



Reduced Triiodothyronine (T₃) Levels are Associated With Decreased Physical Performance in Female Collegiate Rowers: A Case-Control Report

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ABSTRACT

Background: Even though women's rowing has been an Olympic sport for nearly 50 years, it is an understudied topic in female physiology. This oversight is critically important in lieu of the serious health consequences to the training athlete from conditions such as the Female Athlete Triad or Relative Energy Deficiency in Sport. As such, the current study was undertaken to examine hypothalamic-pituitary-thyroidal hormones and select other blood biomarkers (e.g. immune) in female rowers over the course of a 20-week training cycle, to determine whether changes in these parameters differed in athletes whose physical performance varied (improved vs. became worse) during the cycle.

Methods: The approach herein was to conduct a single-subject experimental design in a case-control fashion. A number of biomarkers were assessed at the beginning and end of the 20-week training cycle, as was physical performance via a 2,000-meter time trial (ergometer).

Results: The major finding was that development of a euthyroid sick syndrome-like scenario existed in the female rower who had physical performance compromise (decline) at the end of a 20-week training cycle.

Conclusion: It is hypothesised that the major hormonal outcome of this study, low triiodothyronine (T₃) levels, is a plausible major factor for inducing a maladaptive training response in the athlete with performance decline during the study.

Keywords: Athletes, women, euthyroid sick syndrome, sport, REDs, overtraining, biomarkers

1. INTRODUCTION

Rowing as a competitive sport dates back to the 1800s, with its beginning organisation occurring in England. To that end, men's rowing was added to the formal Olympic programme at the second modern Olympiad in 1900. However, it was not until 76 years later, at the Montreal Games, that women's rowing was added. It is notable that while the sport of rowing has existed for nearly two centuries, the amount of scientific research on the physiology of rowing as an exercise activity is

relatively limited compared to other sports (World Rowing, n.d.; Young, 2008). For example, a 2025 PubMed search resulted in a listing of only 1,895 papers on rowing involving high-level athletes in the last 75 years (N.B., a comparable literature search for running studies results in three times as many papers being identified). While regrettably, but perhaps unsurprisingly, of the papers identified in the search for rowing, only 47 dealt solely with or included women as part of the study sample (Young,



2008). While in the last two decades, there has been an exponential growth in exercise physiology research on the female athlete, a large knowledge gap still exists between what is known about the physiological responses to exercise of men versus women. And while there are great similarities in the physiological systems of each sex, there are substantial differences that have been highlighted by contemporary researchers working in the female physiology space (McNulty et al., 2024).

A multitude of programmatic and behavioural factors come into play to affect training adaptations and ultimately the physical performance of athletes. Maintenance of overall health is critical, as the development of conditions such as Relative Energy Deficiency in Sport (REDs), Overtraining Syndrome, or, in the case of women, the Female Athlete Triad results in maladaptation and ultimately compromised performance (Mountjoy et al., 2023). The aetiology and symptomatology of these conditions vary, but they are all associated with specific aspects of hormonal dysregulation in endocrine function, which leads to subsequent disruption of many physiological systems. Recently, one aspect of the endocrine system receiving close examination relative to physical performance is the hormones of the hypothalamic-pituitary-thyroidal (HPT) axis (Hackney et al., 2025). Substantial research supports that the hormones associated with the HPT axis are critical to a multitude of physiological systems and essential to facilitating the adaptation process within exercise training regimens (Mennitti et al., 2024). However, currently, the research on these hormones, specifically in female rowers, is scant. As such, the current study was conducted to examine HPT axis hormones and related biomarkers of immune function in female rowers during a 20-week training period prior to the athletic competitive season. The intent was to examine whether hormonal/biomarker changes during training were related to physical performance by the rowers. The research approach used here was a 'single-subject experimental design' in a case-control fashion, utilising archived data.

2. METHODS

Subjects

Collegiate female crew rowers were originally recruited for this study, who were members of a university rowing team. The participants had averaged ~3 years of rowing experience, but had engaged in other competitive sports for >5 years or more at the

club/university level (Tier 3 athletes [McKay et al., 2022]). All participants provided written informed consent and underwent a medical review and approval for participation in the study. All participants were medically screened, and none had any existing endocrinological/immunological problems at their entry into the study. Also, all were determined to be naturally menstruating based on four months of menstrual cycle tracking using basal body temperature before the study period. All aspects of the original study were conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the university.

Testing and procedures

Participants reported to the laboratory three times over 20 weeks – before the study began (baseline [BL], week 10 [10WK], and week 20 [20WK]). The 20-week period represented a preparatory phase leading to the competitive period for the athletes. Training was divided into two distinct phases: an initial period of heavy, intense training followed by a slightly more moderate training progression. These phases were determined by the coaching staff. The intense phase was from weeks 1–9, with week 5 being a regeneration–recovery week. The moderate phase was from weeks 10 to 20. Further aspects of training are reported elsewhere (Baylor & Hackney, 2003).

At each laboratory visit, the participants reported 8 h postprandial in the morning (time standardised for each participant), and having not exercised within the 12 h before arrival. Before beginning their 8-hour fast, they were required to eat sufficiently to allow them to be in energy balance during the 24 hours before reporting. Each visit occurred in the morning on approximately the same day of the week, during the follicular phase of their menstrual cycle (~4–7 days after menses ended; however, no hormonal confirmation was obtained to substantiate cycle phase).

Once at the laboratory, participants rested for 10–15 minutes in a quiet area, after which a blood sample was obtained by a certified phlebotomist using a venipuncture procedure (N.B., blood samples were only biochemically assessed at BL and 20WK, due to financial constraints). Next, the following specimens/measurements were obtained: urine specimen, body mass (medical-grade balance scale), height (large sliding anthropometer), body composition by bioelectrical impedance analysis (BIA), and a RESTQ-Sport questionnaire. The RESTQ questionnaire has been validated against

the profile of mood states questionnaire as a means of assessing mood disturbances associated with non-functional overreaching/overtraining (Simsch et al., 2002). Physical anthropometric measures were made with participants wearing only an undershirt and athletic shorts.

Performance testing

On three different occasions (BL, 10WK, and 20WK), the rowers performed an individual 2,000-meter rowing performance time trial on an ergometer to assess training efficacy. These performance tests were conducted during team practice settings under the supervision of the coaching staff. The participants arrived at the team training facility in the afternoon, well rested, having eaten earlier in the day, and hydrated. They completed a ~15-minute self-selected warm-up, then performed the time trial. Afterwards, participants cooled down and completed any other training requirements prescribed by their coaching staff.

Biomarker biochemical analysis

From whole blood samples, haematocrit and haemoglobin (*J & J Inc., USA*) were assessed, then aliquots of plasma and serum were obtained and frozen (–80°C) until later analyses. The biochemical analysis of the blood consisted of determining free (f) T₃, fT₄, TSH, leptin, cortisol, total testosterone, IL-1β, and TNF-α by standard commercial RIA (radioimmunoassay) and ELISA (enzyme-linked immunoassay) assays, which were conducted at the conclusion of the study (*DPC Inc., Linco Inc., and BioRad Inc., USA*). All necessary laboratory

procedures were conducted to ensure that the blood samples were viable. Coefficients of variation for within- and between-assays were ≤10% for all biomarkers (Hackney & Viru, 2008).

The urine specimens were analysed to determine specific gravity to assess hydration status. The specific gravity was measured using optical density scanning from a colorimetric development procedure (*Ames Labs., USA*).

Statistical analysis

As noted, this paper represents a retrospective analysis of archived data. Using this approach, we were able to select a participant who displayed a substantial performance decline at the time trial at 20WK (>5% decline compared to 10WK) (i.e. the ‘case’, denoted as PD) and match them to a participant whose performance improved (i.e. the ‘control’, denoted as PI) (Hopkins & Hewson, 2001; Linton & Gallo, 1975). Matching factors were age, weight, and training history (N.B., these two participants were selected due to the ability to match them so closely on parameters). Descriptive statistics were calculated and reported for all variables.

3. RESULTS

The physical characteristics of the PD and PI participants and performance outcomes from the 2,000-meter time trials are reported in Tables 1 and 2. At 20WK, the PD participant’s performance was 5.9% worse than at 10WK, as well as being 8.0% worse than the PI participant.

Table 1. Physical characteristics of the study participants

Characteristic	PI	PD
Age (y)	22.4	22.5
Height (m)	1.84	1.80
Weight (kg)	73.7	72.9
Body fat ¹	18.7	18.0
Total years in training ²	7.1	6.9

Note: Performance improvement = PI; performance decline = PD. ¹Body fat was estimated based on BIA measurements. ²Denotes the number of years in training post menarche.

Table 2. Performance times (min) for the 2,000-meter ergometer tests at baseline (BL), 10 weeks (10WK), and the 20 weeks (20WK) assessments

Participant	BL (min)	10WK	20WK
PI	7.76	7.64	7.48
PD	7.77	7.63	8.08

Note: Performance improvement = PI; performance decline = PD.

Based upon urine specific gravity measurements, all participants reported for blood biomarker assessments in a hydrated state. All of the BL blood biomarker values were within clinical reference

ranges for resting measurements, and no noticeable differences were observed between the PD and PI participants at BL (see Table 3) (Burtis et al., 2005).

Table 3. Blood biomarker values (clinical units) during the study period, specifically at baseline (BL)

Biomarker	Participants	
	PI	PD
TSH (μIU/ml)	3.6	4.1
fT ₄ (ng/dl)	1.38	1.41
fT ₃ (pg/ml)	1.81	1.90
Testosterone (nmol/l)	1.09	1.14
Leptin (ng/ml)	13.9	15.0
Cortisol (nmol/l)	411	433
IL-1β (pg/ml)	7.5	9.8
TNF-α (pg/ml)	18.7	19.5
Haematocrit (%)	43.7	43.6
Haemoglobin (g/dl)	14.7	13.9

Notes: f – free; T₃ – triiodothyronine; T₄ – thyroxine; TSH – thyroid-stimulating hormone; IL-1β – interleukin 1 β; TNF-α – tumour necrosis factor α.

In the PD participant, fT₃, IL-1β, and TNF-α were reduced from their respective BL values at 20WK (–31.1%, –13.2%, –22.4% [N.B., values represent percentage change from BL values]). These PD changes at 20WK differed from the corresponding 20WK measurements in the PI participant (+2.5%, +4.1%, +1.5%, respectively). Both the PD and PI participants showed relatively equal reductions in testosterone at 20WK (–11.2%, –11.9%). Furthermore, in the PD participant at 20WK, leptin and cortisol were lower and higher than at BL (–15.5%, +26.2%), as well as being different from the PI participant's corresponding 20WK values (vs. their BL; +1.5%, +7.6%).

Finally, RESTQ questionnaire responses were highly variable and not different between the participants. Although both the PD and PI participants did show increased levels of “fatigue” and “physical complaints” questionnaire constructs by 20WK from BL (these data not reported herein).

4. DISCUSSION

This study intended to examine primarily HPT hormones, as well as other select immune and hormonal biomarkers in female rowers over the course of a 20-week training cycle, to determine whether changes in these parameters differed in athletes whose physical performance varied (improved vs. declined) during the training cycle. The major findings were that the athlete whose performance became worse (declined) by the end of the 20 weeks showed reductions in fT₃, IL-1α, and TNF-α. The fact that only T₃ was affected, related to HPT hormones, suggests the development of a euthyroid sick syndrome scenario may have existed in this athlete (Hackney & Saeidi, 2019). Concurrently, the reduced immune biomarkers over the training period suggest some slight degree of immunological suppression/compromise may have also developed in

the PD athlete (N.B., although these biomarkers can be highly variable in athletes and in response to training [Hackney & Saeidi, 2019; Mennitti et al., 2024]).

The more biologically active of the thyroid hormones, T_3 , is critical in many physiological systems and has been associated with a multitude of adaptive responses to an exercise training programme (Hackney & Saeidi, 2019). As such, the reductions in this hormone within the PD participant could be a major cause of the performance reduction/stagnation. This line of rationale fits with postulated theories of exercise maladaptation proposed by several research groups (Hackney et al., 2025; Jeppesen et al., 2025; Mountjoy et al., 2023). In addition, compromised immune function (which can also be linked to low T_3 [Wenzek et al., 2022]) increases the risk for illness, which can affect trainability and the adaptation process in athletes (Nieman, 1999). It is important to note, however, that neither participant reported being ill at the final 20WK assessment.

Euthyroid sick syndrome has several aetiologies for development, including sepsis, severe trauma, surgery, myocardial infarction, malignancies, chronic organ failure, caloric inadequacy, burns, inflammatory bowel disease, or viral infections (Hackney & Saeidi, 2019). None of the major illnesses on this list existed in our athletes; however, it is highly possible that their caloric intake (and/or energy availability) was compromised. Regrettably, the necessary steps to obtain dietary monitoring were not conducted herein due to participant burden and coaching staff concerns. But body weight was obtained, and the PD participant lost substantially more body weight over the course of the training cycle than did the PI participant (−2.1 vs. −1.2 kg; BL vs. 20WK). Numerous research studies support that a negative caloric balance, and/or reduced energy availability, results in reductions in T_3 levels (see review – Di Domenico et al., 2019). The plausibility of these (caloric balance, energy availability) being a potential causative factor in the T_3 findings is supported by the changes in IL-1 β and TNF- α , which are also known to become suppressed with reductions in caloric consumption, and is also reinforced by the trend in the direction of the changes in leptin and cortisol in the PD athlete (Wenzek et al., 2022).

It is difficult to determine whether the PD participant can be categorised as displaying their biomarker responses because of developing the Overtraining Syndrome, REDs, or the Female Athlete Triad (Mountjoy et al., 2023; Stellingwerff et al., 2021). Each of these conditions has some overlapping aetiological components, and the panel of

biomarkers assessed was not complete enough to allow such a differentiation, regrettably.

It is important to acknowledge that there are numerous limitations to the current study. First, the approach used here was a ‘single-subject experimental design’ in a case-control fashion, which has low statistical power and generalisability. Secondly, the lack of dietary monitoring presents a major absence of data that would have been critical to fully understanding a potential causative factor in the differences in performance of the participants. Nevertheless, the parameters assessed and the procedures utilised in this study were highly standardised and controlled throughout the 20 weeks to ensure their ecological validity. Furthermore, though the study has limitations, it is felt that the results provide some new and insightful information in an understudied population of athletes – female rowers.

5. CONCLUSIONS

In conclusion, the findings indicate that a euthyroid sick syndrome-like scenario potentially existed in the female rower who had physical performance compromise at the end of a 20-week training cycle. It is hypothesised that the major hormonal outcome of this syndrome, low T_3 , is a plausible major factor for inducing a maladaptive training response in the athletes studied. Future research is necessary to assess the validity of this hypothesis and further expand the knowledge base of the hormonal responses to exercise training in women.

Author Contributions: All aspects of this paper were developed by A.C.H.

Funding: There was no funding in support of this work.

Informed Consent Statement: Informed consent was obtained from all subjects in this study.

Ethical Approval: This study was approved by the Institutional Review Boards of the Department of Exercise & Sport Science and the University of North Carolina in accordance with the Declaration of Helsinki (#2001-Spring Academic Term).

Acknowledgement: The author thanks the athletes for their involvement.

Conflict of Interest: The author declares no conflict of interest.

Data Availability Statement: The data are not publicly available due to privacy and ethical restrictions.

AI Use Statement: No generative AI and AI-assisted technologies were used in the research or the drafting of the manuscript.

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Received on June 2, 2026
Accepted on June 17, 2026