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Effect of physical activity on erectile and sexual function in healthy males

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Abstract

Physical activity (PA) has beneficial effects on erectile dysfunction (ED). It has been proposed to affect ED physiologically via the vascular and nervous systems. This study aimed to evaluate the effect of physical activity on endothelial erectile function, sex hormones and sperm production in healthy males. Sixty-one healthy men aged 18–35 years were eligible to participate in this biochemical and questionnaire-based study. The participants were classified into two groups according to their physical activity level: a physically active group (PA = 38) and a physically inactive group (PINA = 23). PA was evaluated using the ACTi graph GT1M accelerometer. Erectile function was evaluated using the International Index of Erectile Function (IIEF-15) questionnaire. The levels of the sex hormones testosterone (T) and free testosterone (f-T), and the nitric oxide (NO) and E-selectin levels were measured by enzyme linked immuno sorbent assay (ELISA). In addition, a complete semen analysis was performed for all subjects. Better sperm production was reported in physically active subjects than in nonactive subjects. There was a significant increase (p = 0.001) in the IIEF-15 score, and the levels of T, f-T, NO and E-selectin were estimated in physically active subjects compared with those in nonactive subjects. Erectile function (IIEF-15 score) correlated positively with PA and with increased levels of T, f-T, NO and E-selectin, whereas the IIEF-15 score correlated negatively with age and adiposity. Seminological parameters such as the spermatozoa concentration, sperm viability, motility, morphology and normal forms were significantly improved in physically active subjects. Physical activity at mild to moderate levels is significantly associated with improved erectile function, increased endothelial function, increased sex hormone levels and better sperm production in healthy men aged 18–35 years. This study proposes that physical activity physiologically affects erectile function and spermatogenesis via cellular free radical-antioxidant mechanisms.

Keywords

IIEF-15 score; Erectile function; Physical activity; Sex hormone; Endothelial function

1. Introduction

Erectile dysfunction (ED) refers to the occasional or habitual inability of men to obtain and maintain an adequate penile erection for satisfactory sexual intercourse [1, 2]. This situation has important implications for the quality of life and psychosocial health of men and their partners [3]. More than 40% of individuals aged between 40 and 70 years are influenced by ED, which significantly tends to increase with advancing age [1–3], whereas only 2% of men under the age of 40 experience ED [4–8].

Both neurogenic and vascular factors are the most frequent causes of ED. Both factors reportedly interfere with the mechanisms that lead to the relaxation of cavernous smooth muscles, the key event in penile erection [1, 9, 10].

In most studies, the onset and development of ED in men becomes evident and tends to increase with age, often in combination with other pathologies, such as neurological disorders, hypertension, diabetes, atherosclerosis, systemic arterial heart disease, smoking, excessive alcohol intake, obesity, depression, hyperdyslipidemia, poor dietary choices and metabolic syndrome [9–13], and in many clinical instances, ED is regarded as an indicator of heightened cardiovascular risk [12–15].

Moderate-intensity physical activity (PA) has been shown to promote a healthy lifestyle and prevent individuals from experiencing chronic diseases [16], including disorders in sexual function. Recently, it was reported that PA works as an important promoter of vascular health and is associated with normal erectile function and a lower risk of ED among men [16–23].

In addition, humans with regular PA have reported an en-

hancement in their overall quality of life as well as improvements in other aspects of life such as psychological wellbeing, depression, obesity and other risk factors that collectively lead to enhanced sexual function [24–26]. Supporting results showed that sexual function was significantly improved in both men and women with regular PA following participation in moderate exercise training interventions [27].

Previous studies have shown that physical activity (PA) produces physiological changes in the vascular and nervous systems. However, it plays a crucial role in ensuring proper blood flow to support a healthy erection, as any disruption in blood circulation can result in erectile dysfunction [16]. In addition, in men, PA also improves psychological issues such as depression and enhances neural activity, both of which are also influenced by intricate interactions between vascular tissues and concurrent health conditions; collectively, these factors can improve ED [16, 26–33].

Furthermore, age and the level of physical activity have been identified as significant factors related to ED. Younger men who maintain higher levels of physical activity and better physical fitness are less prone to experiencing erectile dysfunction [34]. Aerobic exercise performed at moderate-to-vigorous intensities is effective in enhancing erections through the regulation of testosterone and endothelial nitric oxide (NO) levels.

Testosterone plays a crucial role in regulating physical performance, and assessing blood levels of this hormone is essential for evaluating erectile dysfunction [35]. Furthermore, nitric oxide (NO) is primarily necessary for the relaxation and erection of the smooth muscle in the penis [13, 36]. Additionally, the cell adhesion molecule E-selectin has shown promise as a serum biomarker for assessing erectile function, particularly in individuals with diabetes and ED [37].

We hypothesized that, in men free of associated comorbidities, the association of modifiable behavioural factors such as physical activity, body weight, smoking, alcohol consumption and dietary patterns, with ED could represents a means for preventing and potentially improving erectile function in patients with ED. Therefore, we studied the influence of factors such as PA on nitric oxide (NO), E-selectin and testosterone levels as well as sperm production in healthy males. Few studies have aimed to elucidate the effect of lifestyle interventional strategies such as PA in healthy men with ED on erectile function and spermatogenesis [26–37].

Generally, lifestyle changes, such as increased physical activity, a healthy diet and reduced caloric intake, are associated with the amelioration of erectile dysfunction among males [29, 38–40]. Recently, a dietary pattern characterized by high consumption of fruits, vegetables, legumes, whole grains, fish and olive oil and low consumption of red meat, processed foods, and simple sugar has been associated with numerous health benefits, including improved sexual function [40–42].

Thus, physical activity could be a good preventive and therapeutic measure for managing erectile dysfunction among healthy men. In this study, we aimed to evaluate the effect of physical activity on endothelial erectile function, sex hormone levels and sperm production in healthy males aged 18–35 years.

2. Materials and methods

2.1 Subjects

This study involved the recruitment of 120 healthy young men between the ages of 18 and 35 years through a random selection process. Individuals with a medical history involving reproductive issues, vasectomy, renal dysfunction, such as macroalbuminuria, pelvic injuries, prostatic conditions, peripheral or autonomic nerve issues, diabetes, abnormal lipid profiles, psychiatric disorders or hypertension, were intentionally excluded from the study. Additionally, participants who used herbal supplements, antioxidants, multivitamins or drugs that may affect erectile function and sex hormones were excluded. In addition, participants with history of alcohol or cigarette use were also excluded from this study. To avoid the influence of dietary parameters on our PA intervention in our analysis of ED, all participants were asked to follow a healthy dietary pattern that included a high content of whole-grain foods, legumes, vegetables and fruits and limited consumption of red meat, full-fat dairy products, and food and beverages high in added sugars as a healthy diet is associated with a reduced risk of ED as mentioned in the literature [38, 39]. After the exclusion of 69 individuals who did not meet the eligibility criteria (30; did not meet the protocol eligibility criteria, 30 unwilling to participate; and 19 withdrew and declined to follow up), the study included only 61 men.

Blood samples were collected from all the subjects, and after a 1-minute centrifugation at 1400 rpm, serum samples were extracted from whole blood. These samples were then stored at −20 °C until further use. Detailed demographic and clinical information about the included participants is shown in Table 1.

2.2 Anthropometric measurements

To gather height and weight measurements from all participants, we employed a standardized approach utilizing a tape measure and a calibrated Salter Electronic Scale (Digital Pearson Scale; ADAM Equipment Inc., Columbia, MD, USA) [43, 44]. Furthermore, we computed adiposity indicators, namely, body mass index (BMI) and the waist-to-height ratio (WHtR), by applying universally validated cut-off values. The BMI threshold values, as outlined in earlier studies, were as follows: underweight (BMI <18.5 kg/m^2), normal weight (BMI 18.5–24.9 kg/m^2), overweight (BMI 25–30 kg/m^2) and obese (BMI ≥ 30 kg/m^2) [43, 44].

2.3 Assessment of physical activity

Physical activity (PA) is widely assessed at all ages, from childhood to old age, using validated and reliable accelerometers [45–47]. This study employed the GT1M accelerometer (model WAM 7164; ACTi graph co., Fort Walton Beach, FL, USA) to assess physical activity, which has been shown to yield comprehensive and objective information across various dimensions of physical activity [48–50]. As previously described [45–51], all participants were subjected to this evaluation. In this investigation, individuals engaging in regular endurance exercise, including activities such as walking, jogging,

TABLE 1. Baseline of clinical and laboratory characteristics of the study groups.

Parameters	Physically active (PA; n = 38)	Physically inactive (PIA; n = 23)	*p*-value
Ethnicity	Asian	Asian	-
Socioeconomic Levels	Medium	Medium	-
Occupational activity			
Employed	30 (79%)	20 (87%)	-
Unemployed	8 (21%)	3 (13%)	
Environmental factors			
Healthy (no exposure)	38 (100%)	23 (100%)	-
Unhealthy (exposure)	0 (0%)	0 (0%)	
Marital status			
Married	36 (95%)	21 (91%)	-
Single	2 (5%)	2 (9%)	
Diet			
Carbohydrates (%)	52 ± 6	54 ± 6	
Protein (%)	11 ± 3	11 ± 3	
Fat (%)	32 ± 6	31 ± 5	
Saturated	14 ± 3.5	14 ± 3.4	
MUFA	12 ± 1.5	12 ± 1.4	0.487
PUFA	9 ± 0.7	8 ± 1.2	
Omega-3 fatty acids (g/d)	0.7 ± 0.13	0.7 ± 0.11	
Olive oil (g/d)	16 ± 2.5	15 ± 2.6	
Fruits, vegetables, nuts and legumes (g/d)	211 ± 52	208 ± 56	
Age in yr	26.5 ± 1.6	26.3 ± 1.8	0.068
BMI (kg/m^2)	18.6 ± 2.3	20.1 ± 1.9	0.180
Waist (cm)	79.3 ± 5.1	84.5 ± 4.5	0.230
Hips (cm)	91.5 ± 2.9	89.8 ± 3.7	0.420
WHR	88.9 ± 2.7	92.7 ± 1.21	0.810
WHtR	0.65 ± 0.15	0.96 ± 0.21	0.082
Glucose, mg/dL	86.5 ± 8.5	92.3 ± 4.2	0.120
Insulin, μU/mL	22.8 ± 1.5	21.8 ± 3.1	0.160
Physical activity (PA)			
BMR (kcal/d)	5.9 ± 4.1	3.2 ± 4.3	
TEE (kcal/d)	8.9 ± 4.6	3.2 ± 2.8	0.001
PA scores	9.2 ± 3.5	4.4 ± 1.8	

Values are expressed as mean ± SD; Kruskal-Wallis one-way ANOVA, and post-hoc (Tukey HSD) test were used to compare the mean values of the studied variables. Variables were considered significantly different at $p < 0.05$. Abbreviation: BMI: body mass index; WHR: waist to hip ratio; WHtR: waist to height ratio; PA: physical activity; BMR: basal metabolic rate (kcal/d); TEE: total energy expenditure (kcal/d); MUFA: monounsaturated fatty acid; PUFA: poly unsaturated fatty acid; Environmental factors like pesticides, solvents, heat or other toxicants.

swimming and jumping rope, excluding bicycling, for at least a year and wearing the monitor for a minimum of 10 hours a day over a span of 3 days (comprising 2 weekdays and 1 weekend day) were considered physically active. Conversely, those who had not consistently engaged in any physical activity over the past year were categorized as physically inactive (sedentary). To determine the average intensity of physical activity for each participant, we calculated the total minutes spent at different intensity levels, employing count thresholds and daily activity counts per minute. Participants with accelerometer counts of 100 or fewer counts per minute were classified as leading a sedentary lifestyle [51–55]. Subsequently, based on the analysis using the ACTi graph GT1M accelerometer, the subjects were divided into two groups: a physically active group (n =

38) and a physically inactive depressive group (n = 23).

2.4 Assessment of energy expenditure rates

To account for variations in resting energy expenditure among all subjects [52], we applied an age-specific equation [53]. To determine the total energy expenditure (TEE), we computed the basal metabolic rate (BMR) for each participant based on their body mass, height, age, sex and type of physical activity, employing a validated equation as previously described [52–56]. Physical activity (PA) was categorized into two levels: moderate physical activity (defined by thresholds of 4 metabolic equivalents METs) and vigorous physical activity (defined by thresholds of 7 METs) [54, 55]. Here, it is important to note that 1 MET corresponds to either an energy expenditure of 1 kcal/kg/h or an oxygen uptake of 3.5 mL/kg/min while in a seated, quiet position. Additionally, we utilized a prevalidated questionnaire to capture information on various sports participation activities within the past year and the number of days within the last week during which subjects engaged in aerobic, strength, or flexibility exercises [54].

2.5 Assessment of erectile function

To assess the erectile function of all participants, we utilized a prevalidated questionnaire, namely, the International Index of Erectile Function (IIEF-15), which has been previously cited in the literature [57, 58]. This questionnaire is a comprehensive tool comprising 15 questions that delve into various aspects of male sexual function. In this study, we only assessed erectile function for each participant by completing questions 1 to 5 and question 15, as shown in Table 2. The IIEF score was derived from the summation of questions 1 to 5 and question 15, with a maximum attainable score of 30 indicating optimal erectile function. Conversely, a score of 24 or lower was indicative of erectile dysfunction, as highlighted in previous research [59, 60]. The maximum score for each participant was categorized into different levels of dysfunction: no dysfunction (25–30), mild dysfunction (19–24), mild to moderate dysfunction (13–18), moderate dysfunction (7–12) and severe dysfunction (0–6), as previously described [59].

2.6 Assessment of erectile endothelial function and sex hormone levels

Enzyme-linked immunosorbent assay (ELISA) was used to assess peripheral levels of NO and E-selectin, which serve as markers of endothelial function, following the manufacturer's instructions, as previously described. In particular, the NO composition was determined by measuring nitrate (NO_3) and nitrite (NO_2) levels using a NO assay kit (12345AB678, Thermo Fisher Scientific, San Diageo, CA, USA) [59, 60]. Additionally, soluble E-selectin levels were quantified using an E-selectin assay kit (ES1234-5678, Thermo Fisher Scientific, San Francisco, CA, USA). The concentrations of NO and E-selectin were determined by measuring the absorbance at 540 nm for the NO assay and the absorbance at 450 nm for the E-selectin assay [59]. A competitive immunoassay technique was used to estimate testosterone levels in the sera of all participants [61, 62].

2.7 Semen analysis

At the time of entry into the study and after one year of regular endurance exercise, semen was collected into sterile collection cups from each participant following a period of refraining from sexual relations of 3–6 days. All physical and qualitative parameters of the sperm were evaluated 30 minutes after sample collection, as previously reported [63].

2.8 Sample power calculation

The sample size was calculated to detect significant differences in the viability of erectile function in healthy men according to whether they were physical active and sedentary, as reported previously [64, 65]. Therefore, a calculated total of 61 participants were deemed adequate to ensure robust statistical power (greater than 85%) for the evaluation of the potential impact of physical activity on parameters related to erectile function and sex hormone levels under the assumption of a two-sided 95% confidence interval.

2.9 Statistical analysis

We utilized SPSS version 18 (SPSS Inc., Chicago, IL, USA) statistical software for the data analysis. The outcomes are presented as the mean values and standard deviations across the various groups. To assess the mean values of the variables under investigation, we employed Kruskal-Wallis one-way analysis of variance ANOVA, followed by *post hoc* analyses using the Turkey's honestly significance difference (Turkeys HSD test). Furthermore, one-way analysis of covariance was applied to determine whether noteworthy variations existed in the study variables among the study groups. To pinpoint significant differences between specific groups, *post hoc* pairwise multiple comparisons were carried out, incorporating Bonferroni correction. A p value less than 0.05 indicated statistical significance.

3. Results

A total of 120 healthy men aged 18–35 years were included in this study. Only 61 participants were ultimately eligible for inclusion in this biochemical and questionnaire-based study based on the exclusion criteria. A higher physical activity score was identified in 62.3% (n = 38) of the study population, and 37.7% were considered physically inactive (n = 23) (Table 1). The physical activity parameters BMR, TEE and the PA score were significantly higher (p = 0.001) in the physically active group of me men compared to inactive group (Table 1). In addition, no significant change was observed for the adiposity markers BMI, WHR and WHtR between the groups (Table 1). Baseline data showed no significant differences in nutrient intake, including the consumption of carbohydrates, proteins, fats, saturated fatty acids, mono and polyunsaturated fatty acids (MUFAs and PUFAs), omega-3 fatty acids, olive oil, fruits, vegetables, nuts and legumes (g/day) (Table 1).

To study the effect of physical activity on erectile function and semen characteristics, all participants were subjected to seminal analysis, and erectile function was estimated by using the International Index of Erectile Function (IIEF-15)

TABLE 2. Erectile function questions from International Index questionnaire of Erectile Function (IIEF-15).

Question numbers	Erectile function questions (IIEF-15 questionnaire)	Response	Score Range
1	How often were you able to get an erection during sexual activity?	0. No sexual activity 1. Almost never or never 2. A few times (less than half the time) 3. Sometimes (about half the time) 4. Most times (more than half the time) 5. Almost always or always	0–5
2	When you had erections with sexual stimulation, how often were your erections hard enough for penetration?	0. No sexual activity 1. Almost never or never 2. A few times (less than half the time) 3. Sometimes (about half the time) 4. Most times (more than half the time) 5. Almost always or always	0–5
3	When you attempted sexual intercourse, how often were you able to penetrate (enter) your partner?	0. No sexual activity 1. Almost never or never 2. A few times (less than half the time) 3. Sometimes (about half the time) 4. Most times (more than half the time) 5. Almost always or always	0–5
4	During sexual intercourse, how often were you able to maintain your erection after you had penetrated (entered) your partner?	0. No sexual activity 1. Almost never or never 2. A few times (less than half the time) 3. Sometimes (about half the time) 4. Most times (more than half the time) 5. Almost always or always	0–5
5	During sexual intercourse, how difficult was it to maintain your erection to completion of intercourse?	0. No sexual activity 1. Almost never or never 2. A few times (less than half the time) 3. Sometimes (about half the time) 4. Most times (more than half the time) 5. Almost always or always	0–5
15	Over the last month, how do you rate your confidence that you can get and keep your erection?	0. No sexual activity 1. Almost never or never 2. A few times (less than half the time) 3. Sometimes (about half the time) 4. Most times (more than half the time) 5. Almost always or always	0–5

IIEF-15: International Index of Erectile Function.

questionnaire, as shown in Table 3. No cases of erectile dysfunction were reported among the physically active (PA) men. The IIEF-15 score was greater (26.0 ± 3.0) in the PA group than in the physically inactive group, who reported mild to moderate erectile dysfunction (18.0 ± 2.0; $p = 0.001$) (Table 3). In addition, the spermatozoa concentration, sperm viability, sperm motility, sperm morphology and normal forms were significantly increased ($p = 0.01$) in the physically active group compared to physically inactive group (Table 3).

The effective effects of PA on erectile endothelial function (NO and E-selectin levels) and sex hormone levels (testosterone (T) and free T) were reported in this study as in Table 4. A significant increase in erectile endothelial function (NO and E-selectin levels) and sex hormone levels (testosterone (T) and f-T) was observed in the physically active group ($p = 0.001$) compared to inactive group (Table 4).

Being physical activity (PA) was significantly correlated with erectile function (IIEF-15 score), increased erectile endothelial function (NO and E-selectin levels) and increased sex hormone levels (testosterone (T) and free-T), as well as reduced adiposity (Table 5). In addition, erectile function measured by the IIEF-15 score correlated positively with NO, E-selectin, testosterone (T) and f-T levels and correlated negatively with adiposity (Table 6).

TABLE 3. Erectile dysfunction score and semen characteristics for all participants at entry of the study and after one year of regular endurance exercise.

Parameters	Physically active (PA; n = 38)		Physically inactive (PIA; n = 23)		*p*-value
	Baseline	1 yr	Baseline	1 yr	
Erectile dysfunction score**	16.0 ± 2.0	26.0 ± 3.0	17.9 ± 2.1	18.0 ± 2.0	0.001
Semen parameters:					
pH	7.5 (6.5–8.5)	8.0 (7.0–8.7)	8.1 (8.0–8.6)	8.0 (8.0–8.5)	0.140
Volume (mL)	3.1 (2.5–5.3)	3.9 (2.6–5.6)	3.0 (2.6–5.4)	3.1 (2.5–5.3)	0.120
Total spermatozoa ($\times 10^6$)	73.2 (36.9–120.3)	75.4 (40.9–125.5)	74.36 (42.1–120.5)	74.4 (40.9–125.5)	0.110
Spermatozoa concentration ($\times 10^6$)	58.3 ± 8.25	68.6 ± 11.36	56.6 ± 11.29	56.5 ± 11.28	0.001
Viability (%)	66.0%	86.0%	76.4%	76.5%	0.001
Total motility:	35.5%	48.9%	41.4%	41.5%	
Progressive motility (%)	26.3%	33.9%	31.5%	31.6%	0.001
Non-progressive motility (%)	10.8%	7.6%	17.1%	17.3%	
Immotile spermatozoa (%)	24.3%	25.6%	31.3%	31.5%	
Sperm morphology:					
Normal up to 4%	4.3%	3.8%	4.6%	4.5%	0.001
Normal forms (%)	12.6 ± 1.4	18.3 ± 2.36	13.5 ± 2.12	13.6 ± 2.16	0.001

*Values are expressed as mean ± SD; Kruskal-Wallis one-way ANOVA, and post-hoc (Tukey HSD) test were used to compare the mean values of the studied variables. Variables were considered significantly different at $p < 0.05$. **Based on the International Index of Erectile Function (IIEF-range, 1–30).*

TABLE 4. Effect of physical activity (PA) on erectile function score (IIEF-score), erectile endothelial function (NO) and sexual hormones in healthy Men (N = 61).

Parameters	Physically active (PA; n = 38)		Physically inactive (PIA; n = 23)		*p*-value
	Baseline	1 yr	Baseline	1 yr	
Erectile dysfunction score	16.0 ± 2.0	26.0 ± 3.0	17.9 ± 2.1	18.0 ± 2.0	0.010
Sexual hormones and endothelial function:					
T (ng/dL)	18.9 (17.5–22.7)	25.5 (23.4–27.6)	11.3 (8.0–13.7)	7.5 (6.5–10.5)	0.001
f-T (ng/dL)	12.8 (10.5–14.7)	14.5 (13.5–16.7)	9.5 (8.1–11.8)	8.7 (8.1–10.8)	0.001
Nitric oxide (NO)	21.6 (18.3–26.3)	25.4 (22.3–27.1)	13.4 (9.1–15.5)	11.5 (9.5–13.2)	0.001
E-selectin	9.1 (8.5–11.5)	11.8 (6.5- 13.6)	5.7 (4.5–7.6)	5.1 (3.9–6.9)	0.001

Values are expressed as mean ± SD; Kruskal-Wallis one-way ANOVA, and post-hoc (Tukey HSD) test were used to compare the mean values of the studied $p < 0.01$ (Kruskale-Walis, Dunn's post hoc test). $p < 0.001$ (Kruskale-Walis, Dunn's post hoc test). PA-score: physical activity score; T: testosterone; f-T: free-testosterone; NO: nitric oxide; IIEF: International Index of Erectile Function.

4. Discussion

Physical activity (PA) has been identified as the lifestyle factor most strongly correlated with erectile function; PA can potentially decrease ED by promoting vascular health in men with associated comorbidities and has consistently been shown to improve erectile function [16, 21, 29].

In the present study, engaging in physical activity demonstrated a noteworthy correlation with enhanced erectile function and improved semen characteristics in healthy men between the ages of 18 and 35. Additionally, there was a marked increase in nitric oxide (NO) and E-selectin levels, both of which are indicators of endothelial function related to erectile health. In addition, physical activity was shown to be linked to improved levels of both testosterone (T) and free T, which are considered significant modulators of physical performance, and low levels of these two hormones in the blood significantly indicate erectile dysfunction. In addition, semen parameters such as the spermatozoa concentration, sperm viability, sperm motility, sperm morphology and normal forms were significantly greater in physically active subjects than in physically inactive subjects.

Prior research has indicated that adopting a nutritious diet and engaging in regular physical activity can contribute to

TABLE 5. Correlations between erectile function score (IIEF-score), adiposity, erectile endothelial function and sexual hormones with physical activity scores in healthy Men (N = 61).

Parameters	Physically active (PA; n = 38)		Physically inactive (PIA; n = 23)	
	R	*p*-value	*R*	*p*-value
Erectile dysfunction score	0.48	0.001	0.125	0.001
T (ng/dL)	0.38	0.003	0.250	0.010
f-T (ng/dL)	0.27	0.001	0.280	0.001
NO	0.38	0.001	0.780	0.001
E-selectin	0.35	0.010	0.235	0.010
Adiposity	−0.35	0.010	−0.350	0.010

T: testosterone; f-T: free-testosterone; NO: nitric oxide.

TABLE 6. Correlations between erectile function score (IIEF-score) with erectile endothelial function and sexual hormones in healthy Men based up on different physical activity (N = 61).

Parameters	Physically active (PA; n = 38) IIEF-score (26.1 ± 2.5)		Physically inactive (PIA; n = 23) IIEF-score (18.3 ± 3.8)	
	R	*p*-value	*R*	*p*-value
T (ng/dL)	0.21	0.001	0.180	0.001
Free-T (ng/dL)	0.56	0.001	0.570	0.001
NO	0.48	0.001	0.780	0.001
E-selectin	0.48	0.001	0.310	0.001
Adiposity	−0.35	0.050	−0.530	0.050
Age	−0.76	0.001	−0.651	0.001

T: testosterone; f-T: free-testosterone; NO: nitric oxide; IIEF: International Index of Erectile Function.

lowering the likelihood of male erectile dysfunction and female sexual dysfunction [13, 66, 67]. Moreover, lifestyle modifications that encompass increased physical activity and weight loss have been observed to enhance both erectile function and sexual performance, especially among obese men [29].

In this investigation, we observed a positive correlation between the level of physical activity and erectile function. Compared with those who were not physically active, physically active individuals displayed a noteworthy increase in their IIEF-15 scores. These findings align with prior research in the field [68, 69], which has consistently established a connection between physical activity levels and the occurrence of erectile dysfunction. These studies have consistently concluded that men who engage in higher levels of physical activity are less susceptible to experiencing erectile dysfunction. Additionally, meta-analyses have reinforced these observations, demonstrating that both moderate and vigorous physical activity is significantly linked to a reduced risk of erectile dysfunction [70], whereas men with low or inadequate physical activity tend to exhibit greater rates of erectile dysfunction [71]. Earlier studies have further highlighted the role of increased energy expenditure (ranging from 1000 to 4000 kcal/w.) in significantly lowering the risk of erectile dysfunction among men [72].

In our research, we found that physical activity was linked to an increase in nitric oxide (NO) and E-selectin levels, which serve as indicators of erectile endothelial function. Physically active men exhibited increased levels of both NO and E-selectin. This observation aligns with previous studies that have emphasized the critical role of nitric oxide (NO) in the physiological relaxation and erection of penile smooth muscle [73–75]. Both NO and E-selectin were shown to have a significant positive impact on erectile function. Nitric oxide (NO), in particular, acts as a potent vasoactive neurotransmitter that is part of the nonadrenergic, noncholinergic (NANC) system and plays a crucial role in erectile function within the corpora cavernosa [73]. Additionally, E-selectin, an endothelial cell adhesion molecule, is considered one of the most important biomarkers for assessing erectile function. Its activation is triggered by cytokines and it plays a significant role in the context of inflammation [75, 76].

The effect of physical activity on male sex hormones was reported in this study. There was a significant increase in the levels of testosterone (T) and free T in physically active men compared with physically inactive men. Physical activity levels were positively correlated with NO oxide, E-selectin, testosterone (T) and free-T levels and negatively correlated with adiposity and age. In a randomized controlled trial, treating men with regular aerobic physical activity for 43 h/week plus a phosphodiesterase type 5 inhibitor significantly reduced erectile dysfunction compared to medication alone [77]. Additionally, several studies conducted in middle-aged and older men who participated in different exercise programs indicated higher concentrations of circulating testosterone with either regular exercise [78, 79] or resistance exercise [54, 55]. Previously, compared with sedentary subjects, physically

active subjects showed improvements in follicle–stimulating hormone (FSH), Leutenising hormone (LH) and Testosterone (T), cortisol (C) levels, and the T/C ratio [80].

Our results showed that erectile function, as measured by the IIEF-15 score, was positively correlated with the PA score, parameters of erectile endothelial function (NO and E-selectin levels) and sex hormone levels (testosterone (T) and free-T), and negatively correlated with adiposity and age. It has been demonstrated that erectile dysfunction increases with age. An increase in age leads to a reduction in the IIEF-15 score of 0.195, which greatly affects the risk for erectile dysfunction [81, 82].

Finally, in this study, several seminological parameters, including the spermatozoa concentration, sperm viability, sperm motility, sperm morphology and normal forms, were significantly improved in the physically active subjects. These findings align with enhancements in estimated sex hormone levels (T and free-T) and indicators of erectile endothelial function (NO and E-selectin levels). This association may be attributed to an active lifestyle, consistent with prior research [83–86] showing a more favourable anabolic environment and improved preservation of spermatogenesis under physically active conditions.

Previously, it was proposed that physical exercise of different intensities significantly activates cellular free radical and antioxidant pathways, which are needed for many physiological processes [87, 88]. Reactive oxygen species (ROS) and antioxidant enzymes function as intracellular signalling molecules that can trigger an adaptive response to exercise following a hormetic pattern [87]. As proposed in earlier research, antioxidant enzymes are believed to activate certain cellular cofactors, including NF-κB and Mitogen-activated protein kinase (MAPK) [88]. These cofactors are known to play a significant role in spermatogenesis, germ cell apoptosis, and various sperm functions, such as sperm motility and fertilization potential [81–88]. Thus, improvements in sex hormone levels, erectile function and semen production among physically active men occurs via cellular free radical-antioxidant mechanisms.

5. Conclusions

In conclusion, mild to moderate physical activity was significantly associated with improved erectile function, increased endothelial function, increased sex hormone levels, and better sperm production in healthy men aged 18–35 years. This study proposes that physical activity physiologically affects erectile function and spermatogenesis via cellular free radical-antioxidant mechanisms, but further studies are needed to confirm and expand this knowledge, especially regarding reactive oxygen species (ROS)-antioxidant pathways and the appropriate threshold of physical activity.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

SAG—design of the study protocol, practical analysis and interpretation of data. AHA, SAG and AI—made substantial contribution to study conception; been involved in the initial drafting of the manuscript; critically revised the manuscript for important intellectual content. AHA—supervision. All authors read, understood and approved the final manuscript version to be published and agreed to be accountable for all aspect of the work were appropriately investigated and resolve.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was performed between January and July 2016. According to the ethical guidelines of the 1975 Declaration of Helsinki, the study protocol was reviewed and approved by the Ethics Sub-Committee, King Saud University, Kingdom of Saudi Arabia, under file number ID: RRC-2016-028. Before data collection, written informed consent was obtained from all participating patients as a proof of consent-to-participate in this study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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