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RESEARCH

Potential Low Energy Availability (LEA) Risk Amongst Amateur and Recreational Athletes in Singapore

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Objectives: This study investigated the prevalence of potential Low Energy Availability (LEA) risk amongst amateur and recreational athletes in Singapore.
Design: In this cross-sectional study, a 52-item online questionnaire was used to determine potential LEA risk in the participants. A mean score of ≥4.0 on any of the Eating Disorder Examination Questionnaire (EDE-Q) subscale, and/or a global score of ≥4.0, and/or Body Mass Index (BMI) <18.5 kg/m^2 were primary measures of potential LEA risk. Other LEA risk correlates included Hooper's Questionnaire, perceptions on body composition and performance, athlete type (amateur or recreational), type of sport (individual or team), and if they trained with or without a coach.
Participants: 318 participants from Singapore, aged 21–35 years old (124 males; 194 females) completed the study questionnaire.
Results: 34.3% of participants were found to be at potential risk of LEA. Female athletes (44.3%) had a significantly higher ($p < 0.001$) potential LEA risk than males (18.5%). However, the potential LEA risk between athlete type, type of sport, those who trained with or without a coach were not significantly different ($p > 0.316$).
Conclusions and Implications: The study found more than one third of the participants being at potential LEA risk. The findings add to the body of evidence on identifying athletes with potential LEA risk. Future studies can investigate the LEA prevalence amongst athletes in Singapore and other Asian populations with more extensive questionnaires that address consequences and symptoms of LEA.

Keywords: Low energy availability; amateur and recreational athletes; male and female athletes; prevalence; Relative Energy Deficiency in Sport; Singapore

Introduction

An adequate diet is critical for athletes to meet the energy needs for optimum health and performance. A state of low energy availability (LEA) occurs when an individual has insufficient energy to support normal physiological functions after deducting the cost of exercise energy expenditure (EEE) (De Souza *et al.*, 2007). It is important to emphasize that this amount of energy is relative to fat-free mass (FFM) (Mountjoy *et al.*, 2014). LEA is more prevalent in athletes, as their EEE is generally higher compared to non-athletic populations (Mountjoy *et al.*, 2014). Potential LEA risks may involve low energy intake with or without disordered eating, compulsive exercise behaviors, higher bone injury risk, psychological consequences (Mountjoy *et al.*, 2014), low awareness and incorrect perceptions on aspects like body weight, body fat and leanness (Loucks, Kiens and Wright, 2011; Mountjoy *et al.*, 2014). Despite being a condition at the early part of eating disorder spectrum, persistent LEA can also negatively impact athletic performance (i.e. poor exercise recovery, decreased endurance performance) (Mountjoy *et al.*, 2014). Therefore, it is critical to identify athletes at potential LEA risk to develop and facilitate the implementation of effective prevention

and remediation measures to mitigate adverse outcomes of LEA on health and athletic performance. This cross-sectional study was aimed to identify amateur and recreational (non-professional, non-elite) athletes who may be potentially at an early stage of LEA, by assessing LEA related factors – disordered eating behaviors and low Body Mass Index (BMI).

LEA can lead to Relative Energy Deficiency in Sport (RED-S), a syndrome that can be experienced by both male and female athletes, defined as impaired physiological functions including, but not limited to, metabolic rate, bone health, immunity, protein synthesis, and cardiovascular health that, apart from the menstrual problems (Mountjoy *et al.*, 2014). The existing body of evidence on LEA is predominantly on competitive female athlete populations (Melin *et al.*, 2015; Muia *et al.*, 2016). This study adds to the literature by investigating the existence of potential LEA risk in males and non-competitive athlete populations.

Scant studies have reported a LEA prevalence (range 25–42%) in male athletes (Heikura *et al.*, 2018; McCormack *et al.*, 2019). This has prompted the International Olympic Committee (IOC) to encourage research on energy demands and sport performance in male athletes (Logue *et al.*, 2018). It is therefore imperative to expand the evidence base by conducting studies including male athletes at a potential risk of LEA. Furthermore, most studies have been conducted on western athletes. There is insufficient evidence on the prevalence of potential LEA risk and its outcomes in Asian athlete populations.

Despite increasing sports participation rates in Asia, including Singapore (Olympic Council of Asia, 2018). There is a lack of studies on energy intake patterns and associated risks in Asian athlete populations. If the magnitude of LEA risk in a population remains undetermined, it may remain unaddressed and has the potential to escalate to RED-S leading to longer-term adverse health and performance consequences. A study reported 7.4% of young females in Singapore being at risk of developing eating disorders (Ho *et al.*, 2006), a figure comparable to western populations (Kjelsås, Bjørnstrøm and Götestam, 2004; Hudson *et al.*, 2007). Another study on energy availability found that 77.8% of competitive female dragon boat athletes (n = 9) in Singapore had LEA (30 kcal·kgFFM^{-1}·day^{-1}) (Ong and Brownlee, 2017). Therefore, the emerging sporting landscape makes it reasonable to hypothesize a growing potential of LEA risk amongst athletes in Singapore.

Currently, LEA risk has been predominantly determined using surrogate markers or self-reported symptoms in elite athletes (Drew *et al.*, 2017), female athletes (Sygo *et al.*, 2018), young athletes (Holtzman *et al.*, 2019), as well as in recreational athletes (Logue *et al.*, 2019). Studies have also frequently used questionnaires to screen for eating disorders as a surrogate marker of LEA (Sim and Burns, 2021). Validated measures like the Low Energy Availability in Females Questionnaire (LEAF-Q) (Melin *et al.*, 2014), and the RED-S clinical assessment tool (RED-S CAT) (Mountjoy, Sundgot-Borgen, Burke, Carter, Constantini, Lebrun, Meyer, Sherman, Steffen, Budgett, Ljungqvist, *et al.*, 2015) have been recommended to screen athletes for LEA and other physiological functions. However, the LEAF-Q is specific to female athletes and the use of RED-S CAT requires specialized manpower, clinical facilities, and measurement of objective anthropometric and biomarkers (Mountjoy, Sundgot-Borgen, Burke, Carter, Constantini, Lebrun, Meyer, Sherman, Steffen, Budgett, Ljungqvist, *et al.*, 2015). Therefore, application of these instruments has limitations for use in large-scale population studies. Furthermore, there is apparently a lack of consensus to measure LEA risk in male athletes. Investigating potential LEA risk in population-based studies including recreational and male athletes warrants continued research in terms of the instruments and methods.

This study was aimed to investigate the potential LEA risk and examined its early-stage factors amongst adult amateur and recreational athletes in Singapore. The Eating Disorder Examination Questionnaire (EDE-Q) (Fairburn and Beglin, 1994) scores and BMI were used as main measures of potential LEA risk. One was classified as at potential LEA risk if mean score was ≥4.0 for any EDE-Q subscale, and/or a global score of ≥4.0, (Fairburn and Beglin, 1994) and/or low BMI <18.5 kg/m^2 (underweight) (Nattiv *et al.*, 2021). Based on the recommended cut-off values of BMI < 18.5 for public health significance (World Health Organization, 2021), and the underweight prevalence amongst adults in the South-East Asia region (World Health Organization, 2017), the study hypothesized that at least 20% of the participants will be at potential LEA risk. The study also hypothesized females to be at a higher potential LEA risk, and a greater proportion of amateur athletes at potential LEA risk than recreational athletes.

Materials and Methods

Participants

This cross-sectional study had 318 participants (124 males; 194 females) that completed a customized online questionnaire to determine potential LEA risk. The eligibility criteria included: (i) 21–35 years old; (ii) physically active, recreationally, or competitively, for more than six months; (iii) not suffering from

musculoskeletal problems that restricted sports and physical activity participation for more than 12 weeks over the past one year; (iv) meet the definition of athlete type (amateur or recreational athlete).

The participants were categorized into two athlete types based on previously suggested definitions for amateur (Dunford and Doyle, 2008) and recreational (Laquale, 2009) athletes. An amateur athlete was defined as an individual participating in competitive physical activities or sports/games that require training of skills, physical strength, agility, or stamina (Dunford and Doyle, 2008), and participates in at least one organized competition every year. A recreational athlete was defined as an individual participating in sports to be physically fit, for social involvement, to have fun, is physically active but does not train for competition at the same level of intensity and focus as a competitive athlete (Blake, 2008; Laquale, 2009). The questionnaire included these definitions for the ease of participants being able to self-categorize themselves in a valid manner.

The study was approved by the University's Institutional Review Board (IRB approval letter IRB-2017-10-055). Participant recruitment was done via convenience sampling. An invitation to participate with the link to the survey questionnaire was provided through different social media platforms, contacting athletes at physical locations (i.e., gymnasiums and running tracks) and flyers pasted in other exercise, sports, and recreational facilities. First section of the survey included study information and the option to provide consent for voluntary participation. Data was collected from January-to-April 2018.

Sample size calculation

The sample size was based on the objective to obtain a sufficient number of participants correctly classified as having the condition of interest or not, with a given confidence about the amount to which this estimate might be affected by sampling error.

The following formula (Daniel, 1999) was used to estimate the sample size:

$$n = Z^2P\,(1 - P)/d^2$$

n = Sample size
Z = Z Statistic for a level of confidence
P = Expected prevalence or proportion (in proportion of 1: if 20%, P = .2)
d = Precision (in proportion of 1: if 5%, d = .05)

Based on the convention of 95% level of confidence (Z = 1.96), prevalence estimates of 20% (P = 0.2), and low precision error (d = .05), a sample size of at least 246 was deemed appropriate for the study. A final sample size of 318 was obtained, thus providing sufficient power to allow conclusions to be drawn about the potential LEA risk in the target population.

Instrument

Participants responded to a 52-item online questionnaire hosted on an institutionally licensed version of the Qualtrics survey software (Qualtrics, Provo, UT, 2018). The questionnaire included sections on participant demographics (age, gender), sports and training history (type of sport, years of training, competition level, train with or without a coach), the EDE-Q (Fairburn and Beglin, 1994), height and weight, Hooper's questionnaire (Hooper and Mackinnon, 1995), and a 5-item questionnaire on perceptions related to body composition and performance (Mukherjee *et al.*, 2016).

Measures for Potential LEA Risk

EDE-Q scores and BMI were the main measures, while Hooper's Questionnaire score, and perceptions related to body composition and performance were considered as likely additional factors related to potential LEA risk.

Eating Disorder Examination Questionnaire

The EDE-Q is a 28-item questionnaire that measures disordered eating psychopathology (Fairburn and Beglin, 1994) is well suited for epidemiological studies (Mond *et al.*, 2004). The EDE-Q is an established, simple and cost-efficient instrument to measure eating disorder psychopathology (Fairburn, Cooper and O'Connor, 2008), and has been used in both research and clinical practice. The EDE-Q has been previously used to identify LEA risk in male and female elite para athletes (Brook *et al.*, 2019). Moreover, males being more likely to have an unspecified eating disorder (Le Grange *et al.*, 2012), the EDE-Q has been found to

be particularly sensitive in this context (Jennings and Phillips, 2017). Furthermore, the EDE-Q has been used in previous studies on healthy women in Singapore (Chen, Mond and Kumar, 2010; Ng, Kuek and Lee, 2018).

The EDE-Q includes four subscales – Dietary Restraint (DR), Shape Concern (SC), Eating Concern (EC), and Weight Concern (WC), and an average of the four subscales, the Global Score (GS). A mean score of ≥4.0 for any EDE-Q subscale, and/or a global score of ≥4.0 is considered 'elevated' and for the purpose of this study, constituted a primary measure of potential LEA risk. The EDE-Q also includes six questions on pathogenic eating behaviors over the past 28 days, which were taken into consideration when the participants reported performing two or more listed pathogenic eating behaviors more than once (Nichols *et al.*, 2006; Thein-Nissenbaum, 2013).

Body Mass Index (BMI)

This index predicts ideal body weight for health concerns, with values below 18.5 kg/m^2 being considered as low BMI (underweight) (Health Promotion Board, 2015), and at LEA (Nattiv *et al.*, 2021). For the purpose of this study, low BMI constituted the other primary measure of potential LEA risk. BMI as a criterion of being underweight, and individuals at LEA risk are more likely to have a BMI below 18.5 kg/m^2. A previous study in para-athletes (Brook *et al.*, 2019) have used self-reported height and weight to calculate BMI. In addition, self- reported anthropometric measures have been suggested to be of acceptable accuracy and validity for public health studies (Lassale *et al.*, 2013; Nikolaidis and Knechtle, 2020).

Hooper's Questionnaire

LEA can influence psychological function (Mountjoy *et al.*, 2014). Hence psychometric variables of the participants' perceived wellness were assessed using Hooper's Questionnaire (Hooper and Mackinnon, 1995). It includes rating on (i) quality of sleep, (ii) stress level, (iii) fatigue and (iv) muscle soreness, measured on a 7-point Likert-type scale ranging from 1 (Very, very low/good) to 7 (Very, very high/bad). A higher index score indicates higher level of stress, fatigue, poor quality of sleep, and severe muscle soreness and a rating score of equal to or more than 5.0 on any parameter indicates sub-optimal wellness.

5-Item Questionnaire on Perceptions on Body Composition and Performance

Affected psychological health and wellness may both lead to and be an outcome of disordered eating and LEA (Mountjoy *et al.*, 2014). Therefore, awareness and perceptions on body weight, fatness and leanness were also determined. This questionnaire has been previously validated in female and male responders (Mukherjee *et al.*, 2016). As this questionnaire was answered by both sexes, for the purpose of this study, one item related to menstrual function in the original questionnaire was omitted, and another item related to only female athletes was modified to include all athletes – "Athletes should eat less to achieve/maintain a lighter body" (Mukherjee *et al.*, 2016). Hence, this section of the questionnaire included five items to assess participants' perception of leanness, fatness, and sports performance (Mukherjee *et al.*, 2016). Item 1, 2, 3, and 5 reflect inaccurate perception while item 4 reflects accurate perception on body composition and performance. Each item was measured on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Data Analysis

Descriptive statistics were formulated for the overall sample. Frequencies and percentages were calculated for categorical variables and mean, and standard deviation were determined for continuous variables.

Differences in mean BMI and EDE-Q scores across sociodemographic characteristics were determined using t-test. Chi-square test of independence was done to determine any significant differences in potential LEA risk between groups (gender, athlete type, training with or without a coach, and type of sport). For descriptive analysis, responses on each item of the 5-item questionnaire were grouped according to accurate and inaccurate perceptions. 'Strongly Agree', and 'Agree' were combined to form the "Accurate" category, while 'Unsure', 'Disagree' and 'Strongly Disagree' formed the "Inaccurate" category.

Statistical significance was accepted at $p < 0.05$. All analyses were performed using SPSS statistical software (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp, 2016).

Results

This study received a total of 412 responses (318 completed, 94 incomplete). Only the complete responses were accepted for data analyses. **Table 1** presents the sociodemographic characteristics of participants.

Table 1: Sociodemographic characteristics of female and male recreational and amateur athletes in Singapore.

		Mean	Range	SD
Age (years)	Overall	23.57	14.00	2.54
	Female	23.16	13.00	2.33
	Male	24.21	14.00	2.73
Body Mass Index (BMI) (kg/m²)[a]	Overall	21.15	13.74	2.62
	Female	20.37	12.06	2.26
	Male	22.37	12.65	2.69
		N		**%**
Gender	Female	194		61.0
	Male	124		39.0
Athlete type	Recreational[b]	189		59.4
	Female	115		61.0
	Male	74		39.0
	Amateur[c]	129		40.6
	Female	79		61.0
	Male	50		39.0
Type of sport	Individual	110		34.6
	Team	94		29.6
	Both	114		35.8
Competition Level	Inter-varsity/Inter-college	28		8.9
	National	62		19.5
	Regional	13		4.1
	International	13		4.1
	Others	13		4.1
Trains with a coach	Recreational Athlete	59		31.2
	Amateur Athlete	108		83.7
Does not train with a coach	Recreational Athlete	130		68.8

Note:
[a] BMI calculated based on self-reported height and weight.
[b] Definition of recreational athlete: individual who participates in sports to be physically fit, socially involved and to have fun, physically active but does not train for competition at the same level of intensity and focus as a competitive athlete.
[c] Definition of amateur athlete: individual who participates in "competitive physical activities" or sports/games that require training of skills, physical strength, agility, or stamina, and also participate in at least 1 organised competition every year.

Results showed that 109 participants (34.3% overall; females ($n = 86$); males ($n = 23$)) were at potential LEA risk, categorized by being underweight (BMI < 18.5 kg/m^2) and/or a score of ≥4.0 on one or more subscales and/or the GS of the EDE-Q. **Figure 1** and **Table 2** presents the potential LEA risk in the participants.

BMI and EDE-Q scores of at potential LEA risk participants was significantly different ($p < 0.001$) from not at potential LEA risk participants. Amongst the at potential LEA risk participants with scores of ≥4.0 for the EDE-Q subscales, underweight and not underweight (**Table 3**), highest numbers with elevated scores were for the SC (51.4%) followed by the WC (32.1%).

Females showed significantly ($p < 0.001$) higher scores than males for subscales EC, SC, WC, and GS scores.

At potential LEA risk participants engaged in pathogenic behaviors, most commonly binge eating and excessively exercising for more instances over the past 28-day period than not at potential LEA risk participants. 26.9% and 20.2% of at potential LEA risk participants and 15.6% and 9.1% of not at potential

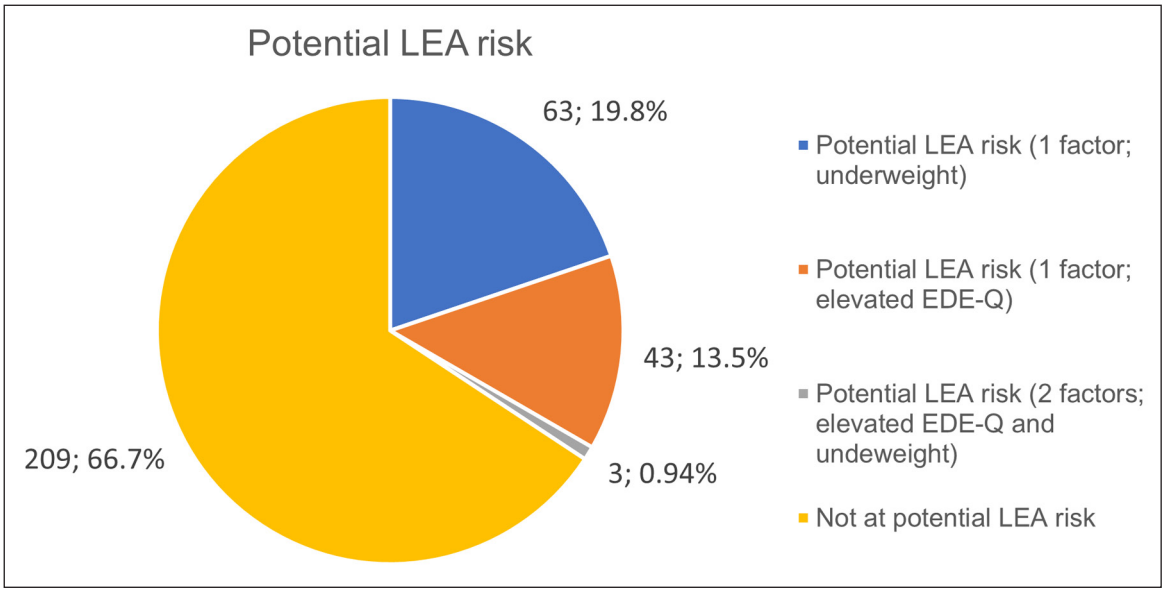

Figure 1: The overall potential Low Energy Availability (LEA) risk in athletes in Singapore.

Table 2: Potential Low Energy Availability (LEA) risk of amateur and recreational athletes in Singapore.

		N	%	*p*-value
Potential LEA risk	Female	86	44.3	
	Male	23	18.5	<0.001[a]
	Recreational	65	34.4	
	Amateur	44	34.1	0.958[a]
	Trains with a coach	53	31.7	
	Does not train with a coach	56	37.1	0.316[a]
	Individual sport	37	33.6	
	Team sport	35	37.2	
	Both (Individual and Team sport)	37	32.5	0.759[a]

Note:
[a] Chi-square test of independence was done to determine any significant differences in potential LEA between not-at-risk and at-risk participants, and amongst groups (gender, athlete type, trains with or without a coach, type of sport).

Table 3: Participants at potential Low Energy Availability (LEA) risk (scores of ≥4.0 on EDE-Q subscales).

EDE-Q scores ≥4.0	**DR**		**EC**		**SC**		**WC**		**GS**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Elevated EDE-Q score (with BMI > 18.5)	15	13.8	8	7.3	56	51.4	35	32.1	16	14.7
Elevated EDE-Q score (with BMI < 18.5)	2	1.8	1	0.9	3	2.8	3	2.8	3	2.8

Note: EDE-Q – Eating Disorder Examination Questionnaire, BMI – Body Mass Index, DR – Dietary Restraint, EC – Eating Concern, SC – Shape Concern, WC – Weight Concern, GS – Global Score. Participants were considered to be at potential LEA risk if they had scores of ≥4.0 on EDE-Q subscales and/or BMI < 18.5 kg/m².

LEA risk participants reported engaging in binge eating and excessive exercising respectively for 5–14 instances. In addition, 7.3% and 9.2% of at potential LEA risk participants and 4.9% and 3.3% of not at potential LEA risk participants reported engaging in binge eating and excessive exercising, respectively,

for more than 14 instances over the past 28 days. Furthermore, 42.2% at potential LEA risk participants and 27.3% not at potential LEA risk participants reported engaging in two or more different pathogenic behaviors more than once over the past 28 days.

The parameters of stress (4.47 *vs* 3.94) and fatigue (4.77 *vs* 4.33) levels in the Hooper's Questionnaire, as well as the Hooper's Index (4.18 *vs* 3.89), was significantly higher ($p \leq 0.001$) amongst the at potential LEA risk participants as compared to the not at potential LEA risk participants.

A significantly higher ($p = 0.003$) proportion of at potential LEA risk participants (69.7% *vs* 52.6%) had inaccurate perceptions related to emphasizing ideal body weight and leanness in athletes. In addition, most of the participants also had inaccurate perceptions related to low body fat and sports performance (**Table 4**).

Lastly, results showed that irrespective of the participant type (amateur, recreational, at potential LEA risk, not at potential LEA risk), internet was the most preferred source of information for training, diet, and nutrition, followed by social media and coaches.

Table 4: Participants' perceptions on body composition and performance.

	Not at potential LEA risk				At potential LEA risk				
	Accurate		Inaccurate		Accurate		Inaccurate		
Item	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	***p*-value**
1. "Low body fat is extremely important for sports performance"	83	39.7	126	60.3	34	31.2	75	68.8	0.136
2. "Ideal body weight and leanness should be constantly emphasised to the athletes"	99	47.4	110	52.6	33	30.3	76	69.7	0.003*
3. "Low body fat also makes the athlete lighter in body weight and thus improves performance"	94	45	115	55	39	35.8	70	64.2	0.115
4. "Low body fat does not mean high muscle mass (lean mass)"	171	81.8	38	18.2	93	85.3	16	14.7	0.529
5. "Athletes should eat less to achieve/ maintain a lighter body"	189	90.4	20	9.6	93	85.3	16	14.7	0.193

Note: * $p < 0.05$.

Discussion

This study endeavors to fill the gap in the existing literature on identifying potential LEA risk in male and female recreational and amateur athletes in Singapore, a part of the Asian population. This cross-sectional study was aimed to identify athletes who may potentially be at LEA risk, by assessing LEA related factors – disordered eating behaviors and low BMI. The present study found that the overall potential LEA risk prevalence was 34.3% and females being at a higher risk than males supported the hypotheses. The two additional significant findings included 18.5% of male athletes at potential LEA risk, and the potential LEA risk being similar in recreational and amateur athletes. In addition, the athletes presented pathogenic eating behaviors and excessive exercising, this implies that potential LEA risk prevalence could be eminent and may be a possible public health concern in Singapore. This potential risk of LEA could be high, especially with a trend of increasing sports participation at both recreational and competitive level.

Being underweight suggests persistent energy deficiency (Mountjoy, Sundgot-Borgen, Burke, Carter, Constantini, Lebrun, Meyer, Sherman, Steffen, Budgett and Ljungqvist, 2015) and elevated EDE-Q scores indicate LEA risk and a likelihood of manipulating eating behaviours (Mountjoy *et al.*, 2014). The EDE-Q concerns may influence eating behaviors, leading to lower energy intake as a compensatory measure to cope with the concerns. However, the results showed that the majority of the at potential LEA risk participants were not underweight, implying that disordered eating behaviors, at least in the early stages, may exist in a state of healthy body weight (i.e. normal BMI), especially in athletes. This is due to their greater muscle mass and higher BMD compared to non-athletic population (Düppe *et al.*, 1997). Therefore, while those at LEA risk are more likely be underweight, low BMI may not be an accurate indicator of potential LEA risk when used as an isolated measure in athletes.

Females had a significantly higher potential LEA risk than males (44.3% *vs* 18.5%). Female athletes tend to manipulate their diet to achieve an ideal weight for health and aesthetic purposes (De Souza *et al.*, 2007).

Furthermore, similar to the present study's findings, higher EDE-Q scores have been reported in females compared to males (Darcy *et al.*, 2013), suggesting that female athletes may be at greater risk of disordered eating and subsequent LEA risk.

The non-significant difference in potential LEA risk between type of sports (individual, team, or both) supports the understanding that the prevalence of the LEA and Triad is not merely limited to sports with emphasis on leanness and aesthetics (George, Leonard and Hutchinson, 2011).

Coaches play a key role in Triad and LEA prevention and education (Brown, Wengreen and Beals, 2014). However, the findings showed there was no significant differences in potential LEA risk in those who train with or without a coach. Coaches in Singapore have been reported to have low awareness and knowledge of the Triad (Mukherjee *et al.*, 2016) and hence also unlikely to be informed about LEA. The low awareness reduces the likelihood of coaches educating and mitigating LEA risk in athletes. This emphasizes the need and significance of educating both coaches and athletes on best practices related to diet, nutrition and energy intake.

The instances and number of different pathogenic eating behaviors reported by at potential LEA risk participants were higher than not at potential LEA risk participants, which increases the risk of developing pathogenic weight manipulation behaviors and LEA, and its associated adverse health and performance consequences. It is also remarkable that 27.3% of the not at potential LEA risk participants engaged in two or more different pathogenic behaviors more than once in the past 28 days. Despite the percentage being lower than the at potential LEA risk participants (42.2%) in the present study, it is still higher than that reported in high-school female athletes (24%) (Nichols *et al.*, 2006). Therefore, signs of pathological eating behaviors and vulnerability to LEA may exist even in the absence of an elevated EDE-Q score or low BMI.

The similar potential LEA risk prevalence between amateur (34.1%) and recreational (34.4%) athletes was contrary to the study's hypothesis. This also in contrast to previous literature reporting increase in LEA with the level of competition (Torstveit and Sundgot-Borgen, 2005). However, a previous study found similar prevalence of the Triad in varsity athletes and sedentary controls (36% *vs* 31%) (Hoch *et al.*, 2009) which was attributed to the possibility of inadvertent caloric restriction, that may have been subconsciously driven by cultural and media influences to be thin.

The results showed that a higher number of at potential LEA risk participants had the misperceptions on emphasizing leanness in athletes. This may lead to high-risk behaviors associated with energy availability such as low caloric intake and excessive exercise to lose weight with the intent to achieve leanness or the desired body shape (De Souza *et al.*, 2007; Logue *et al.*, 2018). Moreover, athletes may perceive low body weight as an indicator of hard work rather than risk of energy deficiency (Mukherjee *et al.*, 2016) and these misconceptions and consequent behaviors can increase LEA risk.

Limitations

There is apparently no consensus on a recommended tool for measuring or screening potential LEA risk in male and female athletes in a large population or field settings that can be implemented in a quick and convenient manner without the need of specialized equipment or expert manpower. Owing to internet-based survey offering a greater reach to the participants, the methodological approach of this study involved collection of self-report data using an online survey. While previous studies show acceptable validity and accuracy of such data, the likelihood of self-reported anthropometric data leading to under-reporting of underweight participants and hence also the true prevalence of potential LEA risk cannot be completely ruled out. The study questionnaire is also limited as psychometric analyses was not done. Furthermore, while the present study adopted an inclusive methodological approach, laboratory-based measurements were not done as no funding was available. However, while it is reasonable to conceive that measuring biomarkers may increase the validity of determining LEA risk, LEA-related biomarkers (e.g. testosterone, cortisol, T3, leptin and ferritin) have been reported to be no different in female athletes with high or low risk of LEA (Meng *et al.*, 2020), implying that biomarkers may not be sensitive measurements especially at the early stages of LEA. Therefore, the inclusive methodological construct of this study using established questionnaire instruments including perceived wellness and perceptions on fatness and leanness, can be deemed as an adequately reflective and reasonably valid as well as an epidemiologically feasible approach to determine the prevalence of potential LEA risk in the athlete population.

This study is also limited by lack of a pilot study. Therefore, our methodology used validated and established questionnaires meet the objectives. It must be noted that while EDE-Q had been found to be useful for measuring the degree of eating psychopathology within the Singapore population (Ng, Kuek and Lee, 2018), this instrument has yet to be validated within a Singaporean population.

Thirdly, owing to a dearth of published research related to LEA and its outcomes in the Asian context, the present study is unable to provide any time trends or comparative elucidation for the prevalence of potential LEA risk in Singapore's athlete population. Lastly, while this study met the statistically adequate sample size required for determining the prevalence of a condition, future studies can endeavor to recruit larger sample size to enhance the power of the data to be generalized to the population. However, this study can be considered valuable in terms of providing the benchmark data suggesting a moderate – high prevalence of potential LEA risk amongst recreational and amateur athlete population in Singapore.

Conclusions and Implications

The overall potential LEA risk of 34.3% amongst female and male amateur and recreational athletes in Singapore is of concern, from both athletic performance and public health perspective. A similar prevalence of potential LEA risk amongst athlete type, type of sport, and whether they train with a coach, suggests a high pervasiveness of the condition in the population. With the known adverse health implications of LEA and RED-S, the findings from this study adds to the body of population-specific evidence further strengthening the case for recognising this condition as a public health concern. In addition, it is critical that various stakeholders like athletes, coaches, parents, sports governing bodies, be made aware of the condition, predisposing factors, risks, and outcomes, and educated on measures of its prevention. Importantly, developing athlete and coach education strategies and programmes on primary prevention of LEA and consequently RED-S would be paramount to cultivate a healthy sporting culture amongst athletes. Lastly, questionnaires that measure LEA related risk factors could potentially be used to indicate potential risk of LEA which may be followed by more extensive clinical measurements to prevent the adverse consequences of LEA and RED-S on health and athletic performance. Future studies can consider including more primary measures of LEA (in addition to EDE-Q and BMI), such as questionnaires that measure exercise behaviours as excessive exercise, and questions that measure changes in body weight, as these constitute risk factors of LEA. Future studies can also investigate validating the EDE-Q and Hooper's Questionnaire within the Singapore population.

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Competing Interests

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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