Amenorrhea and oligomenorrhea risk related to exercise training volume and intensity: Findings from 3,705 participants recruited via the STRAVA™ exercise application

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Abstract

The physiological underpinnings of amenorrhea/oligomenorrhea (AO) among exercising women are complex and incompletely understood. **Objectives:** To investigate associations between self-reported exercise training habits and AO among physically active women. **Design:** A cross-sectional survey was completed by 3,705 women (median age = 40 years [Quartile 1, Quartile 3: 30, 45], body mass index [BMI] = 22.1 kg/m^2 [20.5, 24.2]) representing multiple nationalities and sports via the STRAVA™ exercise application. Respondents selected the amount of time they participated in low intensity (LIT), moderate intensity (MIT), and high intensity exercise training (HIT) domains per week. AO was defined as self-reporting ≤10 menses in the last year. **Method:** Associations between weekly exercise volume for LIT, MIT, and HIT and AO were modeled with univariate logistic regression models, followed by adjustment for age and BMI. **Results:** AO prevalence was 16% (n = 576/3,705), with no difference by country of origin or most sport modes. In adjusted models, participating in LIT ≥7 h/week or MIT ≥6 h/week was associated with 1.43 (95% CI:1.04 - 1.96) and 1.46 (1.10 - 1.95) greater odds of AO compared to 2 to 3 h/week, respectively. Similarly, HIT ≥5 h/week was associated with 1.41 (1.03 - 1.92) greater odds of AO compared to 1 to 2 h/week. Participating in LIT for ≤30 min/week compared to 2 to 3 h/week was associated with reduced AO odds (0.65 [95% CI: 0.44 – 0.94]). **Conclusions:** Taken together, these associations suggest greater weekly exercise volume, irrespective of intensity, may increase AO risk among habitually active women.

Keywords: RED-S, female athlete triad, menstrual cycle, sports, athlete monitoring

Introduction

Menstrual cycle dysfunction, which includes the infrequency or complete absence of menses [i.e., amenorrhea and oligomenorrhea (AO)], affects up to 60% of women who regularly exercise compared to <11% of sedentary women.[1-3] The physiological underpinnings of AO are complex and incompletely understood, but have been attributed to low energy availability with resultant hypothalamic-pituitary-gonadal axis dysfunction and subsequent suppression of ovarian sex hormone production.[4-6] Even when energy balance is maintained during periods of intensified physical training, there is some evidence suggesting the physical stress of exercise itself may increase AO risk.[7,8] Williams and colleagues (2015) previously reported menstrual cycle dysfunction increased linearly with severity of energy deficiency in response to a controlled exercise training and diet intervention.[7] However, 1 in 8 (13%) of control group participants still developed oligomenorrhea despite energy balance being maintained at +80 Kcal/day.[7] Lieberman et al. (2018) also found estrone-1-glucuronide, pregnanediol glucuronide, and luteinizing hormone excretion were significantly suppressed following initiation of a ~3 month exercise training intervention in untrained women independent of varying energy availability status.[8] Such findings suggest the stress of habitual exercise may contribute, at least in part, to the elevated AO risk among habitually active women.

Current clinical guidance for treatment of AO targets energy balance through recommended reductions in exercise training and/or increasing caloric intake.[4-6] Regarding exercise training, it is unclear whether modifications in exercise volume or intensity should be prioritized in attenuating AO risk, as insufficient data exists to make such recommendations. Prior work linking intensified physical training to increased AO frequency has either implemented exercise programs in untrained women (augmenting activity volume *and* intensity)[7-10] or has made associations with training volume without accounting for possible differences in intensity.[11, 12] Identifying whether certain modifiable exercise training characteristics, namely volume and/or intensity, are related to AO risk would improve its management and prevention. Importantly, AO due to chronic ovarian suppression is linked to a host of long-term health consequences including low bone mineral density and cardiovascular disease.[5] Accordingly, the aims of the present investigation were to evaluate the strength of associations between AO and self-reported weekly exercise volume at different intensities in a large convenience sample of habitually active women representing multiple nationalities and primary sport modes who participated in a survey administered to members of the STRAVA™ database.

Methods

An electronic cross-sectional survey localized to 7 countries (United Kingdom, Republic of Ireland, United States of America, France, Spain, Italy, and Germany) was sent to 425,697 women aged ≥ 18 years who were members of the STRAVA™ database. STRAVA™ is a web-based platform used by recreational exercisers to elite level athletes to electronically track metrics such as mode, duration, and intensity of physical activity sessions. The survey was administered via email or hyperlink visible on the STRAVA™ mobile application and was available for 25 days from 14 February 2019 to 11 March 2019. Of those invited, 16,423 (3.9%) women started the survey and 10,371 (2.4%) completed it in its entirety. Additional details of survey design and administration have been published previously.[13] Survey protocol was approved by the Ethics Committee of St. Mary's University (SMEC_2018-19_011), Twickenham, UK and informed consent was obtained prior to participant involvement.

Participants were asked to retrospectively recall how many menses (i.e., periods) they had in the last year and were given options to select *"0-3," "4-6," "7-10," "11-13," "14-16," "17-19," or "19+."* AO was defined as reporting 0-10 periods, eumenorrhea as 11-16 periods, and polymenorrhea as ≥ 17 periods annually. Categories for menstrual cycle status were based on previously published characteristics of 612,613 women, in which 92% reported menstrual cycle intervals between 21 to 35 days.[14] A regular 21-35 day menstrual cycle results in approximately 11-17 menses per year.

Participants were asked to select which exercise modalities they regularly participated in at least once per week (Table 1). Weekly exercise volume was quantified by asking them to recall how much time they usually spent per week doing high intensity training (HIT; *"hard and fast breathing, can't hold a conversation"*), moderate intensity training (MIT; *"hard breathing, can hold a conversation"*), or low intensity training (LIT; *"easy breathing"*) over the last month with the option to select *"none," "0-30 minutes," "30 minutes-1 hour," "1-2 hours," "2-3 hours," "3-4 hours," "4-5 hours," "5-6 hours," "6-7 hours," "7-8 hours," "8-9 hours," "9-10 hours,"* or *"10+ hours."* Prior to analyses, these categories were further collapsed into 7 categories for LIT and 6 categories for MIT and HIT, ensuring that each category constituted ≥10% of responses.

Only participants with complete survey responses were included in the present analyses (*n* = 10,371); from which 6,666 (64.3%) were excluded for the following reasons: reporting never having had a period (primary amenorrhea); currently pregnant / breastfeeding / started going through menopause / menopausal in the last year; diagnosed with polycystic ovary syndrome / endometriosis / premature ovarian failure / excess prolactin production / endometrial polyps or fibroids / adenomyosis / pelvic inflammatory disorder / cancers affecting the uterus or cervix; currently using hormonal contraceptives including implants / injections / hormonal intrauterine devices / vaginal rings / oral contraceptive pills / oestrogen patches / hormonal replacement therapies; or had a hysterectomy. Additionally, those identified as extreme outliers (3*interquartile range [IQR]) for body mass index (BMI) or age were removed along with those who reported having ≥ 17 menstrual cycles in the last year (polymenorrhea). A total of 3,705 (35.7%) women were included in final analyses.

Chi-square tests were used to evaluate associations between AO risk and categorical variables (country, sport). Group differences between AO *vs.* eumenorrheic participants for age and BMI were tested using Mann Whitney U-tests as continuous variables were non-normally distributed. Logistic regressions were used to evaluate associations between weekly LIT, MIT, and HIT exercise volume and AO risk in univariate models, followed by adjustment for age and BMI. Given slight differences in operationalization of LIT, MIT and HIT volume categories, the categories with the most frequent responses for LIT (2 to 3 h; 20.8% [772/ 3,705] of responses), MIT (2 to 3 h; 22.5% [835/ 3,705] of responses), and HIT (1 to 2 h; 22.9%

[850/ 3,705] of responses) were selected as reference categories. Statistical significance was set at *a priori* $p < 0.05$. All statistical comparisons were made using SPSS (v.27.0) software.

Results

Sample demographic information for the included sample (n = 3,705) along with prevalence for AO (n = 576; 16%) or eumenorrhea (n = 3,129; 84%) based on age, BMI, country, and sport are provided in Table 1. AO women were younger and had a lower BMI compared to the eumenorrheic group. AO was not associated with country of origin or most sport modes reported. Notably, women who participated in dance class/dance-based fitness classes were more likely to have AO than women who did not participate in dance despite similar BMI (p = 0.16) and age (p = 0.21).

Table 1. Descriptive information for the sample meeting inclusion criteria (n = 3,705) and for women classified as AO vs. eumenorrheic

	Total Sample n = 3,705	**AO** n = 576 (16%)	**Eumenorrheic** n = 3,129 (84%)	**p-value**
Age (years), median (Q1 - Q3)	40 (30 - 45)	35 (25 - 35)	40 (30 - 45)	<0.01*
BMI (kg/m^2), median (Q1 - Q3)	22.1 (20.5 – 24.2)	21.4 (20.0 – 23.5)	22.2 (20.6 – 24.4)	<0.01*
Country n (%)				0.70
Brazil	384 (10)	50 (13)	334 (87)	
France	652 (18)	97 (15)	555 (85)	
Germany	489 (13)	79 (16)	410 (84)	
Spain	540 (15)	91 (17)	449 (83)	
UK	761 (21)	119 (16)	642 (84)	
USA	879 (24)	140 (16)	739 (84)	
Sport n (%)				
Running	2860 (77)	447 (16)	2413 (84)	0.80
Cycling	1571 (42)	244 (16)	1327 (84)	0.98
Weight Training	1265 (34)	213 (17)	1052 (83)	0.12
Gym Based Classes	1009 (27)	159 (16)	850 (84)	0.83
Other Prolonged Exercise	684 (19)	110 (16)	574 (84)	0.67
Swimming	638 (17)	113 (18)	525 (82)	0.10
Cross Trainer	424 (11)	79 (18)	345 (81)	0.06
Dance Class	206 (6)	45 (22)	161 (78)	0.01*
Team Sports	156 (4)	29 (19)	127 (81)	0.28
Racquet Sports	96 (3)	13 (14)	83 (86)	0.58
Martial Arts	52 (1)	6 (12)	46 (88)	0.42

AO = amenorrhoeic / oligomenorrheic. BMI = body mass index. UK = United Kingdom / Ireland. USA = United States of America. Q1= quartile 1. Q3= quartile 3. *p < 0.05 between AO and eumenorrheic groups.

Table 2 displays unadjusted and adjusted odds ratios with 95% confidence intervals for AO risk based on weekly LIT, MIT, and HIT exercise volume categories. Compared to 2 to 3 h/week of LIT or MIT, participating in ≥ 7 h/week of LIT or ≥ 6 h/week of MIT increased odds of AO by ~43% and ~46% respectively. Similarly, participating in ≥ 5 h/week of HIT compared to 1 to 2 h/week increased AO odds by ~41%. AO odds were reduced for those participating in ≤ 30 min/week compared to 2 to 3 h/week of LIT.

Table 2. OR with 95% CI for AO dependent on self-reported volume of exercise training intensity

	n (%)	**Unadjusted OR (95% CI)**	**p-value**	**Adjusted OR (95% CI)**	**p-value**
LIT					
≤ 30 min	416 (11)	0.64 (0.44 - 0.92)	0.02*	0.65 (0.44 – 0.94)	0.02*
30 min to 1 h	410 (11)	1.12 (0.81 - 1.56)	0.48	1.14 (0.82 – 1.58)	0.45
1 to 2 h	672 (18)	1.06 (0.80 – 1.41)	0.69	1.05 (0.79 – 1.41)	0.72
2 to 3 h	772 (21)	**Ref.**		**Ref.**	
3 to 4 h	450 (12)	1.20 (0.88 - 1.65)	0.25	1.20 (0.87 – 1.64)	0.27
4 to 7 h	605 (16)	0.92 (0.68 – 1.25)	0.61	0.91 (0.67 – 1.24)	0.55
≥ 7 h	380 (10)	1.51 (1.10 – 2.07)	0.01*	1.43 (1.04 – 1.96)	0.03*
MIT					
≤ 1 h	431 (12)	1.09 (0.79 – 1.51)	0.61	1.13 (0.81 – 1.58)	0.47
1 to 2 h	630 (17)	0.87 (0.64 – 1.18)	0.36	0.85 (0.63 – 1.16)	0.32
2 to 3 h	835 (23)	**Ref.**		**Ref.**	
3 to 4 h	613 (17)	1.23 (0.92 – 1.64)	0.17	1.20 (0.90 – 1.61)	0.21
4 to 6 h	615 (17)	1.24 (0.93 – 1.65)	0.15	1.17 (0.88 – 1.57)	0.28
≥ 6 h	581 (16)	1.45 (1.09 – 1.93)	0.01*	1.46 (1.10 – 1.95)	0.01*
HIT					

≤ 30 min	405 (11)	1.16 (0.84 – 1.61)	0.37	1.26 (0.91 – 1.78)	0.17
30 min to 1 h	706 (19)	0.82 (0.61 – 1.10)	0.18	0.84 (0.62 – 1.13)	0.24
1 to 2 h	850 (23)	**Ref.**		**Ref.**	
2 to 3 h	707 (19)	1.11 (0.84 – 1.47)	0.46	1.08 (0.81 – 1.43)	0.59
3 to 5 h	609 (16)	1.30 (0.98 – 1.73)	0.07	1.28 (0.96 – 1.70)	0.10
≥ 5 h	428 (12)	1.44 (1.06 – 1.95)	0.02*	1.41 (1.03 – 1.92)	0.03*

OR = odds ratio unadjusted and adjusted for age and BMI. Ref. = reference category. LIT = low intensity training. MIT = moderate intensity training. HIT = high intensity training. *p < 0.05 between AO and eumenorrheic groups.

Discussion

In our analyses of 3,705 women representing multiple nationalities and sports, 16% (n = 574) reported AO, i.e., infrequent (≤ 10 menstrual cycles) or no menses in the last year. Weekly exercise volume when performed above a certain threshold was associated with increased AO risk, regardless of intensity. For example, AO was 1.43 (1.04 - 1.96) and 1.46 (1.10 - 1.95) times more likely among women participating in weekly LIT exercise volumes ≥ 7 h/wk or weekly MIT exercise volumes ≥ 6 h/wk compared to 2 to 3 h/wk, respectively. A similar strength of association was observed for weekly HIT exercise volumes, wherein participating in ≥ 5 h/wk was associated with 1.41 (1.03 - 1.92) times greater odds of AO compared to 1 to 2 h/wk. Taken together, these associations suggest weekly exercise volume above a certain threshold, irrespective of intensity, may increase AO risk among habitually active women.

A comprehensive understanding of factors contributing to the disproportionately higher AO prevalence among habitually exercising women remains elusive; however, intensified exercise training has been theorized to increase AO risk.[4, 15, 16] Initial work responding to the influx of women competing in endurance events such as the marathon during the 1980's ascribed higher exercise training volumes and/or intensity to the greater prevalence of AO observed within certain sports. For example, positive correlations were reported between frequency of amenorrhea and weekly mileage in runners, [11, 12] but possible differences in training intensity between runners completing fewer vs. more miles per week was not considered. It is plausible, for example, that those running more miles per week would have been training at a more competitive level and therefore would have been performing more weekly sessions at a higher relative intensity. Russell et al. (1984) also observed (unspecified) reductions in training volume triggered a resumption of normal menses among oligomenorrheic club-level swimmers practicing 25 hours/week – although again whether training intensity was maintained during these reductions was not specified.[17] While the conclusions of these earlier studies generally support periods of intensive physical training contribute to greater incidence of AO in physically active women, they do little to clarify whether the likelihood of developing AO is modified by certain specific training characteristics: exercise volume *or* exercise intensity.

One of our primary findings is the association between exercise volume and increased odds of AO, irrespective of exercise intensity. We found AO odds were elevated to a similar extent for women reporting LIT, MIT, and HIT volumes comprising the top 10-16% of responses. It is plausible that women who report relatively high weekly exercise volumes may be at an increased likelihood for low energy availability due to greater gross energy expenditure with longer duration exercise training sessions. Greater weekly exercise volumes might also be indicative of a higher frequency of training sessions performed per week, which due to the anorexigenic effect of acute exercise that lasts for several hours after exercise, could result in an inadequate intake of calories to match energy expenditure between subsequent training sessions [18]. Previous work has shown that the risk of low energy availability increases for every hour of exercise per week, but is not dependent on intensity of exercise sessions among recreational exercisers.[19] As such, increased odds of AO observed with greater weekly exercise volumes may be due to an increased susceptibility to low energy availability rather than the stress of exercise, independently. Findings from Loucks et al. (1998) provide support for this theory, demonstrating 4 days of exercise energy expenditure equivalent to 30 Kcal/ kg lean body mass/ day had no disruptive effect on luteinizing hormone pulsatility when energy intake was matched.[20] However, additional controlled exercise training interventions held over durations longer than several days are needed to determine whether *habitually* elevated exercise volume may increase the likelihood of developing AO independent of energy availability.

Interestingly, reporting LIT volumes ≤ 30 min/week was associated with reduced AO odds compared to 2 to 3 h/week while similar associations were not observed for MIT or HIT. Greater volumes of LIT may reflect exercise sessions that are non-specific to competitive training objectives, such as adding in "junk miles" or cross-training sessions for the purpose of increasing caloric expenditure rather than improving fitness or a specific sports skill. In support of this theory, Tomten et al. (1996) found long-distance runners with regular and irregular menstrual cycles to practice similar amounts of HIT (sessions >85% maximum heart rate), while women with irregular cycles engaged in more LIT (sessions <85% maximum heart rate).[21] Ravi et al. (2021) also observed higher daily step counts despite similar reported sport-specific volumes among AO versus eumenorrheic Finnish athletes, with a difference of ~5,000 steps per day between groups.[1] As such, the reduced AO odds we observed for women reporting the lowest amounts of LIT per week may be reflective of differences in exercise session intention and susceptibility to low energy availability between those engaging in low compared to high weekly amounts of LIT.

Our finding that odds of AO were not increased to a greater extent with HIT vs. LIT or MIT contradicts previous evidence suggesting higher training intensities have a suppressive effect on ovarian sex hormone production. The stimulatory effects of *acute* high-intensity exercise on β-endorphin[22] or glucocorticoid release[23] have been cited as reasons for AO in women undergoing intensive exercise training due to interactions with the hypothalamic-pituitary-adrenal axis and suppression of luteinizing hormone.[17] However, some evidence suggests *chronic* strenuous exercise training lowers basal plasma β-endorphin concentrations,[24] and blunts the rise in plasma β-endorphin and glucocorticoid release[25] experienced with acute high-intensity exercise. Such adaptions oppose the heightened endocrine response to exercise stress observed in women with AO.[26] As such, accustomed HIT *per se*, may not increase AO risk.

Furthermore, previous evidence suggests that HIT, only when combined with low energy availability, may result in AO. For example, Loucks and colleagues (1998) have demonstrated 4 days of high-intensity (70% maximal aerobic capacity) and high-volume (~3 hours/ day) disrupts luteinizing hormone pulsatility only when energy expenditure is not matched with energy intake.[20] Performing greater amounts of HIT has also been linked to improved BMI and fat free mass index in anorexia nervosa patients,[27] and it has been suggested that HIT may increase *ad libitum* caloric intake to a greater extent than LIT in the meal directly following exercise in recreationally active women.[28] These energy balancing effects might be attributed more to a psychological (i.e., self-granted "allowance" to eat more after a training session that is deemed as strenuous vs. non-strenuous) versus physiological response as there is inconsistency in the literature and a paucity of data collected in women to support the effects of exercise intensity on appetite.[27, 29]

The relatively low prevalence of AO reported in our sample compared to other accounts could be attributed to the median age of participants (40 years [Quartile 1, Quartile 3: 30, 45]) as previous work has demonstrated greater resiliency against reductions in luteinizing hormone with low energy availability attained through diet and exercise intervention in women as gynecological age advances.[30] Alternatively, it could be attributed to the wide-range of competitive levels (i.e., recreational to professional athletes) and sport types of exercisers who use the STRAVA™ exercise application. While the diversity of sport type and ability level along with the multinational representation of survey respondents is a strength of our investigation, our sample represents a group of physically active women who were users of the STRAVA™ exercise application, and therefore their exercise and diet habits likely differ from a more general population. Notably, the majority of our sample met minimum moderate to vigorous physical activity recommendations of ≥ 150-300 min/week of moderate or ≥ 75-150 min/week of vigorous aerobic activity or an equivalent combination of moderate and vigorous activity (n = 3168; 86%).

We acknowledge there are at least several limitations to our analyses which limit the generalizability of findings to populations of premenopausal exercising women. Accordingly, we recommend conclusions of this research be confirmed by controlled, objective measures (i.e., accelerometry, blood/ saliva hormone confirmation of AO). Further, as this survey was administered cross-sectionally, additional work is needed to establish how changes in exercise volume and intensity may longitudinally influence AO risk.

- To minimize potential recall or social desirability biases, only participants with complete survey responses were included and those who were identified as extreme outliers for age and BMI were removed. Yet, consistent with any self-reported measure, we cannot exclude the possibility of recall or social desirability biases.
- It is plausible that characteristics of the included sample of women (n = 3,705) may not be representative of all premenopausal women who habitually exercise. The low response rate (3.9%) may likely indicate that women who attempted or fully completed the survey were more invested in topics addressed by this study such as their menstrual health. Additionally, responders were limited to women who had access to technology. Due to potential confounding influence on menstrual cycle regularity, women who were taking any form of hormonal contraceptive or who indicated they had a medical condition affecting their reproductive organs such as polycystic ovary syndrome or endometriosis were excluded. It is therefore possible that different relationships between exercise habits and AO risk may exist for these populations of exercising women.
- Associations between exercise volume and AO were restricted to categorical response options provided in the survey. As such, it was not possible to combine responses to report total exercise training volume (i.e., HIT + MIT + LIT) and its association with AO risk. Accordingly, we are unable to determine the exact proportion of participants engaging in exercise training volumes that would be classified in the upper extremes of normative. Notably, 72 participants (1.9%) reported HIT, MIT, and LIT exercise volumes ≥ 7 h per week (≥ 21 h total exercise volume) and 1,081 (29.2%) reported HIT, MIT, and LIT exercise volumes ≥ 2 h per week (≥ 6 h total exercise volume). However, these are likely underestimations of the actual proportion of participants meeting these total exercise volumes as other combinations of categories are possible such that, for example, a participant reporting 5 to 6 h of LIT and only 1 to 2 h of HIT to achieve ≥ 6 h total exercise volume per week is not included.

Conclusion

Our analyses of 3,705 women representing multiple nationalities and sports suggest the likelihood of AO is influenced by greater weekly exercise training volume, irrespective of intensity. AO odds were ~41 to 46% greater for women reporting weekly LIT, MIT, or HIT exercise volumes in the top 10 to 16% of responses. Collectively, these findings suggest evaluation of weekly exercise volume should be considered in strategies targeting identification and management of AO among physically active women.

Practical Implications

- Our primary findings suggest that women who participate in relatively high weekly volumes of exercise, regardless of the intensity at which exercise sessions are performed, are at increased odds of having infrequent or absent menses (i.e., periods).
- Reducing exercise volume, while maintaining intensity, may be a strategy to decrease odds of infrequent or absent menses among female exercisers.
- Practitioners should consider assessing exercise volume as a risk factor for infrequent or missed menses among physically active women.

Data Availability

Data underpinning these analyses are available from the authors upon reasonable request.

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Declarations of Interest

M.N.B., S.J.C., and J.M.B. have no competing interests to declare. G.B., C.R.P., and J.A.F., are employees or consultants for Orreco and creators of the FitrWoman™ application.

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