

Cognition on a Caloric Cliff: Analyzing the Impact of Self-Reported RED-S Risk Factors on Female Adolescent Athlete's Cognition

Lila Fenimore

lfenimore1@verizon.net

ABSTRACT

Women are more susceptible to developing Alzheimer's disease. Specifically, women are two to three times more likely to develop Alzheimer's compared to their counterparts (Aggarwal, 2023). Estrogen levels in the female body have been studied by previous researchers to attempt to address the disparity. Their findings suggest that estrogen acts as a protective barrier from neurological decline for peri-menopausal women and may lead to a different chance for developing Alzheimer's disease (McCellan, 2025). If the depletion of estrogen has a monumental impact on cognition in adulthood, the neurological role of estrogen in adolescence must also be examined. A biological driver of estrogen suppression in adolescence is hormonal imbalance. While the causes of a disruption of hormonal levels in young females may vary, a common incidence is inadequate nutrition. Many active female youth develop Relative Energy Deficiency in Sport (RED-S) - a condition that develops due to a caloric imbalance in the body (Mountjoy et al., 2014) - which in some cases, may lead to a decrease in estrogen levels throughout a woman's reproductive system (Gibson, 2025). This may mirror a similar sense of estrogen depletion that occurs in post-menopausal women, calling to question a similar relationship between cognitive decline and estrogen in adolescent females. This study aims to fill the gap in previous literature by examining RED-S lead and cognitive decline in female adolescent athletes. This inquiry led the researcher to arrive at their ultimate research question, "to what extent are self-reported RED-S risk factors associated with cognitive performance in adolescent female athletes?"

INTRODUCTION

Cognition is a keystone function of the human brain, relied on by humans for daily tasks. It is the functioning of the brain in all aspects. Cognition can be affected by different factors which can alter the efficacy of the brain's performance. Most notably, Alzheimer's disease is a condition that can affect cognition and lead to the degeneration of brain tissue. It is essential to investigate the causes behind Alzheimer's disease and other forms of cognitive decline as they can lead to a decreased quality of performance in simple tasks and alter an individual's lifespan. It is notable in existing Alzheimer's

Sep 2026

Vol 11. No 3.

research that women are more susceptible to develop Alzheimer's disease. Specifically, women are two to three times more likely to develop Alzheimer's disease compared to their male counterparts (Aggarwal, 2023).

Previous researchers have attempted to understand the disparity of Alzheimer's diagnoses between sexes by analyzing the protective nature of estrogen on the female body, or more specifically, the degenerative effects of estrogen depletion on women's brains. Estrogen levels in the female body diminish during menopause and its effects have been studied by previous researchers. Their findings suggest that estrogen acts as a protective barrier from neurological decline for peri-menopausal (pre-menopausal) women and depending on the levels in a female's brain, they may be at a different level of risk for developing Alzheimer's disease (McCellan, 2025). If the depletion of estrogen has a monumental impact on cognition in adulthood, the neurological role of estrogen suppression in adolescence must also be examined in order to protect younger generations. In doing so, preemptive measures could be taken to prevent the development of Alzheimer's disease in women during their late adulthood, starting as early on as adolescence.

A biological driver of estrogen suppression in adolescence is hormonal imbalance. While the causes of a disruption of hormonal levels in young females may vary, an arguably common incidence is inadequate nutrition. Young women often feel an overwhelming sense of pressure to conform to societal expectations and develop improper nutritional care to achieve a thinner aesthetic. In many active female youth, this leads to them to develop Relative Energy Deficiency in Sport (RED-S). RED-S is a condition that develops due to a caloric imbalance in the body of an athlete (Mountjoy et al., 2014). Whether it be from an unintentional or intentional caloric deficit, the disproportion between caloric expenditure and intake leads to an injurious impact on the overall health of the affected athlete.

The three major indicators of RED-S have been assigned the title of the Female Athlete Triad by previous studies, denoting low bone density, the lessening of bone mass; hypothalamic amenorrhea, the absence of a menstrual cycle for three or more months consecutively; and low energy availability (LEA) in the body – having less than 30 kcal/kg of fat free mass per day, as the most impactful symptoms of RED-S. Notably, hypothalamic amenorrhea leads to a decrease in estrogen levels throughout a woman's reproductive system (Gibson, 2025). This mirrors a similar sense of estrogen depletion that occurs in post-menopausal women, calling to question a similar relationship between cognitive decline and estrogen in adolescent females.

However, previous studies have not recognized the risk of estrogen depletion from RED-S on adolescent female athletes' cognitive abilities. Many other researchers tend to emphasize the physiological impacts of the Female Athlete Triad and neglect the proposed risk to the neurological function of a young woman. This gap in existing literature is a noteworthy oversight considering the impact of estrogen levels on Alzheimer's risk in older women.

This study aims to fill the gap in previous literature by examining if the risk factors of RED-S lead to cognitive decline in female adolescent athletes. This inquiry led the researcher to arrive at their ultimate research question, "to what extent are self-reported RED-S risk factors associated with cognitive

performance in adolescent female athletes?” Contingent on the protective nature of estrogen on older female’s cognition, the researcher hypothesizes that self-reported RED-S risk factors lead to cognitive decline in young female athletes.

LITERATURE REVIEW

5.7 million Americans live with Alzheimer’s disease, and a disproportionate majority are women (Aggarwal, 2023). The imbalance in Alzheimer’s disease diagnoses between differing sexes has sparked curiosity in neurocognitive fields of research, in which researchers aim to discover the driving factors behind the obscurity. A relationship has been discovered between estrogen levels and the rate of cognitive decline in post-menopausal women. Estrogen exposure during menopause is associated with a 26% decreased risk of dementia post-menopause, while delayed hormone therapy may lead to an increased risk for degeneration (Tokar, 2011). In this exploration of estrogen’s effects on the female brain, Tokar unveiled the importance of timing with estrogen therapy in women. Similarly, Anna McCellan, a researcher investigating the role of sex hormones on cognition, relates earlier menopause to an increased risk for Alzheimer’s disease. McCellan identifies that an earlier suppression of estrogen is associated with worsened cognitive health (McCellan, 2025). This not only establishes a connection between estrogen levels and cognitive function, suggesting that estrogen deficiency leads to cognitive inefficiency with the development of Alzheimer’s disease, but also highlights time as a considerable variable in women’s cognition. Notably, an occurrence of earlier estrogen suppression in women is adolescence.

Hypothalamic Amenorrhea and Estrogen Depletion

Adolescence is a critical time of development for the human brain. While existing studies surrounding female cognition focus on long-term effectors in adulthood, very few consider short term cognitive performance in adolescent development. A limited number of studies consider the link between RED-S and effects to adolescent cognition. Margo Mountjoy, a renowned sports medicine clinician scientist, collaborates with a team of researchers to explicate the long-term physiological risks of RED-S, emphasizing a risk for cardiovascular, metabolic, endocrine and neurological health (Mountjoy et al., 2014). However, the study does not focus on cognition or explicitly analyze the effects of estrogen depletion from RED-S on the cognition of female athletes. In an attempt to interpret the influence of RED-S on the physiological health of female athletes, researchers have discovered that in RED-S athletes experiencing hypothalamic amenorrhea (HA), the hypothalamus fails to release gonadotropin-releasing hormones, which curbs estrogen secretion throughout the endocrine system (Gibson, 2025). Estrogen is relied on by the female body for wide-encompassing biological functions, and without adequate levels of the hormone, female body systems begin to fail. Cognition could be similarly affected. Estrogen suppression from hypothalamic amenorrhea during the critical development period of adolescence could possibly lead to similar risks observed in women experiencing menopause and Alzheimer’s exposure. However, existing research focuses on the effects of HA on bone and menstrual health rather than cognition, suggesting a significant gap in published literature.

THE GAP

Most studies in this field focus on physical outcomes of RED-S, leaving a critical gap in understanding how self-reported RED-S risk factors may influence cognition during adolescence. Additionally, estrogen suppression's risk on adolescent cognition has been neglected, despite Alzheimer's research evidencing a connection between cognition and estrogen. It is repeatedly acknowledged that RED-S leads to hormonal suppression, particularly of estrogen, through amenorrhea and hypothalamic dysfunction. Researchers acknowledge that estrogen plays a protective role in neurological health, by sharing that reduced exposure has been associated with cognitive decline and increased dementia risk later in life. However, despite strong evidence linking estrogen to brain function, there is a lack of research directly examining how RED-S-related hormonal disruption and physiological stress affects cognitive performance in adolescent female athletes. This highlights the gap in research that fails to consider the effect on cognitive performance associated with self-reported RED-S risk factors in adolescent female athletes. Understanding this relationship could inform early intervention strategies, improve diagnostic tools, and broaden the clinical perspective on RED-S beyond physical health. By addressing this underexplored portion of nutrition, hormones, and cognition, future research may contribute to both athlete well-being and long-term neurological health.

METHODOLOGY

Mixed Methods Approach

The researcher took a mixed method approach, utilizing both quantitative and qualitative methods of study. Quantitatively, the researcher elected to employ a survey as it would contribute to a controlled data collection – allowing the researcher to distribute a uniform questionnaire to each participant – something an interview could not accomplish. Additionally, in obtaining private medical information, the researcher could maintain complete anonymity, which also could not remain if the researcher elected to conduct interviews with each participant. Anonymity was essential for the project to remain ethical, as the information the researcher collected was particularly vulnerable to share due to the sensitive nature of the survey. The researcher modeled their assessment of each participant based on the Low Energy Availability in Females Questionnaire previously used by the International Olympic Committee (Meyer, 2025). Both a Low Energy Availability Questionnaire in Females (LEAF-Q) and two digital cognition evaluations were employed to measure cognitive abilities. The cognition tests incorporated a reaction time assessment that measured the cognitive processing speed of participants, which is crucial for athletic performance during competitions (Manci et al., 2025). In addition, a digit span test was administered which measured the working memory of each participant, a component of an athlete's cognition. All three aspects of the distributed survey mentioned above were measured quantitatively through a point allocation system. A survey was applied as a part of the methodology in order to address the researcher's hypotheses surrounding the assumed impact of risk factors for Relative Energy Deficiency in Sport (RED-S) on each participant. The results of the survey allowed the researcher to scale the extent of RED-S risk and was critical in identifying cognitive disparities between individuals with RED-S compared to those without

RED-S. The two scales of cognitive functionality were further cross-analyzed in a data analysis with the results of the LEAF-Q as a part of the methodology. This was done in order to allow a possible relationship to be discovered. Qualitatively, the researcher produced a section of the survey to analyze the quality of life of each participant and to garner additional information that would provide insight if the participant was at risk for RED-S. For example, the quality-of-life assessment (QLA) prompted each participant to share their: birth control use, prior eating disorder diagnoses, age, grade, primary sport and hours of training dedicated each week. The QLA allowed the researcher to grasp a greater understanding of each participant's possible risk for energy deficiency as different variables could affect menstruation length, a critical component of the point allocation system in the LEAF-Q. Without knowing additional medical details, a participant could have been mislabeled as at risk for energy deficiency, which could have significantly altered the researcher's findings and conclusions.

Alignment to Research

The researcher elected to include the online cognition tests in their survey rather than choosing to work with a focus group in order to maximize the participation in the study. Using a focus group would have led to an extended period to complete data collection; however, using a survey with attached online assessments provided quicker results. It is important to note that the researcher would have opted to measure estrogen levels in each participant to establish a causation, but the researcher did not have the adequate resources or amount of time to do so. Instead, the researcher relied on the survey. In order to attain a larger quantity of responses and accuracy in data, the survey was released to the entirety of the females in the researcher's high school through a recruitment email. Additionally, the researcher presented the project proposal to two English classes to inform them about their study to possibly gain a larger sample population. Participants were required to provide their age and biological sex when initially completing the survey. The researcher opted to allow many student types to participate, instead of focusing on only athletes in order to create diversity in the study. By testing subjects that both participate in athletics and don't participate, the researcher was able to discover the discrepancies in cognition between participants without any risk for RED-S and those at risk. If the researcher only assessed athletes, there could have been potential for the study to culminate with an outcome of all individuals experiencing RED-S risk factors, which would diminish the ability to find a correlation between RED-S and cognition as there would be no null value for RED-S risk.

Foundational Studies

The design of the study was curated based on the LEAF- Q designed by the International Olympic Committee. The survey prompts participants to share information about their athletic training levels, physical health and quality of life. This questionnaire accurately scales the potential for Low Energy Availability (LEA), a common risk factor for RED-S. The LEAF-Q has been successfully used by the IOC to assess collegiate athletes in prior literature (Koikawa). Koikawa et al., a group of researchers that examined the effect of LEA in Division 1 distance runners, utilized the LEAF- Q. The researchers used a scale of 0 through 49, modeled off of 25 questions. Those with a score of 8 or higher were at risk for LEA. The researcher in this paper used a similar model which is expanded upon in further discussion. The researcher modeled their survey in a similar fashion as Koikawa et al., but it is not completely

indistinguishable. Instead of 25 questions, in this study there were 19. The IOC's scoring was still utilized, nonetheless. The researcher eliminated questions that were repetitive or not relevant to their study. The simplification of the survey allowed for an easier distribution of the survey and was not significant to the conclusions of the study.

Cognition Tests

After a completion of a quality-of-life assessment, the survey provided a link to a digit-span test. Nine digits appear on the screen independently, and when the test culminates, the participant is prompted to type the nine digits they saw appear on their screens. The results of the digit-span test are on a scale of zero to one. If the participant entered all of the numbers correctly, they received a score of one. If the numbers were entered incorrectly, their score would have amounted to zero. This remained the scale for all participants. Next, the survey provided a link to a reaction-time test. Participants raced to click their mousepads as the traffic light on their screens changed from a red light to a green light. This provided a stimulus to scale each participant's reaction time. The data was based on the time it took for the participant to react over a course of five assessments. The average reaction time for female adolescents from the ages 14 through 17 is 0.47 seconds (Statistics Canada, 2007). If this value exceeds 0.47, the individual will be identified at risk for poor cognition in terms of reaction time.

LEAF-Q Questionnaire

Finally, the survey provided a series of questions to assess the RED-S risk in the participants. The questionnaire covered topics of amenorrhea, weight loss, fatigue and low bone density, which are all indicators of RED-S. The participant was always given the option to respond "prefer not to say" to avoid any inaccuracies in data, but to also address ethical concerns of vulnerability throughout the study. The results of the LEAF-Q were analyzed as a reflection of the LEAF-Q scale generated by USA Climbing (Melin, 2024). The scale ranges from a point total of zero to forty-nine. If the participant scored a seven or below, they were not considered at risk for LEA. If a participant scored an eight or higher, they were evaluated and identified as at risk for LEA, which consequently put them at risk for RED-S. The researcher inferred throughout the process that participants with a higher LEAF-Q score had lower estrogen levels, based on the previous research that established the hormonal suppression of estrogen can be caused by hypothalamic dysfunction - a symptom of RED-S. Below, is an example of a question from the LEAF-Q. To the left are the possible answer selections of the participant, and the right are the points that would be allotted to their ultimate LEAF-Q score. The same layout continued throughout the LEAF-Q.

Hypothetical LEAF-Q Calculation:

Time Since Menstruation	Points Allocated to Participant
1-2 Months Ago	0
3-4 Months Ago	1

5-6 Months Ago	2
6+ Months Ago	3

Ethical Concerns

Additionally, the last question of the survey addressed potential ethical concerns by prompting participants to enter a unique participant identification number in order to maintain anonymity in the study. The participant ID number was then emailed to the social worker at the researcher's school by each participant. The social worker was also available to any participant who felt uncomfortable throughout any point of the survey. The social worker stored the numbers in a locked Microsoft Excel tab in order to ensure that any participants determined to be considered at risk for LEA and RED-S could be sent the support to reach out to a medical team to be physically assessed. The researcher did not have access to the names of the participants, still, ensuring privacy. In addition, the researcher provided each participant with a mandatory parental consent form that was required to be completed before the participant was distributed the survey link. The parental consent required participants to be from the ages of 14 to 17 and producing estrogen in order to participate in this study. The entirety of the research design and content was determined by the Institutional Review Board (IRB) at the researcher's school to be ethical and proposed a minimal risk to participants.

Analysis of Findings

The researcher opted to perform a T-Test – an inferential statistical analysis that measures the difference between the means of two variables – to analyze the data collected from their study through an online program named Data Classroom. In this study, the T-Test was conducted twice. In the first instance, the researcher analyzed the difference in means between LEAF-Q score and digit span score. Subsequently, the researcher then compared the means between LEAF-Q score and the average reaction times. The researcher examined major trends and themes and compared their original hypotheses to their findings through the production of a T-score and a P-value through their statistical analysis. The T-value represented the difference between the means, and the P-value represented the statistical significance of the data collected. In a T-Test, the greater the T-value is, the stronger relationship between two variables. A P-value less than 0.05 meant the researcher could reject their null hypothesis and that their findings were statistically significant.

RESULTS

Participants

The researcher distributed the survey to over 50 female students in their school, however due to vulnerability concerns, only a small portion completed the study. A total of 21 adolescent females participated in the LEAF-Q, digit span assessment, and reaction time assessment, ranging from athletes to non-athletes. Although the original study design intended for both athletes and non-athletes to participate

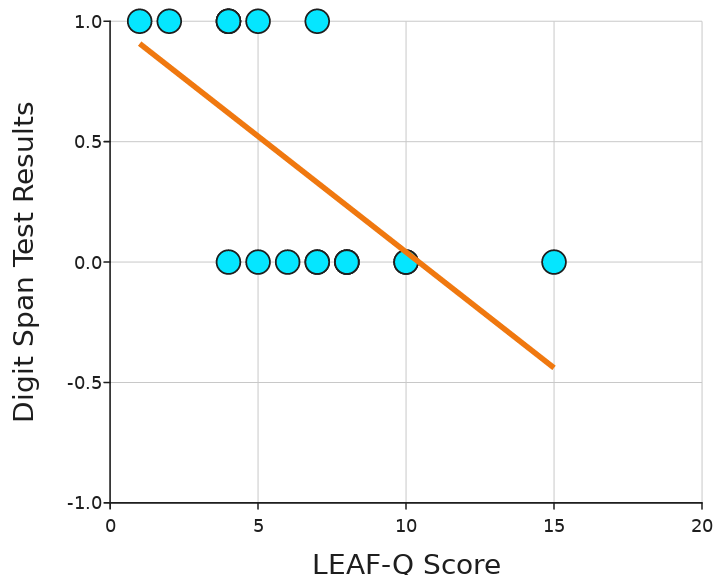
in order to compare the two populations, the final data set contained predominately athletes. The study did not contain a sufficient control group to support a comparison between the two groups. Therefore, the primary analysis in this study focused on RED-S risk factors and cognition rather than athletic participation. In addition, participants ranged from 14 to 17 years old, encompassing a diverse sample size, regardless of the actual quantity of participants. While the researcher acknowledges that a difference in age may have altered the results, the researcher elects to believe that it also tracks the consistency of the impact of RED-S on cognition throughout adolescence, which is valuable to consider. Due to this, the researcher believes their findings are still somewhat statistically significant, however encourages future researchers to gather a larger sample size, and establish specific control groups to solidify the experiment further.

Analysis of Survey Results

To scale the extent of the impact of RED-S on cognitive performance – a participant's working memory and reaction time – in female athletes, the researcher collected the three aforementioned values. 21 participants participated in each statistical analysis (n=21). The researcher calculated a numerical value for the LEAF-Q assessment - which measures risk for Low Energy Availability (LEA), an indication of RED-S - a digit span score, and reaction time. In addition, the researcher prompted the participants to provide information regarding their use of hormonal birth control as the medicine may mimic amenorrhea, leading to irregularities in menstruation, skewing the results of the LEAF-Q (Esther et.al, 2025). One participant who reported the use of birth control, scored a 15 on the LEAF-Q, a 0 on the digit span test, and had a reaction time of 0.42 milliseconds. The researcher noted that the LEAF-Q score of this participant may have been affected by the use of hormonal birth control as experiencing amenorrhea leads to a higher score. The participant's score was specifically elevated by their response to a question regarding their most recent menstrual cycle. The participant shared that their last menstrual cycle was more than six months prior to when the survey was completed. Additionally, the participant answered a question regarding the number of menstrual cycles they endured in the past year. Both responses led to an escalation of their score by eight points. Therefore, it was not clear if this participant was at risk for RED-S or the standard effects of hormonal birth control.

Digit Span Test

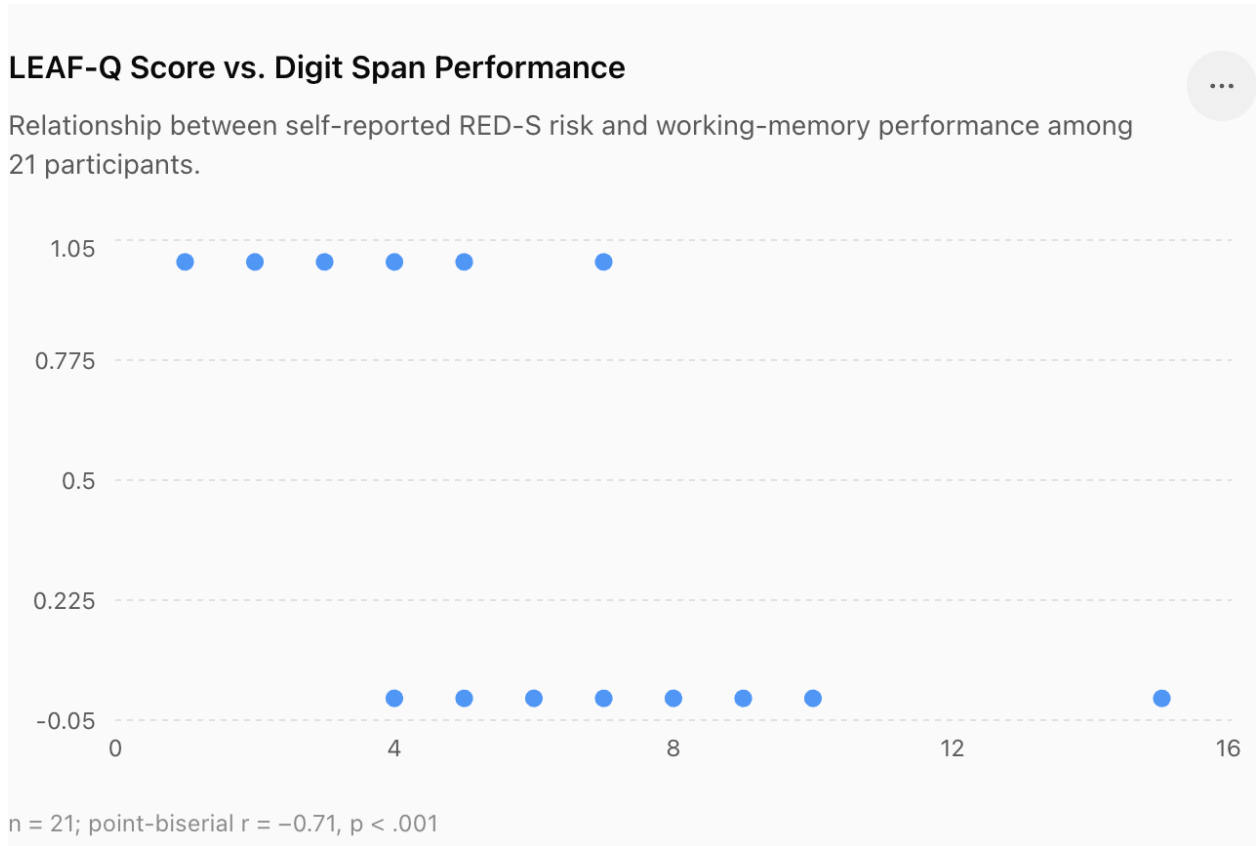
Table 1



(Data Classroom, 2026)

To assess the relationship between RED-S risk and working memory performance, the T-Test was employed between the means of the LEAF-Q scores and digit span performance. The numerical values of the digit span score were coded by the researcher as a zero for an incorrect completion of the exam, and a one for correct completion of the exam. Results revealed a strong negative correlation, with $p < 0.01$. This finding was determined to be statistically significant by the researcher. In addition to the primary analysis, the researcher performed a point-biserial correlation approach. This is appropriate as LEAF-Q scores were continuous while digit span scores were binary and coded as 0 or 1. The correlation between digit span scores and LEAF-Q scores was strongly negative with $r = -0.71$, $p < .001$, 95% CI $[-0.86, -0.39]$. Thus, the researcher can reject their null hypothesis: that there is no relationship between working memory and RED-S risk factors. Athletes with higher LEAF-Q scores scored lower on the digit span assessment, suggesting that a greater RED-S risk was associated with reduced working memory capacity.

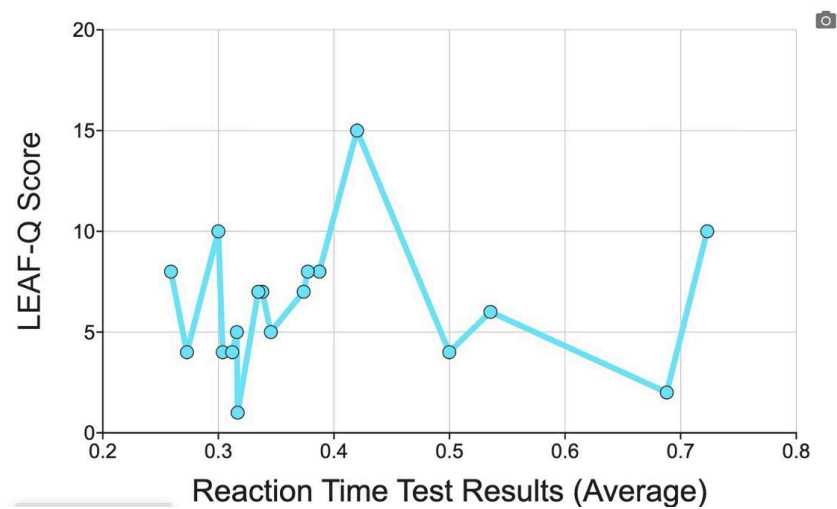
Table 2



(Data Classroom, 2026)

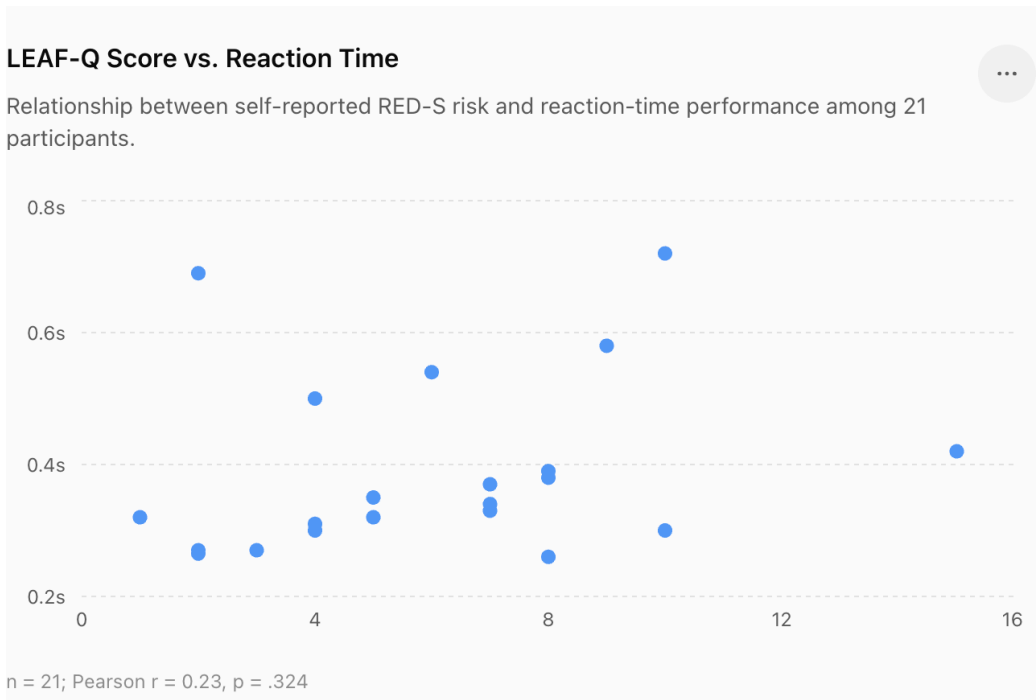
Reaction Time Assessment

Table 3



(Data Classroom, 2026)

Table 4



(Data Classroom, 2026)

Similarly, a T-Test was performed by the researcher to determine the difference in the means of RED-S risk on reaction time. No significant association between the means of LEAF-Q score and reaction time was found. The researcher discovered a weak positive correlation between LEAF-Q score and reaction time, with $r = 0.73$. The researcher additionally elected to perform a Pearson correlation test because both variables - LEAF-Q scores and reaction times - are continuous. Similarly, a weak positive association was discovered between the two variables $r = 0.23$, $p = .324$, 95% CI $[-0.22, 0.59]$. Since $p > 0.05$, this relationship was not statistically significant, indicating that higher RED-S risk scores were not significantly associated with slower reaction times in this sample. Accordingly, the researcher failed to reject their null hypothesis: there is no correlation between reaction time and RED-S risk factors.

Overall, while RED-S risk was not significantly associated with reaction time, it was significantly associated with working memory performance. The researcher's findings suggest that RED-S risk factors may possibly be more closely associated with executive cognitive functioning (working memory) than with processing speed and reaction in adolescent female athletes.

It is also important to note that the variability in reaction time may be due to the small sample size, or other environmental factors, such as distractions in participants' environment or misuse. The researcher acknowledges that due to this, a focus group may have been beneficial. Located at the end of the researcher's survey was an additional comments section, in which many participants reported difficulty in completing the cognition assessments. The researcher recognizes that directions to a greater length may have benefited in lessening the confusion of participants throughout the study. This incongruity could have led to inaccuracies in data and altered the relationship discovered between reaction time and RED-S risk. In addition, a selection of elite athletes who participated in the study may have increased ability in reaction time as it is a valued skill in most athletics to perform.

Table 5

Participant Number	Hours of Training Per Week	Use of Hormonal Birth Control	Digit Span Test Results	Reaction Time Test Results	LEAF-Q Score	Is the participant an athlete?
1	9	No	0	0.54	6	Yes
2	0	No	1	0.69	2	No

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3	2	No	0	0.72	10	Yes
4	8	No	0	0.3	10	Yes
5	8	Yes	0	0.42	15	Yes
6	9	No	0	0.34	7	Yes
7	5	No	0	0.32	5	Yes
8	5	No	0	0.26	8	Yes
9	5	No	1	0.30	4	Yes
10	9	No	0	0.33	7	Yes
11	8	No	1	0.31	4	Yes
12	5	No	0	0.50	4	Yes
13	8	No	1	0.32	1	Yes
14	5	No	1	0.37	7	Yes
15	5	No	0	0.39	8	Yes
16	9	No	1	0.35	5	Yes
17	8	No	0	0.38	8	Yes

18	9	No	1	0.27	2	Yes
19	9	No	1	0.27	3	Yes
20	2	No	1	0.265	2	Yes
21	7	No	0	0.58	9	Yes

Additional Information

Table five contains the results from all aspects of the researcher's survey. It provided the researcher a means to discover any additional factors that may have elevated a participant's LEAF-Q score. Additionally, it allowed the researcher to be able to differentiate between athletes and non-athletes in order to identify those inconsiderable for RED-S risk. However, only one respondent reported not being an athlete, so this was not significant. The researcher recommends that in future endeavors, control groups should be established to prevent the effect of these differing variables on the outcome of the study.

DISCUSSION

The findings of the researcher suggest that there is a strong link between working memory and RED-S risk. The researcher made a hypothesis based on established studies that suggested estrogen suppression can result from RED-S. It is inferred that is the case in the participants who scored above an 8 on the LEAF-Q in this study. From data set 1, all students who tested with a score of one, were not at risk for Low Energy Availability (LEA), which translates to a null risk for RED-S. These seven students scored a seven or below on the LEAF-Q scale provided by the International Olympic Committee (IOC), meaning they were not at risk. That said, the 14 participants that scored a zero were correspondingly at risk for LEA, scoring an eight or above on the IOC's scale. The T-value for this specific data set was 3.4, indicating a strong relationship between the means of LEAF-Q score and digit span scores. Additionally, the p value was less than 0.01, indicating a strong relationship as well and the researcher rejected the null hypothesis. The data collected in set one led the researcher to conclude that there is a correlation between working memory and RED-S, based on the increase in cognitive functioning, with an increase in energy levels – as seen through a decreased LEAF-Q score. This discovery from the researcher supports the notion that the suppression of estrogen from hypothalamic amenorrhea seen in females at risk for RED-S emits a similar degenerative effect on the brain as estrogen does to Alzheimer's diagnoses in adulthood.

Another possible impact of RED-S on female adolescents inquired upon by the researcher was the impact of an elevated LEAF-Q score on their reaction time. Reaction time portrays relevancy in daily life for

many adolescents, from being challenged in athletics, to the classroom. Data set two explores the impact of a participant's LEAF-Q score on their performance on the reaction time assessment. Many participants scored poorly in terms of average reaction time. The T-value of the data was 0.35, while the P-value was greater than 0.05, which leads the researcher to fail to reject their null hypothesis. The statistical analysis performed on the results of the reaction time assessment was not adequate however, because the lack of empirical data from a small sample size, led to inequities in results. It would have been beneficial for the researcher to find a larger sample size; however, the researcher struggled due to the vulnerability of the topic surrounding nutritional intake, menstrual cycles and overexertion in exercise. No relationship was found between reaction time and LEA.

Finally, table three explicates the most relevant information garnered from each participant throughout the survey process. Table three highlights if the participant was an athlete, which helped the researcher determine if their score on the LEAF-Q was due to overexertion, or possibly stemming from an environmental factor – such as birth control. Hormonal birth control can affect menstrual cycles, leading to amenorrhea, which could have altered the researcher's findings as many sections of the LEAF-Q focuses on menstrual functioning. In fact, the sole participant that was taking hormonal birth control, scored a 15 on the IOC's scale of the LEAF-Q, indicating that hormonal birth control could have affected the researcher's findings. Finally, table three states the digit span scores, reaction time scores and LEAF-Q scores of all participants which has been previously discussed above.

Through the quantitative data, the researcher was able to discover that with an increase in LEAF-Q score, there is a decrease in working memory – proven by the digit span results. However, a correlation between reaction time and LEAF-Q score was not revealed, which may be due to the limiting nature of a small sample size. LEAF-Q score represents RED-S risk and indirectly measures the risk for estrogen suppression by hypothalamic amenorrhea in females as well.

CONCLUSION

Implications

Due to a possible correlation between cognitive health and energy levels being established by the researcher, it leads to an incentivization to further develop knowledge on nutrition in female adolescents and its effects. Based on the conclusions of the researcher, it can be inferred that there is a modeled association between estrogen suppression on adolescent brains, as there is in post-menopausal females. There are multiple solutions to address this disparity, but one seems the most direct and effective solution: educate young females on their nutritional needs in order to protect their short-term cognitive abilities. A long-term impact of adolescent estrogen depletion on cognition cannot be assumed based on the researcher's findings because the variables tested by the researcher did encompass prolonged impact on cognitive abilities. Nonetheless, a short term association between estrogen suppression and cognitive decline can be presumed by assuming that estrogen suppression occurred in all participants in the study declared at risk for RED-S. It is noteworthy that this cannot be determined as a definite causation, however, because estrogen levels were not collected into a data set due to limitations to the researcher.

If female adolescent athletes are educated about their nutrition, they can effectively fuel their bodies in order to increase their energy levels. In doing so, they will simultaneously be maintaining cognitive function, in terms of working memory.

Limitations

The researcher acknowledges that limitations existed within this study. Most importantly, the sample size of this study was limited. The method of distributing the surveys was appropriate for the researcher in the context of this project, however future researchers should participate in a further widespread distribution when conducting a survey such as the one done in this study. For this researcher, it was difficult due to the vulnerability of the topic and their limited resources. The researcher was constrained to one school as Institutional Board Review was necessary to gather information from participants. The researcher acknowledges the limited ability to create an assumption based on their findings due to the sample size. A smaller sample size risks a lessened ability to generalize an association within the findings. The results of all statistical analyses should be interpreted in the context of this sample only. Future researchers would be recommended to distribute a survey similar to this through multiple grade levels and schools rather than through one school in order to create an aspect of diversity throughout their data collected. The digit span assessment primarily evaluates working memory, while the reaction-time assessment provides information related to processing speed and response performance. Therefore, performance on these two assessments should not be interpreted as a comprehensive measure of participants' overall cognitive function. If the researcher had more time, they would have garnered a larger sample size, used variable-specific focus groups, and tested other aspects of cognition. The researcher only managed to analyze working memory and processing speed - only a fraction of the brain's abilities.

Furthermore, the researcher acknowledges that an assumption was made regarding hypothalamic amenorrhea and estrogen suppression. It would have been infeasible to physically test the blood of each participant for estrogen levels as the researcher did not have the resources to do so, and this would have diminished anonymity in the study. To deny anonymity to participants would have lessened the integrity of the study, causing less participation in an already small sample size. The researcher instead chose to scale estrogen suppression by determining if the participant experienced hypothalamic amenorrhea through the LEAF-Q, which would consequently increase their RED-S risk. As previously stated, it cannot be definitively established that estrogen suppression occurs in every female that experiences hypothalamic amenorrhea, but is probable, as previous studies have supported that hypothalamic dysfunctioning disrupts hormonal levels (Gibson, 2025). However, the researcher assumed that this assumption was negligent in terms of their findings in order to produce a conclusion based on their data. It would be beneficial for future researchers with more time and resources to sample estrogen from each participant.

Future Research

Future research should be done to further the understanding of this topic. Although the researcher has uncovered a pattern in cognitive function and energy availability, there are other aspects of this research discipline that have not been thoroughly examined. The researcher failed to acknowledge the impact of

Low Energy Availability on other brain functions such as: attention, executive function, processing speed, and cognitive flexibility. The differing variables would have become too complex with the time the researcher had to complete their study, however it is encouraged to be explored. Future researchers may also elect to further inquire upon how cognitive decline in adolescence may lead to increased degeneration in adulthood. It is important to continue to develop the impact of estrogen on female cognition as it could possibly lead to generational breakthroughs in Alzheimer's research. Advancements in this field could lead to prevention for the disease years before symptoms primarily appear. The researcher in this study established RED-S as possibly harmful for cognition in adolescence, but only for the brain's functioning of working memory. Other researchers could opt to compare LEAF-Q scores to other neurological functions. Finally, the research performed by this researcher should be repeated with a larger sample size to ensure the findings are sound.

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