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Original Article

Evaluation of the effects of acute taurine supplementation on aerobic physical performance in active young adults

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Abstract
Taurine, a prevalent amino acid in the human body, plays a crucial role in energy metabolism and cardiorespiratory muscles. Recently, taurine-based energy drinks have been promoted as ergogenic aids that may enhance athletic performance. However, scientific evidence supporting these claims is limited. This study aimed to assess the impact of acute taurine supplementation on maximal oxygen consumption, ventilatory thresholds, and total time to exhaustion in active young adults. The research used an experimental design featuring a cross-sectional, crossover, randomized, and double-blind approach. For the level of physical activity and readiness to practice physical activity, the International Physical Activity Questionnaire (IPAQ) and the Physical Activity Readiness Questionnaire (PAR-Q) were used, respectively. Data were collected from 20 volunteers (11 women and 9 men) through a progressive cardiopulmonary exercise test (CPET) conducted in the Ergospiratory Laboratory of the Department of Physical Education at the Federal University of Pernambuco (DEF-UFPE). After familiarization with the test, the volunteers were randomized and performed 2 tests, with supplementation of 1g of taurine or placebo in identical capsules 1 hour before and separated by an interval of 7days (washout). The results showed no significant differences in time to exhaustion ($\Delta = 1.4\%$; $p = 0.352$), $VO_{2\ PEAK}$ ($\Delta = 6.0\%$; $p = 0.158$), and ventilatory thresholds – VT (VT1 $\Delta = 3.9\%$; $p = 0.381$ and VT2 $\Delta = 2.7\%$; $p = 0.486$) between the taurine and placebo groups. However, the group that received taurine showed a slight advantage compared to the placebo group. It is concluded that the acute ingestion of 1 g of taurine one hour before a CPET did not result in significant improvements in $VO_{2\ PEAK}$, ventilatory thresholds, or total time to exhaustion. Future studies may explore different dosages, forms of taurine ingestion, and include assessments among subjects with varying levels of physical fitness.
Keywords: Taurine; Adults; Ergogenic; Ergospirometry; Performance.

Introduction

Supplementation refers to the ingestion of substances that contain nutrientes in greater quantities compared to a daily diet, aiming to supply some deficiency or enhance some physiological process (Morgans et al., 2024). In the universe of physical activities, encompassing exercises and sports, ergogenic resources have grown worldwide as a strategy to improve physical performance, especially in active Young adults, promising better muscle efficiency, greater energy and time until fatigue arrives (Naimah et al., 2022; Saleh et al., 2023). Mosto f these ergogenic resources have several substances in their composition, one that stands out for the amount used is Taurine (López-Torres et al., 2022).

Interest in taurine began in the 1960s when studies revealed its presence in various body tissues (Agnol & Souza, 2009). Taurine is an amino acid synthesized in the pancreas, liver, and kidneys, with endogenous production often being insufficient and thus requiring supplementation through certain foods and supplements (Schaffer & Kim, 2018). Taurine is involved in essential biological processes, including calcium modulation, muscle contraction, immune regulation, and central nervous system development. Its deficiency is linked to developmental dysfunctions and cardiomyopathies (Jong, Sandal & Schaffer, 2021).

Additionally, taurine plays a crucial role in mitochondrial biogenesis, contributing to energy generation and cellular respiration. It is involved in the respiratory chain, particularly in heart cells (cardiomyocytes), where it regulates mitochondrial functions (Schaffer et al., 2016; Waldron et al., 2018). Taurine is predominantly found in type I muscle fibers, known as oxidative or "aerobic" fibers (Ward et al., 2016).

In recent years, numerous taurine-based energy drinks, along with powdered and capsule supplements, have emerged in the market. These products are widely used in the sports community and are promoted as ergogenic substances capable of enhancing physical performance. However, these claims often lack robust

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scientific backing and clear evidence of their potential effects on performance (Jeffries et al., 2020; Erdmann et al., 2021). Associated with this scenario, scientific organizations have shown concern about the overdoses that have been used of these products and the potential adverse effects (Higgins et al., 2018).

When considering health and performance markers, one of the most important physiological variables is maximal oxygen consumption ($VO_{2\ MAX}$), which represents the human body's maximum capacity to uptake, transport, and utilize oxygen (O_2) during aerobic metabolism (Soares & Mota, 2023). The $VO_{2\ MAX}$ can be evaluated through the progressive cardiopulmonary exercise test (CPET), which also provides the measurement of peak oxygen consumption ($VO_{2\ PEAK}$), varying according to the specific intensity of the physical effort performed (Pavlovic, 2016; Lundby, Montero, & Joyner, 2017).

In this context, ergospirometry is the gold standard test that measures a person's respiratory capacity during maximal or submaximal effort, typically conducted on a treadmill or stationary bike. This test directly and non-invasively assesses oxygen consumption and carbon dioxide production (Yazbek Jr et al., 1998). The most commonly used evaluation protocol is the CPET, which provides crucial information for health assessment, disease prevention and detection, sports performance evaluation, and measuring capacity or intolerance to specific types of exercise (Stavrou et al., 2018).

In ergospirometry, besides $VO_{2\ MAX}$, several other crucial physiological parameters are assessed during exercise. These include the volume of oxygen (VO_2) and carbon dioxide (VCO_2), as well as the anaerobic thresholds (AT) such as the first threshold (AT 1) at 60% of $VO_{2\ MAX}$ and the second threshold (AT 2) at 80% of $VO_{2\ MAX}$ (Massini et al., 2016). AT 1 indicates the limit of the majority use of the oxidative, aerobic system for energy production, while AT 2 occurs due to elevated metabolic acidosis caused by lactate accumulation, leading to CO_2 hyperventilation for compensation. These parameters are essential for a detailed evaluation of the physiological response during exercise, offering important insights into an individual's aerobic and anaerobic capacity (Tebexreni et al., 2009; Massini et al., 2016).

However, previous studies do not clearly establish the potential beneficial effects of acute taurine intake, especially in prolonged predominantly aerobic activities (Kurtz et al., 2021). Many studies on taurine have focused on aspects such as strength, speed, and anaerobic capacities (Warnock et al., 2017; Figueiredo et al., 2020), as well as its potential therapeutic use in metabolic, cardiac conditions, muscle damage, and the impacts of energy drink consumption on health (Schaffer & Kim, 2018; Wen et al., 2019; Gerede et al., 2022). In addition, using samples of trained people and athletes, predominantly male, making it difficult to extrapolate the results to other audiences, such as active people (Kurtz et al., 2021). This makes it impossible for taurine to be considered an effective ergogenic resource in aerobic modalities (Waldron et al., 2018).

Therefore, the present study aimed to assess the effects of acute pre-exercise taurine supplementation on ergospirometric variables, during a CPET, including $VO_{2\ PEAK}$, ventilatory thresholds, and total time to exhaustion, in active young adults. The hypothesis is that taurine is able to positively impact aerobic physical performance. Highlighting that this is one of the first studies to evaluate and compare the effects of this supplementation in women.

Material & Methods

Study Design and Sample Population

This was an experimental study with a cross-over, randomized, double-blind design (Thomas, Nelson, & Silverman, 2009), conducted at the Ergospirometry Laboratory of the Department of Physical Education at the Federal University of Pernambuco (DEF-UFPE). The study was approved by the Research Ethics Committee of UFPE (approval number 6.701.859), and all subjects signed an Informed Consent Form, declaring their voluntary participation and right to withdraw at any time.

The sample consisted of 20 volunteers (11 women and 9 men), university students from DEF-UFPE, recruited through informational posters displayed in DEF-UFPE notice boards, social media, and communication apps. To be included in the study, participants could be of any gender, over 18 years old, self-reported as apparently healthy based on the Physical Activity Readiness Questionnaire - PAR-Q (França et al., 2020), physically active according to the International Physical Activity Questionnaire - IPAQ (Matsudo et al., 2001), and not using medications such as beta-blockers, ACE inhibitors, ARBs, calcium channel blockers, and diuretics. Subjects with any discomfort, allergy, or aversion to supplementation use, or those who missed any evaluation steps, were excluded from the study.

Experimental Design

Each participant underwent three consecutive stages. Initially, 40 volunteers agreed to participate, meeting the aforementioned inclusion criteria and signing the Informed Consent Form before the baseline intervention. They were briefed on the project's objectives, as well as its risks and benefits. However, 5 participants withdrew, and 15 were excluded for missing one of the research stages, resulting in a final sample of 20 participants.

The first stage involved anthropometric assessment and study familiarization, including an incremental test and instructions for the preparation of the subsequent stages. In the second stage, after a 7-day interval,

participants were randomly assigned to receive either taurine supplementation (1g) or placebo (1g starch) one hour before the incremental test protocol using CPET (Herdy et al., 2016).

The third stage, following a wash-out period (1 week without supplementation) (Agnol & Souza, 2009; Balshaw et al., 2013) from the first intervention, involved the second intervention. In each session, participants could receive either taurine or placebo supplementation. The order of supplementation for each participant was determined by prior randomization using the website Randomizer.com.

Incremental CPET Protocol

The protocol was conducted at the Ergospirometry Laboratory of DEF-UFPE, where participants performed a 5-minute warm-up on a treadmill at 6 km/h before starting the protocol. Subsequently, they underwent progressive stages of 2 minutes each, starting at 7 km/h and increasing by 1 km/h every two minutes until voluntary exhaustion. The average of the last 30 seconds of each stage during the incremental protocol was used to obtain the corresponding ergospirometric variables for that stage, and peak values were determined as the highest values observed during the test (Herdy et al., 2016; Reis, 2019).

As a preparatory condition for the tests in the second and third stages, volunteers were instructed to avoid strenuous physical activity in the 24 hours preceding the tests and to abstain from consuming beverages or foods containing caffeine or taurine in the 12 hours before the tests, similar to the protocol proposed by Milioni et al. (2016). The dosage of taurine supplementation was determined based on the amount present in energy drinks from major brands: Redbull (1g/250ml), Monster (0.8g/200ml), and TNT (1g/250ml) (Ramada & Nacif, 2019).

The taurine supplementation process was conducted in a double-blind manner, meaning neither the evaluators nor the participants were aware if they were receiving taurine or placebo. It was also randomized, where participants were randomly assigned to receive either the supplementation or placebo. The placebo control group received a dummy medication instead of none (Colagiuri, 2010).

Data Collection Instruments

As inclusion criteria, volunteers were required to report being apparently healthy. For this purpose, the PAR-Q was used, aiming to gather relevant information about the individual's clinical status before subjecting them to physical exercise (De Oliveira Luz & Farinatti, 2005). The shortened version of the questionnaire used in this study consists of 7 questions about the participant's health history. If the participant answered "yes" to at least one of the questions, medical evaluation and clearance were required for inclusion in the study (França et al., 2020).

Another criterion for inclusion in the study was the level of physical activity, which was assessed using the IPAQ, a self-administered questionnaire developed by the World Health Organization (WHO, 1998) and adapted for the Brazilian population by Matsudo et al. (2001). In this study, the short version of the IPAQ was used, consisting of seven open-ended questions. The responses allowed estimation of time spent per week in different dimensions of physical activity (such as walking and moderate and vigorous physical activities) and physical inactivity (time spent sitting), classifying participants into four categories: sedentary, irregularly active (subdivided into A and B), active, and very active. Participants classified as Active or Very Active were included in the study.

For sample characterization, body mass (in kg) was measured using a portable scale (PL 200, Filizola S.A., São Paulo, Brazil) with a precision of 0.1 kg, while height (in cm) was recorded using a portable professional stadiometer (Sanny, São Paulo, Brazil) with a precision of 0.1 cm for all participants. Subsequently, the body mass index (BMI) was calculated by dividing body mass by the square of height for each individual (Peterson et al., 2016).

To analyze the application of the CPET, the following ergospirometric variables were measured: $VO_{2\ MAX}$, $VO_{2\ PEAK}$, VO_2 and VCO_2, VE/VO_2, VE/VCO_2, LAN 1, and LAN 2, using a gas analyzer (VO2000, Aerosport, Medgraphics, St. Paul, Minnesota). Gas samples were collected every 10 seconds during the test. This equipment is considered a gold standard for measuring these variables, validated and reliable (Anderson, 2006).The gas analyzer is compact, attached and properly installed near the treadmill (Ibramed Inbrasport Master Super ATL 32 X 26), connected to a computer via cable, and linked to the system through aerograph® software, responsible for analyzing and interpreting the results. Three cables of different colors (green, red, and white) extend from the equipment and are connected to the subject's facial mask, allowing measurement and distinction of inspired and expired gases and their volumes throughout the test. The entire operation follows the manufacturer's specifications and guidelines.

Data analysis

The data are shown as mean and standard deviation (SD). The significance level for all analyses was accepted as $p < 0.05$. The Shapiro-Wilk test was preferred because the sample sizes ($n < 50$) were low (Myers et al., 2013). An independent two-sample t-test was performed to determine whether there were significant differences between the sexes. The effect size of Cohen's d was calculated, with values > 0.8, 0.5–0.8, 0.2–0.5, and < 0.2 being considered high, moderate, small, and trivial, respectively for pairwise comparisons (Cohen, 1992). JASP Software and GraphPad Prism v.8 was used for all statistical analyses and for all graphs, respectively.

Results

The study comprised 20 volunteers, with 55% being women, and a mean age of 22 years. The sample characterization is described in Table 1.

Table 1. General characteristics of the volunteers (n=20)

	Total (n=20) Mean ± SD (Median)	**Men (n=9) Mean ± SD (Median)**	**Women (n=11) Mean ± SD (Median)**	***p***
Age (years)	22.2 ± 2.7 (21.0)	23.1 ± 3.4 (23.0)	21.4 ± 1.6 (21.0)	0.003
Body mass (kg)	64.5 ± 11.2 (62.0)	72.0 ± 10.5 (75.0)	58.3 ± 7.5 (57.0)	0.001
Height (cm)	169.0 ± 0.11 (169.0)	178.0 ± 0.06 (179.0)	161.0 ± 0.07 (160.0)	0.152
IMC (kg/m2)	22.6 ± 2.9 (22.5)	22.5 ± 2.5 (22.5)	22.6 ± 3.2 (22.1)	0.962

Table 1. General characteristics of the volunteers (n=20)

In Table 2, the mean values of $VO_{2\ PEAK}$ and ventilatory thresholds (%VO_2) between the taurine group and the placebo group are presented. No differences were found in $VO_{2\ PEAK}$ values or ventilatory thresholds between the groups.

Table 2. Comparison of mean values of $VO_{2\ PEAK}$ and ventilatory thresholds (%VO_2 LAN 1 and %VO_2 LAN 2).

	Placebo	**Taurine**		**Paired t-test**			
	Mean ± SD	**Mean ± SD**	***Δ %***	***t***	***df***	***p***	**ES**
$VO_{2\ PEAK}$ (ml.kg^{-1}.min^{-1})	30.1 ± 6.2	31.9 ± 6.9	6.0	-1.747	19	0.158	-0.33
LAN 1 (%$VO_{2\ PEAK}$)	51.1 ± 8.4	53.1 ± 10.2	3.9	-0.900	19	0.381	-0.20
LAN 2 (%$VO_{2\ PEAK}$)	79.7 ± 14.1	81.8 ± 12.4	2.7	-0.710	19	0.486	-0.16

Table 2. Comparison of mean values of $VO_{2\ PEAK}$ and ventilatory thresholds (%VO_2 LAN 1 and %VO_2 LAN 2).

When observing the same variables divided by sex and between the Taurine and Placebo groups (Figure 1), no significant differences were found in the mean $VO_{2\ PEAK}$ for the male group (t = 0.580; p = 0.570; ES = 0.29) and female group (t = 0.324; p = 0.749; ES = 0.14) with Taurine supplementation versus Placebo. Similarly, for ventilatory thresholds (%$VO_{2\ PEAK}$), LAN 1 (♂ t = -0.226; p = 0.824; ES = 0.11; ♀ t = 0.580; p = 0.570; ES = 0.26) and LAN 2 (♂ t = 0.493; p = 0.628; ES = 0.25; ♀ t = 0.169; p = 0.867; ES = 0.08).

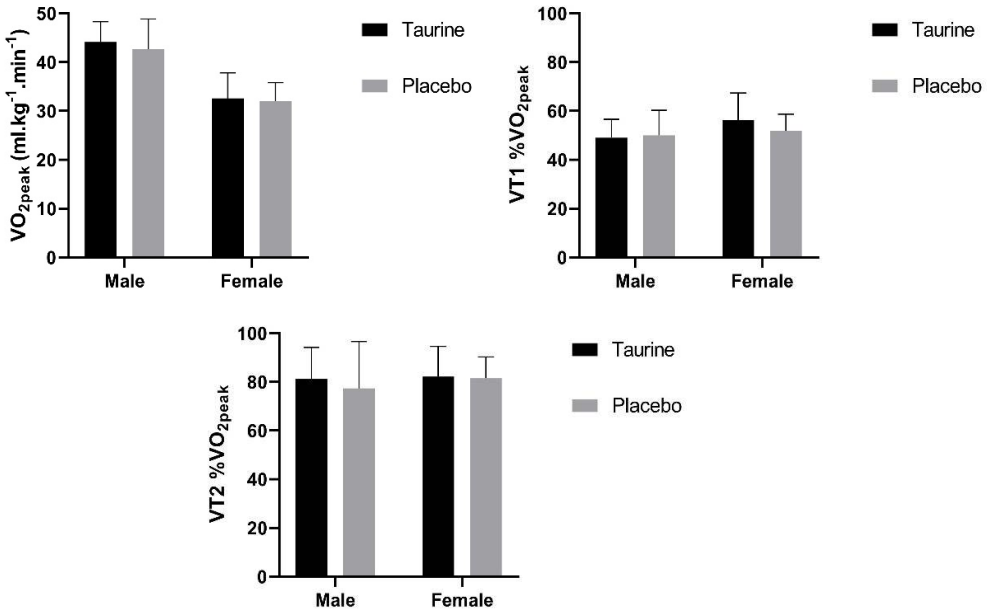

Figure 1. Comparison between mean $VO_{2\ PEAK}$ values and ventilatory thresholds (%VO_2 LAN 1 and %VO_2 LAN 2), stratified by sex and between the Taurine and Placebo groups

In Table 3, the mean time to exhaustion between the groups and the speeds at the ventilatory thresholds (%$_{MAX}$ Speed) are presented. Similar to the $VO_{2\ PEAK}$ values and the %VO_2 at the thresholds, the time to exhaustion and the speeds at the thresholds also did not show significant differences in the means between the Taurine and Placebo groups.

Table 3. Comparison between exhaustion time (s) and speeds at ventilatory thresholds (%$_{MAX}$ Speed)

	Placebo	**Taurine**	**Paired t-test**				
	Mean ± SD	**Mean ± SD**	***Δ %***	***t***	***df***	***p***	**ES**
Exhaustion Time (s)	1098.7 ± 277.2	1136.8 ± 267.5	1.4	-0.954	19	0.352	-0.21
LAN 1 (%$_{MAX}$ Speed)	62.3 ± 8.3	60.0 ± 7.5	3.7	1382	19	0.138	0.31
LAN 2 (%$_{MAX}$ Speed)	88.8 ± 4.3	88.9 ± 5.7	0.0	-0.047	19	0.936	0.01

Table 3. Comparison between exhaustion time (s) and speeds at ventilatory thresholds (%$_{MAX}$ Speed)

In Figure 2, we present the graphs of Time to Exhaustion, LAN 1, and LAN 2 as a %$_{MAX}$ Speed by sex and divided into Taurine and Placebo groups. No significant differences were found in the mean Time to Exhaustion for the male group (t = 0.580; p = 0.570; ES = 0.58) and female group (t = 0.324; p = 0.749; ES = 0.14) with Taurine supplementation versus Placebo. Similarly, no differences were found in the speeds at the ventilatory thresholds *%$_{MAX}$ Speed), LAN 1 (♂ t = -0.226; p = 0.824; ES = 0.11; ♀ t = 0.580; p = 0.570; ES = 0.26) and LAN 2 (♂ t = 0.493; p = 0.628; ES = 0.25; ♀ t = 0.169; p = 0.867; ES = 0.08).

Figure 2. Comparison between exhaustion time (s) and speeds at ventilatory thresholds (%$_{MAX}$ Speed), stratified by sex and between the Taurine and Placebo groups

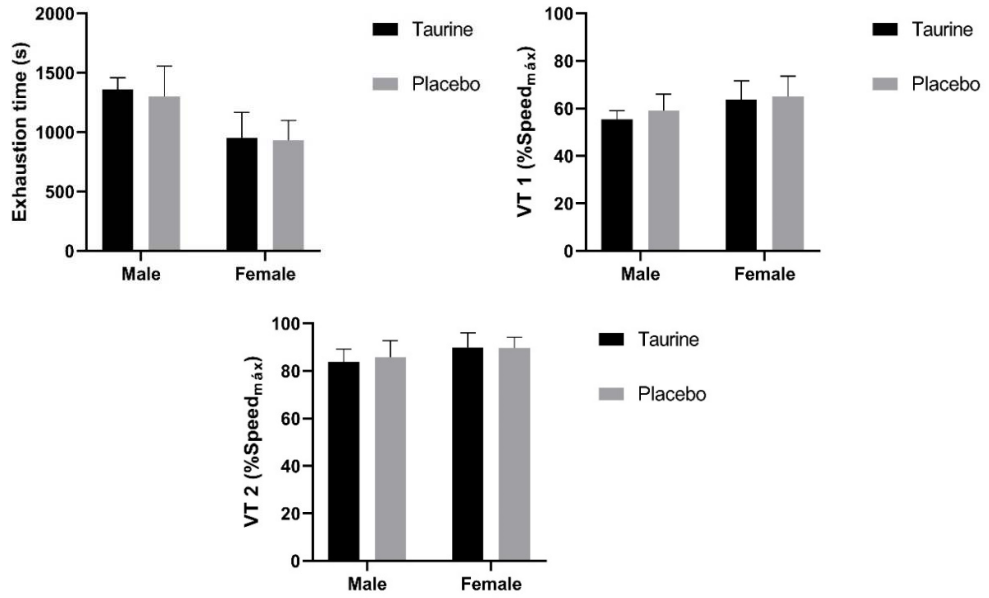

Figure 2. Comparison between exhaustion time (s) and speeds at ventilatory thresholds (%$_{MAX}$ Speed), stratified by sex and between the Taurine and Placebo groups

Discussion

Taurine supplementation to enhance ventilatory capacities is based on the physiological mechanisms in which it participates and its presence in body tissues. This amino acid is present in cardiomyocytes, heart cells that modulate mitochondrial phosphorylation and help maintain the proper functioning of the respiratory chain, influencing $VO_{2\ MAX}$ (Ramila et al., 2015; Schaffer et al., 2016). Additionally, taurine also participates in the modulation of muscle damage, oxidative stress (by removing metabolites), and calcium levels, enhancing the contractile properties of the skeletal muscle membrane. These effects reflect in the cardiorespiratory capacity, delaying the time to exhaustion (Waldron et al., 2018; Carvalho et al., 2020).

Thus, ventilatory thresholds may be influenced by this supplementation, as they pertain to metabolic transition zones (60% and 80% of $VO_{2\ MAX}$), marked by the production and accumulation of blood lactate and increased pulmonary ventilation (Tebexreni et al., 2009). Monitoring these thresholds is extremely important for

human performance, as they are directly linked to health and performance indicators, especially in predominantly aerobic activities, integrating responses from the muscular, cardiac, and respiratory systems (Herdy & Caixeta, 2016; Tarekegn, 2017). This relationship can be observed in the CPET through $VO_{2\ PEAK}$ and the ventilatory thresholds (VT1 and VT2).

When comparing the groups (with and without taurine supplementation) in $VO_{2\ PEAK}$ and ventilatory thresholds (VT1 and VT2), we did not find significant differences. However, the taurine-supplemented group showed a slight advantage compared to the placebo group: $VO_{2\ PEAK}$ $\Delta = 6.0\%$ ($p = 0.158$), VT1 $\Delta = 3.9\%$ ($p = 0.381$), and VT2 $\Delta = 2.7\%$ ($p = 0.486$). The same was observed in relation to time to exhaustion; although not significant, the taurine group took $\Delta = 1.4\%$ ($p = 0.352$) longer to reach exhaustion.

The slight positive response, which was not statistically significant, observed in the taurine-supplemented group may have been due to the dosage (1 g) used in the supplementation. This amount is commonly found in major energy drink brands (Ramada & Nacif, 2019). Other studies that evaluated the effects of taurine supplementation on various markers used dosages of up to 6 g (Waldron et al., 2018; Kurtz et al., 2021).

With a higher dosage of taurine (6 g), Milioni et al. (2016) evaluated supplementation on time to exhaustion and $VO_{2\ MAX}$, finding no significant difference in subjects who received the supplementation. In contrast, with a supplementation of 1 g (as in the present study), Balshaw et al. (2013) assessed the response of taurine in runners during a 3 km time-trial performance test in the laboratory, finding a 1.7% improvement (range of 0.34 to 4.24%) in performance in the taurine group compared to the placebo (646.6 ± 52.8 s vs. 658.5 ± 58.2 s; $p = 0.013$). However, there was no impact on other variables evaluated: $VO_{2\ MAX}$, heart rate, rating of perceived exertion, and lactate ($p = 0.803$, 0.364, 0.760, and 0.302, respectively).

Even though Balshaw et al. (2013) found this benefit in endurance running performance, they assert that the mechanism by which taurine acts in this regard remains unclear, as does the lack of influence on other measured variables. They hypothesize that the effect might be related to muscle force production, given that taurine is involved in calcium metabolism in cell membranes (Jong, Sandal, & Schaffer, 2021). The fact that their sample consisted of trained runners helps explain the difference in results compared to the present study, as physical conditioning and the predominance of muscle fibers have implications for taurine concentration (Ward et al., 2016).

Using a 1 g taurine supplementation and finding no significant responses compared to placebo, Ward et al. (2016) evaluated trained cyclists in a 4 km time-trial test on a cycle ergometer. Similarly, Agnol and Souza (2009), combining 2 g of taurine with 160 mg of caffeine, compared it to placebo in healthy subjects through ergospirometry, finding no differences between the groups.

On the other hand, Rahnama, Kazemi, and Gaeini (2010), in a randomized placebo-controlled trial with active individuals of both sexes, found a significant difference in $VO_{2\ MAX}$ and time to exhaustion in a CPET with taurine supplementation. However, their methodology involved taurine supplementation using an energy drink, with a dosage of 1 g of taurine per 250 ml of beverage. This could introduce bias into the results, as energy drinks contain other substances besides taurine, such as caffeine and B vitamins.

Regarding sample composition, factors such as age, sex, biological conditions, level of physical fitness, and characteristics of sports modalities practiced can influence the effects of taurine supplementation. Previous research has shown that there is a higher prevalence of this amino acid in "aerobic" muscle fibers (type I), and that $VO_{2\ MAX}$ and ventilatory thresholds, being trainable capacities, naturally have higher levels in trained individuals (Herdy & Caixeta, 2016; Ward et al., 2016).

It's worth noting that the results presented by this study stem from the analysis of acute ingestion of isolated taurine, unlike many investigations in the field that associate it with other substances, energy drinks, or vary the timing of pre-test ingestion. This variability makes it difficult to ascertain and compare the effects specifically attributed to taurine.

Furthermore, small differences such as those found in this and other studies, which were not statistically significant, may not reliably reflect physical performance outcomes. This is because depending on the subject's level of conditioning, the margin of improvement achievable with the aid of resources or intervention programs may be small, given the level of trainability already attained. Therefore, it is important to note that in this and other studies, only trained subjects were evaluated, without quantifying the degree of training of these individuals, and responses in subjects with low physical fitness were not assessed.

Conclusion

Thus, we observed that acute ingestion of 1 g of taurine one hour before a CPET did not result in significant improvements in $VO_{2\ PEAK}$, ventilatory thresholds, and total time to exhaustion. Although the literature is inconclusive about the positive aerobic impacts of taurine supplementation, this research provides relevant information for sports practice, especially in modalities that are decided by milliseconds oy by adjusted aerobic endurance, since the use of taurine promoted a small advantage in time to exhaustion and maximum oxygen consumption compared to placebo.

However, considering the biological and physical variables of the participants, there is a suggestion for the need for additional approaches. Future studies could explore different dosages, forms of taurine ingestion, and include evaluations in subjects with varying levels of physical fitness and practitioners of different sports modalities, aiming for a more precise understanding of responses and better guidelines for taurine supplementation.

Disclosure statement

No potential conflict of interest was reported by the author(s)

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