from the start, translated by two bilingual employees at the University of Copenhagen. A test–retest was performed to assess item performance and estimate reliability. The participants received the LEAF-Q twice within a 2-week period and a letter of information to which the participants were asked to reply within 2 days. After filling out the LEAF-Q the second time, the participants were interviewed to assess response bias. The participants were asked to comment whether questions or response categories were not clearly stated, whether they perceived any question as irrelevant, whether response options were inadequate and whether the volume of the questionnaire was appropriate. One variable, illness, was added.

Verification of self-reported symptoms

The version of the LEAF-Q used in the next part of the validation process included 14 items in the introduction, including occupation, type of sport, age, height, weight and training, followed by 30 items divided into six variables: dizziness, gastrointestinal function, cold sensitivity, illnesses (during the last year), injuries (during the previous year) and menstrual function (present and in the past). The variables for dizziness and cold sensitivity included one item assessed by self-reporting the frequency of the symptom on a Likert-type ordinal scale: (1) Yes, several times a day; (2) Yes, several times a week; (3) Yes, 1–2 times a week and (4) Rarely or never. The injury and illness variable contained three items for which the frequency and duration were assessed by ordinal scales and an open category to specify the types of injuries/illness. The open response for the variable of injuries was divided into two main types of injuries —accidental or overload. The variable for gastrointestinal function contained four items and was assessed by self-reporting gastrointestinal symptoms such as pain/cramps/bloating on a Likert-type ordinal scale. Nominal scales assessed stool frequency and consistency. Menstrual function included 12 items and was measured on dichotomous as well as ordinal scales. Age of menarche was measured on an ordinal scale and previous MD on a nominal scale. Bleeding pattern related to exercise was measured on dichotomous and nominal scales. The use of hormonal contraceptives contained six items and was assessed on dichotomous and nominal scales. After filling out the LEAF-Q, the endurance athletes (n=47) were invited to take part in a standardised verification programme to verify self-reported symptoms by assessment of EA, clinical verification of DE/ED, orthostatic BP, hypothyroidism, reproductive function and bone health.

Dietary intake and training intensity were recorded by the participants for seven consecutive days to assess EA.[19] The participants were instructed to maintain and follow their normal eating pattern and training regime. Energy intake was calculated from weighed food records using a nutrient analysis programme, Dankost 2000 (Dankost, Copenhagen, Denmark), for Danish foods and Dietist XP (Kost och Näringsdata AB, Bromma, Sweden) for Swedish food items.

The participants were instructed to maintain and follow their normal training regime. Heart rate (HR) monitors (Polar RS400, Stockholm, Sweden) were used to assess exercise energy expenditure (EEE) based on individual prediction equations from measured HR and corresponding energy expenditure (EE) during an incremental maximal exercise test in the laboratory. The individual equation provided the basis for the calculation of EEE using HR measurement for each training session.[20] Regression lines were calculated for the corresponding values of HR and EE during the incremental exercise test in the laboratory. HR were highly correlated with O_2 consumption during increasing workloads (r=0.94, 95% CI 0.93 to 0.96). EA was calculated by subtracting mean EEE from the mean energy intake, after calculating EEE by subtracting from total EEE the total EE during an equivalent time period without exercise. To calculate daily total EE, HR monitors (Polar RS400) were used to assess EE during bicycle transportation; actigraphy (ActiGraph GT3X, Pensacola, Florida, USA) and the data analysis software ActiLife 5 (ActiGraph) were used for the assessment of non-exercise physical activity thermogenesis. The participants were instructed to wear an accelerometer on the wrist during sleep, and on the hip from the time they wake up in the morning until bedtime, taking it off only during showering, swimming, bicycle transportation and training.

Eating behaviour was assessed using the Eating Disorder Inventory (EDI-3), a questionnaire assessing behaviour and attitudes related to DE behaviour.[21] Participants were categorised as having DE behaviour when the subscale drive for thinness was ≥14 and/or body dissatisfaction ≥19.[21] The Eating Disorder Examination (EDE-16.0)[22] was used to determine whether participants met the criteria for ED according to the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) criteria for anorexia nervosa, bulimia nervosa and ED not otherwise specified. All interviews were performed by the same EDE-certified member of the research team.

Participants using OC were requested to stop for a minimum of six weeks prior to examination in order to secure a sufficient washout period for exogenous oestrogen and progesterone. Participants not recovering their menstrual bleeding within the six weeks were monthly contacted by the research team during a follow-up period of minimum of three months before gynaecological assessment. Menstruating athletes were examined in the early follicular phase, defined as the third to fifth day of menstruation. A pregnancy test was performed and menstrual function was examined by an experienced gynaecologist who performed a transvaginal ultrasound examination. The maximum number of ovarian follicles present in a single plane was counted and the total volume of these follicles was assessed.

Sex hormone status (oestrogen, LH, follicle stimulating hormone (FSH) and androgens) and anamnestic assessment, including age of menarche, OC and previous MD were recorded. Participants were then classified as *eumenorrhoea* (menstrual cycles of 28 days±7 days); *oligomenorrhoea* (menstrual cycles >35 days); *FHA* (either primary; no menarche after 15 years of age, or secondary; absence of ≥3 consecutive menstrual cycles); *other MD* (anatomic defects, hyperprolactinemia or other dysfunctional ovarian conditions); *polycystic ovary syndrome* (PCOS; ≥2 of the following criteria fulfilled: (1) enlarged ovaries with a volume greater than 10 mL and/or ≥one ovary demonstrating ≥12 follicles in one plane, (2) oligomenorrhoea/amenorrhoea and (3) elevated androgen level or otherwise androgen stigmatised).

Body weight was measured, with the participants in underwear, on an electronic scale and height was measured using a fixed stadiometer. Dual-energy X-ray absorptiometry (DEXA; Hologic, Model Discovery 2009, Hologic Inc Waltham, Massachusetts, USA) was used to determine fat-free, fat and bone mass. All measurements and scans were performed in the fasted state between 7:30 and 9:00, and were assessed by the same technician and performed on the same scanner. Calibration of the DEXA was performed weekly using a phantom provided by the manufacturer. The participants were classified as having normal bone mineral density (BMD) when Z-scores were >−1 in all measured sites, low BMD when Z-score was −1 to −2 in at least one site and osteoporosis when Z-score was ≤−2.[1]

Changes in blood pressure (BP) when moving from a supine to a standing position were measured using a standardised tilt table and an electronic sphygmomanometer (Microlife BP A100, Widnau, Switzerland). After resting in a supine position for 7 min, BP was measured three times before (the mean was used) and once directly after tilting the participants to 70° standing position. Hypotension was defined as a supine systolic BP <90 mm Hg and/or a diastolic BP <60 mm Hg. Orthostatic hypotension was defined as a fall in systolic BP >20 mm Hg and/or a fall in diastolic BP >10 mm Hg when moving from a supine to a standing position.[5 23]

Blood samples were drawn from an antecubital vein in a resting state after an overnight fast. Oestrogen, FSH, LH and androgen were analysed using ADVIA Centaur Immunoassay Systems (Siemens Healthcare Diagnostics Products GmbH, Germany). The analytical sensitivity was 18.4–15 781 pmol/L for oestrogen, 0.3–200 IU/L for FSH, 0.07–200 IU/L for LH and 0.1–28.0 nmol/L for androgen. The intra-assay and interassay precision coefficient of variability (CV) for oestrogen was 2.6% and 4.1%, for FSH 1.2% and 2.0% and for LH 2.9% and 2.3%. The CV for androgen was 4.7% at 7.5 nmol/L. T_3 was analysed using the ARCHITECT system assay (Abbott Laboratories, Longford, Ireland) with an analytical sensitivity of ≤0.25–8 ng/mL and a total assay precision CV of <10%. Capillary blood glucose was analysed using Biosen C Line (EKF Diagnostic, Germany) with a measurement range between 0.5 and 50 mmol/L and a CV of 1.5% at 12 mmol/L. Cortisol was analysed using Roche Electro Chemiluminiscence Immunoassay (ECLI, Roche Diagnostic, Bromma, Sweden). Analytical sensitivity for the cortisol assay was 0.5–1750 nmol/L with an assay precision CV of 1.3–2.1%. Leptin was analysed using Quantikine ELISA (R&D Systems Europe Ltd, Abingdon, UK). The lower analytical limit for leptin was 1.56 ng/mL; lower concentrations are associated with some uncertainty, and therefore not automatically calculated. Seven participants had results <1.56 ng/mL, and in order to calculate their concentrations, the concentration was extrapolated using the formula for the standard curve: $\log_{10}(\text{ABS}) = A \times \text{Log}_{10}(\text{concentration}) - B \rightarrow \text{concentration} = 10^{\log 10\ (\text{ABS})+B))/A}$. The intra-assay and interassay precision CV for leptin was 3.0–3.3% and 3.5–5.4%, respectively.

Statistical methods

Distributional features of variables were measured on a continuous scale (height, etc) and variable scores were examined for central tendency. Skewed data were log transformed before further analysis. The intraclass correlation coefficient was used to calculate the difference between the test and test–retest scores. In this group of female endurance athletes, oligomenorrhoea/FHA existed with and without the presence of low current EA (<125 kJ/kg FFM/day). Owing to this mismatch, the participants were divided into 50% with the highest current EA and 50% with the lowest current EA, to examine discriminant validity. The statistical procedure for questionnaire validation described by Black *et al*[5] was used, where discriminant validity was assessed by testing the mean item score for each of the six variables for significant difference (two-sample t tests) between the groups with lower EA versus higher EA, MD versus eumenorrhoea and low BMD versus normal BMD. To measure concurrent validity and the degree of association among the total LEAF-Q score, LEAF-Q variables and *Triad* conditions, Pearson's correlation coefficient (r) was calculated. Furthermore, the contribution of LEAF-Q variables to the different *Triad* conditions was calculated using an ordinal logistic regression. Pearson's correlation coefficient (r) was also calculated to assess the degree of association between self-reported training hours per week and training hours registered during the week of data collection, as well as self-reported and measured body weight. For comparison of means between the participants categorised at risk for the *Triad* versus those categorised with low risk, Student's paired t test was used. To test whether there was a difference between the two kinds of classifications, for example, the number of participants categorised at risk for the *Triad* versus those categorised with low risk having MD, Fisher's exact test was applied. Statistical significance was declared for $p<0.05$. Internal consistency between questionnaire variables was examined by Cronbach's α.[24] The items found to significantly predict lower EA, MD and/or low BMD were retained and summed up to provide an overall LEAF-Q score. To test the validity of the LEAF scale, sensitivity and specificity were calculated.

RESULTS

During the first part of development and testing reliability (n=37), internal consistency testing of the main variables resulted in an overall α of 0.86, suggesting a relatively high homogeneity of the LEAF-Q. The intraclass correlation coefficient was used to calculate the difference between the test and the test–retest score. Test–retest reliability was 0.79 after a two-week interval of retesting. The responders found all the questions relevant, easy to read and understand. The response options were, in general, adequate but an open response category to individual explanations was lacking in items regarding training, injuries, menstruation and OC, and this was, therefore, addressed in the final version used for validation.

EA was 120±46 kJ/kg FFM/day in the group with the lower current EA and 205±29 kJ/kg FFM/day in the group with the higher current EA. Twenty-four participants were diagnosed with FHA/oligomenorrhoea, three with PCOS and two with other MD. Twenty-one had low BMD (Z-score ≤−1). Eleven participants were diagnosed with an ED, and, in addition, one

Table 1 Variables associated with lower current energy availability, menstrual dysfunction and impaired bone health

Variable	Verifying variable	OR	95% CI
Gastrointestinal symptoms	Lower current EA	3.39	1.03 to 11.15*
Injuries	Low BMD	1.43	1.04 to 1.96*
Menstrual dysfunction	Menstrual dysfunction	1.65	1.23 to 2.20**

OR >1 is a risk factor and indicates the contribution of the different LEAF-Q variables to lower current energy availability, menstrual dysfunction and low-BMD, respectively.
*p<0.05, **p<0.01.
BMD, bone mineral density; EA, energy availability; LEAF-Q, Low Energy Availability in Females Questionnaire.

was classified as having DE. Seven participants had hypotension in a supine position, while one participant had orthostatic hypotension. One participant had hypothyroidism (T_3<1.2 ng/mL), 32 had low leptin levels (<3.88 pg/mL), 16 had hypoglycaemia (<4 mmol/L) in the fasted and rested state and one had elevated cortisol (>800 nmol/L).

Self-reported training hours/week correlated with registered training hours/week (r=0.49, p<0.01) and self-reported body weight to measured body weight (r=0.97, p<0.001). The variable scores for gastrointestinal symptoms, injuries and MD showed significant differences between the groups—gastrointestinal symptom: lower current EA versus higher current EA (p=0.023); injury: low BMD versus high BMD (p=0.021) and menstrual function: MD vs eumenorrhoea (p<0.001). These three variables were significantly associated with a lower current EA and/or MD and/or low BMD using a logistic regression (table 1), and the mean variable score for the remaining variables correlated with the total LEAF-Q score (table 2). The three variables had values of Cronbach's α ≥0.71 (table 3); they were, therefore, retained and provided an overall LEAF-Q score.

The variable score producing the highest sensitivity and specificity for the corresponding *Triad* end point was used as the cut-off for each item score (≥2 for gastrointestinal symptoms, ≥2 for injuries and ≥4 for MD). The total LEAF-Q score ≥8.0 produced a sensitivity of 78% and a specificity of 90% for correctly classifying current EA and/or reproductive function and/or bone health. When excluding the athletes with PCOS and other MD than oligomenorrhoea/FHA, the total LEAF-Q score produced a sensitivity of 83% and a specificity of 90%, with an overall validity of 73% for correctly classifying current EA and/or reproductive function and/or bone health (see online supplemental digital content 1; The LEAF-Q and 2; The LEAF-Q scoring key).

Summary statistics for all participants (n=45) participating in the verification programme and divided as participants categorised at risk for the *Triad* (total LEAF-Q score ≥8) versus those categorised as having low risk (total LEAF-Q score <8) are shown in table 4. Participants at risk for the *Triad* had a lower body fat and there was a trend towards lower body weight and BMI compared with participants categorised with low risk. Furthermore, the participants at high risk had lower levels of leptin, T_3 as well as fasting blood glucose compared with participants with low risk, while there was no difference in cortisol levels.

More participants categorised as at risk for the *Triad* were diagnosed with MD and hypoglycaemia, while there were no significant differences in the number of participants diagnosed with DE/ED, impaired bone health or hypotension between the groups (table 5).

Table 2 Correlations between total LEAF-Q and variable scores

Total LEAF scale score	Rho
Gastrointestinal symptoms	0.53**
Injuries	0.49**
Menstrual dysfunction	0.87**

Pearson's correlation coefficient, **p<0.01.
LEAF-Q, Low Energy Availability in Females Questionnaire.

Table 3 Cronbach's α for variables, and total LEAF-Q test scale

Item	α
Gastrointestinal symptoms	0.75
Injuries	0.79
Menstrual dysfunction	0.61
Test scale	0.71

LEAF-Q, Low Energy Availability in Females Questionnaire.

DISCUSSION

The intension of the LEAF-Q was to construct a brief questionnaire focusing only on self-reported physiological symptoms linked to persistent energy deficiency, with or without DE/ED, which can be routinely used to identify individuals at risk of the *Triad*. Overall, the LEAF-Q had an acceptable sensitivity and specificity as well as internal consistency, indicating that it has the potential to be a useful screening tool for the identification of female athletes at risk for the *Triad* and a relevant complement to existing validated DE screening instruments.

In contrast to pure psychometric scales, on which direct measuring of the underlying concept is impossible, the validity testing of the LEAF-Q included the verification of self-reported symptoms linked to the three endpoints of the *Triad* by objective confirmation. This created an opportunity to test the score of the LEAF-Q against measured current EA, MD and bone health, and to calculate the sensitivity and specificity of the LEAF-Q. The sensitivity and specificity found indicate that the LEAF-Q has the ability not only to correctly characterise eight of ten female athletes with lower current EA and/or oligomenorrhoea/FHA and/or low BMD, but also to correctly classify nine of 10 athletes with higher current EA, eumenorrhoea and normal BMD.

DE behaviour and ED are most often accompanied by energy deficiency and other end points of the *Triad*.[25–27] The prevalence of DE/ED in this study was high (n=12, 27%). Only 58% of these participants had, however, lower current EA, while they all had additional MD and/or low BMD. The LEAF-Q was not constructed to discriminate between normal and pathological eating behaviour, but to detect female athletes at risk for the *Triad*. Findings of either one of the end points in the *Triad* when using the LEAF-Q should, therefore, implicate assessment for the other conditions, including a pathological eating behaviour.

Gastrointestinal problems are commonly reported in female endurance athletes[28] and in patients with DE/ED.[1 5] In this group of female endurance athletes, the variable for gastrointestinal problems was verified by lower current EA. Persistent energy deficiency causes mucosal atrophy characterised by diminished intestinal function as well as morphological changes,[29] linking lower current EA to gastrointestinal problems.

Table 4 Descriptive details on all participants and divided by total LEAF-Q score

	All (n=45)	LEAF-Q ≥8 (n=28)	LEAF-Q <8 (n=17)	p Value
Age (years)	26.6±5.4	26.0±5.6	27.5±5.1	0.35
Height (cm)	169.3±0.05	168.7±0.06	170.2±0.05	0.38
Weight (kg)	58.7±6.8	57.1±6.4	61.2±7.0	0.05
BMI (kg/m^2)	20.5±1.8	20.0±1.7	21.1±1.9	0.06
Body fat (%)	20.2±3.4	19.2±3.2	21.8±3.4	0.01
Whole body Z-score	0.1 (−0.7–0.4)	−0.1 (−0.7–0.5)	0.2 (−0.7–0.4)	0.91
Lumbar spine Z-score	−0.7 (−1.6 to −0.1)	−0.8 (−1.6 to −0.2)	−0.7 (−1.3–0.3)	0.39
EA (kJ/kg FFM/day)	161±58	156±55	169±64	0.49
Energy balance (%)	86±19	85±18	89±21	0.46
EDI-3				
DT-score	4.0 (1.0–9.0)	4.0 (1.5–9.0)	4.0 (0.0–9.5)	0.16
BD-score	5.5 (2.0–10.5)	5.0 (3.0–10.0)	6.0 (2.0–17.0)	0.29
Blood pressure (mm Hg)				
Supine systolic	113.0±10.6	111.5±11.1	115.4±9.7	0.24
Supine diastolic	68.2±9.5	66.1±8.4	71.4±10.5	0.07
Standing systolic	111.7±10.5	109.2±9.9	115.4±10.5	0.06
Standing diastolic	72.3±9.1	70.4±8.9	75.1±9.0	0.10
T_3 (ng/mL)	1.61±0.27	1.54±0.22	1.74±0.29	0.01
Cortisol (nmol/L)	453±135	477±142	412±115	0.13
Leptin (pg/mL)	2.9 [1.6–4.1]	2.0 [1.4–3.2]	4.1 [1.4–5.3]	<0.01
(pg/mL/kg FM)	0.24±0.17	0.21±0.19	0.29±0.31	0.02
Glucose (mmol/L)	4.1±0.5	4.0±0.5	4.3±0.3	0.02
Exercise (h/week)	11.3±4.3	11.7±4.8	10.6±3.2	0.39
VO_{2peak} (l/min)	3.2±0.4	3.2±0.4	3.2±0.4	0.78
VO_{2peak} (mL/kg/min)	55.7 [48.2–58.8]	56.7 [49.2–61.2]	52.4 [46.5–56.0]	0.13

Data are presented as mean±SD for normal distributed data and as median and IQR (25–75) for skewed data. Student's paired t test was used after skewed data were log transformed. BD-score, body dissatisfaction score; BMI, body mass index (kg/m^2); DT-score, drive for thinness score; EA, energy availability, EDI-3, Eating Disorder Inventory-3; FM, fat mass; LEAF-Q, Low Energy Availability in Females Questionnaire; T_3: triiodothyronine; VO_{2peak}: maximal oxygen uptake, ¤ determined by DEXA scan.

Thein-Nissenbaum *et al*[30] showed an increased risk for muscular skeletal injuries in female athletes with restricted eating behaviour and MD. These results confirm earlier findings of increased risk for muscular skeletal injuries in female athletes with restricted eating behaviour, MD as well as low BMD.[11] In this group of female endurance athletes, the LEAF injury score correlated with impaired bone health and not with MD or current EA. A subanalysis showed that the group with impaired bone health exercised more compared with those with normal BMD (13.4±5.1 h/week vs 9.6±2.5 h per week, p<0.01), supporting similar findings regarding impaired bone health in studies with female elite athletes from weight-bearing endurance sports.[26 31] Furthermore, it is well established that prolonged, exhaustive endurance exercise is capable of inducing skeletal muscle damage and temporary impairment of muscle function,[32] making the association between LEAF injury score and impaired bone health physiological plausible.

Table 5 Prevalence of triad-associated conditions in all participants and divided by total LEAF-Q score

	All (N=45)	LEAF-Q ≥8 (n=28)	LEAF-Q <8 (n=17)
BMD Z-score ≤−1¤	(N=17)	(n=13)	(n=4)
BMD Z-score ≤−2¤	(N=4)	(n=2)	(n=2)
Eating disorders	(N=11)	(n=7)	(n=4)
Disordered eating	(N=1)	(n=1)	(n=0)
Underweight (BMI <18.5)	(N=6)	(n=5)	(n=1)
Menstrual dysfunction	(N=29)	(n=23)	(n=6)**
Hypotension	(N=7)	(n=6)	(n=1)
Hypoglycaemia	(N=16)	(n=13)	(n=3)*

*p<0.05, **p<0.01, tested with Fisher's exact test.
BMD, bone mineral density; BMI, body mass index, ¤ determined by DEXA scan; DEXA, LEAF-Q, Low Energy Availability in Females Questionnaire.

PCOS is reported as common among female elite athletes,[13] and is not associated with hypothalamic inhibition because of energy deficiency. In this group of athletes, however, three of five participants diagnosed with PCOS or a MD other than oligomenorrhoea/FHA had low BMD and four had lower current EA. Our findings emphasise the importance of differential diagnoses in order to secure proper intervention for MD in female athletes and indicate that assessment of coexisting *Triad* conditions could be relevant despite the type of MD.

Efforts were made to improve content validity through focusing on physiological plausibility, examining the research literature to identify the most discriminating variables between the participants with long-term energy deficiency. The strength of this study is that standardised objective methods have been used to assess DE/ED, orthostatic BP and reproductive function as well as bone health. Gastrointestinal function, including stool frequency and consistency, as well as reproductive function and the reason for use of OC, are personal issues, and questions in this regard may be considered offensive and as intimidating with regard to personal integrity. Therefore, the LEAF-Q and the results should be carefully administered and evaluated by medically qualified personal. The LEAF-Q has thus far been validated only in this group of female endurance athletes. Since sports-specific issues may be relevant to assess, the LEAF-Q needs to

be tested in other areas, such as aesthetic sports and sports that require weight categories for competition, and also in sports not focusing on weight, such as soccer and team handball.

The LEAF-Q is brief and could be considered for use to identify female athletes at risk of the *Triad* in order to promote early detection and treatment.

What are the new findings?

- Validated screening tool.
- Identified female athletes at risk for the *Triad.*

How might it impact on clinical practice?

Could enable early detection and intervention.

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Contributors AM, ÅBT, SS, AS and JS-B designed the study. AM constructed the LEAF-Q and analysed data and together with AS and JS-B was primarily responsible for writing the manuscript. AM and ÅBT collected data. CR, JF and SS provided advice and consultation in their areas of expertise and contributed together with ÅBT to the writing of the manuscript.

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