Associations between Self-Reported Physical Activity, Autonomic Reactivity, Interoception, and Sexual Dysfunctions in Men

Caoyuan Niu
cn2250@nyu.edu

East China Normal University https://orcid.org/0000-0003-2195-0710
Daniel Ventus
https://orcid.org/0000-0002-2347-8213
Guangju Wen
Pekka Santtila
NYU Shanghai https://orcid.org/0000-0002-0459-1309

Article

Keywords: Physical Activity, Autonomic Activity, Interoceptive Awareness, Premature Ejaculation, Erectile Dysfunction

Posted Date: March 19th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-4011489/v1

Additional Declarations: There is **NO** conflict of interest to disclose.

Abstract

Premature ejaculation and erectile dysfunction are prevalent male sexual dysfunctions worldwide, causing significant distress for men and their partners, as well as resulting in reduced quality and stability of romantic relationships. We aimed to investigate how physical activity in free time was associated with self-reported interoceptive awareness and autonomic nervous system reactivity during sex as well as with premature ejaculation and erectile dysfunction. The sample of 1976 Chinese urban men aged 18 to 50 (M = 31.5 years, SD = 5.3), responded to a questionnaire on two online survey platforms. Participants reported their age, height, and weight, and filled out the Physical Activity Questionnaire, the Body Perception Questionnaire Short Form adapted for sexual events, the Multidimensional Assessment of Interoceptive Awareness, the International Index of Erectile Function-5, and the Checklist for Early Ejaculation Symptoms. Results indicated that more physical activity was associated with more self-reported parasympathetic activity during sex, better interoceptive awareness, and fewer premature ejaculation and erectile problems. The associations between more physical activity and fewer premature ejaculation and erectile problems were mediated by more parasympathetic reactivity during sex and more interoceptive awareness. The present study was the first to investigate the associations between physical activity, autonomic activity, interoceptive awareness, and sexual dysfunction. More physical activity was associated with better erectile function and ejaculation control through heightened interoceptive awareness and better sympathovagal balance during sexual activity. This suggests that physical exercise may enhance sexual function through both psychological and physiological pathways.

Introduction

Normal male sexual function includes the physiological processes of erection, orgasm, and ejaculation (1). Premature ejaculation (PE) and erectile dysfunction (ED) are prevalent sexual dysfunctions globally and lead to a range of negative outcomes for men and their partners. More physical activity, better autonomic nervous system reactivity, and better interoceptive awareness have been associated with fewer PE problems (2). However, few studies have explored the associations between these variables simultaneously. Therefore, we aimed to investigate the association and potential mediation effects between physical activity, autonomic nervous system reactivity, interoceptive awareness, and both PE and ED.

PE and ED

PE refers to the inability to control or delay the timing of ejaculation also with a short intravaginal ejaculation latency time (i.e., the time between when penetrating the vagina and ejaculating) which also leads to subjective distress (3,4). Almost 3% of men fulfill the above criteria including shorter than one minute of intravaginal ejaculation latency time (3). A range of negative psychological outcomes occur in men with PE and their female partners, including men's lower self-confidence (5) and self-esteem (5,6), higher anxiety and depression (7) and interpersonal difficulties (5,8,9), their female partners' lower relationship and sexual satisfaction (5,10) including an increased prevalence of sexual dysfunctions (5,10). In addition, PE problems were reported to be the main reason for one in five women to break up or divorce men in a large cross-cultural study (11).

ED refers to the inability to attain or maintain an erection sufficient for satisfactory sexual intercourse (12). The prevalence of ED varied from 35% to 45% in Chinese samples (13,14). ED also leads to negative outcomes for men, for example, lower self-esteem, more depression, and lower sexual satisfaction (15,16). In addition, several studies have revealed that men with ED have an increased risk of PE (17–19). The underlying mechanism may be the association between the autonomic nervous system and both erection and ejaculation processes (1).

Sympathovagal Imbalance Hypothesis

The understanding of the etiology of PE is limited (1). Although the autonomic nervous system mechanism of the male sexual response is not entirely clear, the balance and appropriate timing between the sympathetic and parasympathetic nervous systems seem crucial for a well-functioning sexual response (1). During the erection phase, first, while sympathetic activity decreases, parasympathetic activity has the dominating role in inducing the relaxation of muscles that otherwise constrict the flow of blood into the penis, enabling an erection (1). Then, in the ejaculation phase, the sympathetic nervous system has the dominating role, facilitating the emission of seminal fluid (1).

A few preliminary studies suggest sympathovagal imbalance may have a role in PE (20,21). Sympathovagal imbalance refers to an autonomic state of sympathetic overactivation which is associated with a higher risk of stress, cardiac morbidity, mortality (22), and psychopathology (23). Men with PE may have higher levels of sympathetic activation than men with normal sexual function in non-aroused (21,24) and aroused (25) settings. In addition, compared with men without PE, men with PE displayed lower levels of parasympathetic activity and a higher sympathetic/parasympathetic ratio which is an indicator of sympathovagal balance in a 24-hour heart rate monitoring examination (20). More importantly, a sympathetic/parasympathetic ratio greater than 2.7 may serve as a predictive indicator for PE with high sensitivity (20). Therefore, we assumed that sympathovagal imbalance during sexual activity might have a role in the causation of PE.

Physical Activity

Physical activity has been associated with fewer PE symptoms (26,27). Previous studies have demonstrated that multiple physical exercises can alleviate PE symptoms, for example, yoga and running (28–30). For example, men with lifelong PE have reported a longer intravaginal ejaculation latency time after undergoing moderate physical exercise training (running for 30 minutes) five times a week for thirty days compared with before the intervention and a sham (walking for 30 minutes) group (29).

A possible underlying mechanism may be that physical exercise positively affects sympathovagal balance (31,32). Brenner and colleagues (2020) found that a 12-week period of low-intensity exercise (pain-free walking) enhanced autonomic nervous system regulation compared to a control group in patients with peripheral artery disease (33). This intervention resulted in increased parasympathetic activity and decreased sympathetic activity which indicates

improved sympathovagal balance (33). In addition, another study found that 20 minutes of high-intensity interval training (HIIT) - consisting of repeated high-intensity exercises separated by short recovery interval periods - for two weeks improved sympathovagal balance in physically active men (34). A recent study found that seven minutes of HIIT for two weeks improved ejaculation control for men with PE (35). Also, this study found that higher heart rate increases during exercise were associated with more decrease in PE symptoms (35). We, therefore, expected autonomic nervous system activity during sex to potentially mediate the relationship between physical activity and ejaculation control.

Importantly, more frequent participation in physical activity has also been associated with less erectile dysfunction (36,37). Based on the dominating role of parasympathetic activity in enabling penile erection, we also expected that autonomic activity during sex may mediate the relationship between physical activity and erectile function.

Interoceptive Awareness

Interoception refers to sensing internal signals from the body, including physical aspects such as the heartbeat, breathing rate, temperature, pain, and other somatic feelings (38,39). Interoception is crucial for maintaining bodily homeostasis (38,39), regulating emotion, and memory (40), and developing the sense of the self (41). The bidirectional communication between the central nervous systems, autonomic nervous systems, and the other internal tissues of the body generates interoception (38,39,42). Sympathovagal balance may play some role in the neural circuits of interoception, for example, the vagus nervus serves as a prominent conduit for interoceptive signals, predominantly functioning as an afferent pathway that conveys information from bodily interoceptors (43). Additionally, the vagus nerve plays a role (43).

Interoceptive awareness refers to the individual's ability to perceive, identify, and appropriately respond to internal signals from the entire body (44,45). Previous studies have shown that individuals with higher interoceptive awareness tend to have better emotion regulation (41,46). In addition, a study indicated that less interoceptive awareness was associated with more difficulty delaying ejaculation (2). However, to our best knowledge, previous studies have not found any significant association between interoceptive awareness and erectile function (2). Therefore, we hypothesized that less interoceptive awareness would be associated with more PE symptoms and just explored the association between interoceptive awareness and ED symptoms. Furthermore, physical exercise may enhance interoceptive accuracy (47) which refers to the accuracy of perception or detection of interoceptive signals (48) and is closely associated with interoceptive awareness (49). Considering the association between physical exercise and ejaculative control, we explored if interoceptive awareness would mediate the association between physical activity and PE and ED symptoms.

Body awareness refers to the sensitivity to internal bodily signals from body functions (50). According to the definition of interoceptive awareness, body awareness seems to be part of it. However, one previous study found no significant association between body awareness and interoception accuracy (48). Therefore, we only explored the association between body awareness, physical activity, and PE and ED symptoms.

Hypotheses

We expected that more physical activity would be associated with fewer PE and erectile problems (Hypothesis 1). We expected that more participation in physical activity would be associated with more parasympathetic activity during sex (Hypothesis 2) which in turn would be associated with fewer PE and erectile problems (Hypothesis 3). We also expected that more physical activity would be associated with heightened interoceptive awareness (Hypothesis 4) which in turn would be associated with fewer PE problems (Hypothesis 5).

Material and Methods

Participants

We recruited adult men who lived in Shanghai, China, to participate in the study. In total, 2051 participants gave their informed consent and filled out an online survey via two online survey platforms. The final sample included 1976 participants who were aged from 18 to 50 (M = 31.5, SD = 5.3) and who reported that their biological sex at birth was male (n = 2048), they were only sexually attracted to women (n = 1998), had a stable sexual partner (n = 1985), and their sexual identity was straight (n = 1976). Our initial focus was to investigate the PE and ED in straight men with female partners excluding gay men. This decision was considering that, in Chinese context, men attracted to the same sex are likely to engage in a sexual relationship with women which may affect their sexual arousal and introduce a confounding factor (51).

Measures

Demographic Information

Initially, participants were instructed to report their age, height, weight, assigned sex at birth, sexual identity, and if they had a stable sexual partner or not. Participants also were instructed to indicate their sexual identity with the response options including "straight, gay, bisexual, asexual, and unsure" and the sex of the persons they were attracted to with response options including "men, women, both, neither, unsure".

Physical Activity Questionnaire

Physical Activity Questionnaire was used to measure participants' level of physical activity in their free time for the frequency, duration, intensity, and overall length of a series of physical activities (52). Each item was rated on a 5-point Likert scale ranging from 1 to 5. In the present study, we included three sets of four questions. Each set of questions consisted of inquiries about the frequency, duration, intensity, and overall length of cardiovascular exercise, resistance exercise, and flexibility exercise, respectively. An example item was "How intensely do you participate in cardiovascular exercise?" with the response options

ranging from 1 = very light to 5 = very hard. For example, participants who engaged in two types of physical activity (i.e., cardiovascular and resistance exercises) would answer questions including the frequency, duration, intensity, and overall length of the cardiovascular and resistance exercises, respectively. We calculated summary scores according to the original instructions (52). First, we added the score of the frequency, duration, intensity, and overall length to get a sum score for the cardiovascular and resistance exercises. Then, we calculated the mean score of the two types of physical activity. Finally, we multiplied the previous mean score by "4" which is the score for the options that participants engaged in two types of physical activity in the first question. Higher values indicated a higher level of physical activity.

Body Perception Questionnaire-Short Form (BPQ-SF)

The 46 items of the BPQ-SF (53) were used to measure three subscales: body awareness (Cronbach's alpha = .904; 26 items), supradiaphragmatic (Cronbach's alpha = .882; 12 items) and subdiaphragmatic reactivity (Cronbach's alpha = .838; 5 items). In this study, participants answered this questionnaire in relation to when they had sexual activity. The instruction was: "When I am about to have sex and/or during sex, I usually experience…". For this reason, we deleted four questions that were unlikely to occur in association with sexual activity: "When I am eating, I have difficulty talking", "When I eat, food feels dry and sticks to my mouth and throat", "When I eat, I have difficulty coordinating swallowing, chewing, and/or suck with breathing", "After eating I have digestive problems". The body awareness subscale (e.g., "An urge to cough or clear my throat") measured sensitivity for internal bodily signals emanating from bodily functions (50). The supradiaphragmatic (e.g., "When I breathe, I feel like I cannot get enough oxygen") and subdiaphragmatic (e.g., "I have 'sour' stomach") reactivity subscales measure the response of autonomically-innervated organs above or gastrointestinal organs below the diaphragm associated with two distinct circuits (ventral vagal complex and dorsal vagal complex) in the parasympathetic nervous system (50, 53, 54). Therefore, the supradiaphragmatic and subdiaphragmatic reactivity subscales are assumed to measure parasympathetic nervous system reactivity (50, 53, 54). The items were evaluated on a 5-point, bipolar, Likert scale ranging from 1 = never to 5 = always. Higher subscale values indicated more sensitivity for internal bodily functions or more parasympathetic reactivity during sex. A previous study has shown that the BPQ-SF demonstrates good reliability and validity among Chinese college students (54).

Multidimensional Assessment of Interoceptive Awareness (MAIA)

The multidimensional assessment of interoceptive awareness was used to measure interoceptive awareness (45, 55). The subscales of noticing (Cronbach's alpha = .811; 4 items), not-worrying (Cronbach's alpha = .194; 3 items), self-regulation (Cronbach's alpha = .844; 4 items), and body listening (Cronbach's alpha = .849; 3 items) were used in this study. We only measured three items of the not-worrying subscale after deleting questions including "I can stay calm and not worry when I have feelings of discomfort or pain" and "When I am in discomfort or pain I can't get it out of my mind" which are unlikely to be related to sexual activity. The mean of the subscale items formed the score for each subscale. The noticing subscale (e.g., "When I am tense, I notice where the tension is located in my body") assessed the awareness of neutral, (un)comfortable body feelings (45). The not-worrying subscale (e.g., "When I feel overwhelmed, I can find a calm place inside") assessed the ability not to experience emotional distress with uncomfortable physical feelings (45). The self-regulation subscale (e.g., "I listen for information from my body about my emotional state") assessed the ability to regulate distress by focusing on the body's feelings (45). The body listening subscale assessed the tendency to listen to the information from the insight body (45). The response options were from 0 = never to 5 = Always. Higher subscale values indicated better interoceptive awareness.

Checklist for Early Ejaculation Symptoms (CHEES)

The 5-item diagnostic tool CHEES, which was derived from three earlier ejaculation diagnostic tools with improved validity, was used to measure the PE symptoms (56). The sum of the five items was calculated for each participant, with each item being rated on a 5-point Likert scale ranging from 1 to 5. An example item is: "Over the past six months, was your control over ejaculation during sexual intercourse:" The response options were from 1 = very good to 5 = very poor. In the present study, Cronbach's α was .776. The higher value indicated more PE problems.

In addition, for assessing the individual's control of ejaculation without relationship factors, we used the sum score of the three items: "Was your control over ejaculation during this sexual intercourse?", "Did you ejaculate with very little stimulation?", "During this penile-vaginal sexual intercourse, how much time elapsed between when you first entered your partner vaginally with your penis and when you first ejaculated?" to form a new variable "Control Problems". Higher values indicated more ejaculation control problems.

International Index of Erectile Function-5 (IIEF-5)

The 5-item version IIEF (57) was used to measure ED which was developed from the 15-item version (58). The sum of the five items was calculated for each participant, with each item being rated on a 5-point Likert scale ranging from 1 to 5. An example item is: "When you had erections with sexual stimulation, how often were your erections hard enough for penetration?". The response options were from 1 = almost never/never to 5 = almost always/always. In the present study, Cronbach's α was .784 for these items. Higher values indicated better erectile function.

Procedure

We created questionnaires on two Chinese online survey platforms: WJX (https://www.wjx.cn) and CREDAMO (https://www.credamo.com). Both platforms sent a link to the questionnaire to the potential men aged 18–50 years old and currently living in Shanghai in the two online survey platforms. The potential participants who were interested in participating could click the survey link. Upon clicking the link, they would read the consent form online and decide whether they participated in the study. If they agree, they click the "Yes, I agree to participate (and confirm that I am eligible for this study)" option. Institutional Review Board reviewed and approved the present study. In accordance with the internal processes of the two platforms, participants who completed the survey on WJX received a payment ranging from 4 to 7 RMB, while those who completed the survey on CREDAMO received 12.5 RMB for their participation. In total, 1055 participants on WJX and 996 participants on CREDAMO completed the survey.

Participants on CREDAMO had higher age ($t(1974) = 6.394$, $p < .001$) and lower BMI ($t(1973) = -7.659$, $p < .001$) than those on WJX. For this reason and also because age and BMI (Body Mass Index, which is commonly used to assess the level of fat accumulation in adults, is defined as a person's weight in kilograms divided by the square of their height in meters) have been found to be associated with sexual dysfunction variables (18, 59), we included these variables as covariates in the regression analyses.

Statistical analyses

We used SPSS 27.0 and Mplus 8.1 to conduct the data analyses.

First, we conducted Harman's single-factor test for Common Method Variance (CMV) in SPSS to test the common method variance of the BPQ-SF and the MAIA. The result indicated that the total variance for a single factor is less than 50% (MAIA: 43.085%; BPQ-SF: 33.509%) which means the common method variance did not affect the data.

Then, we used SPSS to conduct a bivariate Pearson correlation analysis to explore the association between age, BMI, body awareness, parasympathetic reactivity, interoceptive awareness, physical activity, CHEES, IIEF, and Control Problems.

Next, we used Mplus to conduct the Bootstrap with 1000 replication to explore the indirect effect between physical activity and CHEES, IIEF via body awareness, parasympathetic reactivity, and interoceptive awareness before and after controlling for age and BMI and to test the structural regression model. We evaluated model fit by the Chi-square test (χ^2), a root mean square error of approximation (*RMSEA*), a comparative fit index (*CFI*), Tucker-Lewis index (*TLI*), and a standardized root mean square residual (*SRMR*) (60, 61).

Finally, we conducted the Bootstrap with 1000 replication in Mplus to explore the indirect effect between physical activity and Control Problems, IIEF via body awareness, parasympathetic reactivity, and interoceptive awareness before and after controlling for age and BMI and to test the structural regression model in Mplus.

Results

Table 1 shows the relationships between age, BMI, physical activity, body awareness during sex, supradiaphragmatic and subdiaphragmatic reactivity during sex, interoceptive awareness, CHEES, IIEF, and Control Problems. Results showed that more physical activity was associated with fewer PE and erectile problems and fewer ejaculation control problems. More physical activity was associated with more supradiaphragmatic and subdiaphragmatic reactivity during sex and a higher level of noticing, not-worrying, self-regulation, and body listening. More supradiaphragmatic reactivity during sex was associated with more PE problems. More supradiaphragmatic and subdiaphragmatic reactivity during sex were associated with more erectile problems. Greater noticing, not-worrying, self-regulation, and body listening were associated with fewer PE and erectile problems and fewer ejaculation control problems.

[Table 1 near here]

Table 2 shows the direct effects of physical activity on body awareness, supradiaphragmatic and subdiaphragmatic reactivity, and interoceptive awareness, and the direct effect of body awareness, supradiaphragmatic and subdiaphragmatic reactivity, and interoceptive awareness on PE and erectile problems, ejaculation control problems. Table 3 shows the indirect effects of physical activity on PE and erectile problems and ejaculation control problems. Figure 1 shows the mediating effects of body awareness, supradiaphragmatic and subdiaphragmatic reactivity on the relationship between physical activity and PE and erectile problems, and ejaculation control problems. The model fit indicators showed a good fit (*RMSEA* < .08, *CFI* > 0.95, *SRMR* < .05). Values of the model fit indicators included a χ^2 = 68.291/,68.558, *df* = 6, p-value < .001, an *RMSEA* = 0.073/0.073, [90 % C.I. = 0.058/0.058, 0.088/0.089], a *CFI* = 0.988/0.987, a *TLI* = 0.949/0.947, and a *SRMR* = 0.035/0.035.

The mediation model showed that more physical activity was associated with more supradiaphragmatic reactivity ($\beta = .051$, $p = .008$) which was in turn associated with fewer PE problems ($\beta = -.127$, $p = .008$) and ejaculation control problems ($\beta = -.129$, $p = .003$). The direct effects of physical activity on PE ($\beta = -.319$, $p < .001$) and ejaculation control problems ($\beta = -.320$, $p < .001$), and erectile function ($\beta = .255$, $p < .001$) were significant. The indirect effect of physical activity on PE problems and ejaculation control problems was also significant.

[Table 2 near here]

[Table 3 near here]

[Figure 1 near here]

Figure 2 shows the mediation effect of interoceptive awareness on the relationship between physical activity in free time and PE and erectile problems, and ejaculation control problems. The model fit indicators showed a good fit (*RMSEA* < .08, *CFI/TLI* > 0.95, *SRMR* < .05). Values of the model fit indicators included a χ^2 = 48.825/53.055, *df* = 8, p-value < .001, an *RMSEA* = 0.051/0.053, [90 % C.I. = 0.038/0.040, 0.065/0.067], a *CFI* = 0.992/0.990, a *TLI* = 0.965/0.958, and a *SRMR* = 0.027/0.028.

The mediation model indicated that more physical activity was associated with a higher level of noticing ($\beta = .369$, $p < .001$), not-worrying ($\beta = .129$, $p < .001$), self-regulation ($\beta = .398$, $p < .001$), and body listening ($\beta = .439$, $p < .001$).

A higher level of not-worrying (β = -.245, p < .001; β = -.179, p < .001) and self-regulation (β = -.203, p < .001; β = -.269, p < .001), and body listening (β = -.118, p = .001; β = -.006, p = .953) were associated with fewer PE problems and ejaculation control problems. The direct effects of physical activity on PE (β = -.162, p < .001) and ejaculation control problems (β = -.181, p < .001) were significant. Results revealed significant indirect effects of physical activity on PE problems via not-worrying, self-regulation, and body listening, on ejaculation control problems via not-worrying and self-regulation.

A higher level of noticing (β = .095, p = .001), not-worrying (β = .141, p < .001), and self-regulation (β = .166, p < .001) were associated with fewer erectile problems. The direct effect of physical activity on erectile function (β = .110, p < .001) was significant. Results indicated significant indirect effects of physical activity on erectile function via noticing, not-worrying, and self-regulation.

[Figure 2 near here]

Discussion

The present study investigated the association and the potential mediation between physical activity in free time, body awareness during sex, parasympathetic activity during sex, interoceptive awareness, PE, and ED. First, as expected, the association between more physical activity, better erectile function (36), better ejaculation control (27), more parasympathetic activity during sex (2, 34), and better interoceptive awareness (2) were consistent with previous studies (Hypothesis 1, 2, 4). The correlation results revealed more physical activity in free time was associated with fewer PE symptoms (better ejaculation control) and better erectile function (Hypothesis 1), more parasympathetic activity (specifically supradiaphragmatic reactivity) during sex (Hypothesis 2), greater interoceptive awareness (Hypothesis 4). In contrast with our hypothesis, the bivariate correlation analysis revealed a weak negative association between more parasympathetic activity during sex and more PE and ED symptoms. However, these results might be due to suppression effects, since the multivariate mediation model showed that parasympathetic activity was associated with lower levels of PE and ED symptoms (Hypothesis 3). Second, as expected, the mediation models indicated that more physical activity in free time was associated with more parasympathetic reactivity during sex (Hypothesis 2) which in turn was associated with fewer PE symptoms and better ejaculation control (Hypothesis 3).

According to the role of the autonomic nervous system in male sexual response, during the erection phase, the parasympathetic nervous system enables penile erection (1). More parasympathetic activity may lead to a better erection and a harder penis which may also give the man an experience of a positive feedback loop during sex. After the erection phase, sympathetic activity increases with the sexual excitation increase, and parasympathetic activity decreases. More parasympathetic activity may inhibit the increase of the sympathetic activity which could delay the sympathetic activity reaching the ejaculation threshold and may be helpful for ejaculation control. In addition, this positive feedback due to the sufficient penile erection may lead to less sexual performance anxiety which in turn is associated with better ejaculation control (62). The association between erectile function and ejaculation control also may give some supporting pieces of evidence supporting the feedback loop between erection and ejaculation control during sex. The mediation model also suggested that more physical activity in free time more parasympathetic activity during sex which may calm down the sympathetic activity and improve the sympathovagal balance during sex (33, 34) which in turn improves ejaculation control.

The mediation models also indicated that more physical activity in free time was associated with heightened interoceptive awareness (Hypothesis 4) which in turn was associated with fewer PE symptoms and better ejaculation control (Hypothesis 5). The association between greater interoceptive awareness and better ejaculation control was consistent with the previous study (2). The present study first found the association between greater interoceptive awareness and better erectile function and ejaculation control simultaneously. These models are the first to show that the association of more physical activity in free time for the better control of ejaculation and better erectile function may be underpinned by both physiological and psychological mechanisms.

Interestingly, in the mediation model, more physical activity was associated with the noticing and body listening ability of interoceptive awareness which in turn seemed to be separately associated with erectile function and ejaculation control. Noticing reflects the ability to notice the body's sensations (45). We considered that more physical activity may lead to better awareness of the sexual bodily sensations during the erection phase which in turn may enhance sexual excitability and enable better penis erection, probably the sexual desire increase when individuals notice the hard penis or other body reactions which will give a positive feedback loop during sex. Body listening, on the other hand, reflects the tendency to actively perceive and process information from the body for insight (45). More physical activity may lead to a better capacity to attentively listen to insightful bodily cues and signals for ejaculation control before the ejaculation phase (i.e., individuals know how close they are to the ejaculation threshold, and take the necessary action to stop themselves from ejaculating before they want to).

As expected more physical activity in free time was associated with better interoceptive awareness which in turn was associated with better erectile function and ejaculation control, especially for the not-worrying and self-regulation which indicated individuals' ability to regular the negative mood by translating the attention from the mood self to the body sensation (45). Therefore, we considered that individuals with a higher ability to regularize the negative mood may also have a higher ability to regularize the attention to sexual excitability and body sensation during sex. In particular, during partner sex, individuals can focus on the sexual excitability during the erection phase and translate the attention partly from the sexual excitability to the body's feelings during the ejaculation phase (41). Therefore, the underlying mechanism would be that more physical activity increases regular attention and awareness of body sensations (47). During partner sex, individuals can enhance their erection by focusing on sexual excitability during the erection and decrease sexual stimulation by changing the location of genital contact. However, more research was needed to investigate the effect of different interoceptive awareness on the male sexual response.

Limitations and Future Directions

The present study had several limitations. First, the autonomic nervous system reactivity during sex was measured by self-report without using physiological measurement given that it would not be practically feasible with this large sample size. While the measure has been validated (63), future studies should use more direct measurement indices, for example, electrodermal activity and heart rate variability. Second, the age of the sample was relatively young. Future studies should recruit participants from a wider range of ages. Last but not least, the present study was cross-sectional which precludes causal inference. Further studies should include physical exercise intervention experiments and investigate the change in sexual function and mediating variables during the intervention.

Conclusions

The mediation model suggested the association of more physical activity with the better erectile function and ejaculation control may be mediated by better sympathovagal balance during sexual activity and interoceptive awareness. This suggested that physical exercise may effectively enhance sexual function through both psychological and physiological pathways.

Declarations

Data Availability Statement

The datasets generated during and/or analysed during the current study are available in the OSF repository, [PERSISTENT WEB LINK TO DATASETS].

Author Contributions

CN: Investigation, Data Collection, Data curation, Methodology, Formal analysis, Writing-original draft, Visualization. **DV:** Formal analysis, Writing-Review & Editing. **GW**: Formal analysis. **PS**: Conceptualization, Supervision, Writing-Review & Editing.

Funding

This work was supported by the internal New York University Shanghai grant to PS.

Competing Interests

The authors report there are no competing interests to declare.

Ethical Approval

This study was reviewed and approved by the institution's Institutional Review Board. All participants gave their consent by reading the consent form online and click the "Yes, I agree to participate (and confirm that I am eligible for this study)" option.

References

1. Alwaal A, Breyer BN, Lue TF. Normal male sexual function: emphasis on orgasm and ejaculation. Fertility and Sterility. 2015 Nov;104(5):1051–60.
2. Berenguer C, Rebôlo C, Costa RM. Interoceptive Awareness, Alexithymia, and Sexual Function. Journal of Sex & Marital Therapy. 2019 Nov 17;45(8):729–38.
3. Althof SE, McMahon CG, Waldinger MD, Serefoglu EC, Shindel AW, Adaikan PG, et al. An Update of the International Society of Sexual Medicine's Guidelines for the Diagnosis and Treatment of Premature Ejaculation (PE). Sexual Medicine. 2014 Jun;2(2):60–90.
4. Gao J, Peng D, Zhang X, Hao Z, Zhou J, Fan S, et al. Prevalence and Associated Factors of Premature Ejaculation in the Anhui Male Population in China: Evidence-Based Unified Definition of Lifelong and Acquired Premature Ejaculation. Sexual Medicine. 2017 Mar;5(1):e37–43.
5. Rowland DL, Patrick DL, Rothman M, Gagnon DD. The Psychological Burden of Premature Ejaculation. Journal of Urology. 2007 Mar;177(3):1065–70.
6. Symonds T, Roblin D, Hart K, Althof S. How Does Premature Ejaculation Impact a Man's Life? Journal of Sex & Marital Therapy. 2003 Jan;29(5):361–70.
7. Porst H, Montorsi F, Rosen RC, Gaynor L, Grupe S, Alexander J. The Premature Ejaculation Prevalence and Attitudes (PEPA) Survey: Prevalence, Comorbidities, and Professional Help-Seeking. European Urology. 2007 Mar;51(3):816–24.
8. Giuliano F, Patrick DL, Porst H, La Pera G, Kokoszka A, Merchant S, et al. Premature Ejaculation: Results from a Five-Country European Observational Study. European Urology. 2008 May;53(5):1048–57.
9. Patrick DL, Althof SE, Pryor JL, Rosen R, Rowland DL, Ho KF, et al. Premature Ejaculation: An Observational Study of Men and Their Partners. The Journal of Sexual Medicine. 2005 May;2(3):358–67.
10. Jern P, Sola IM, Ventus D. Do women's Relationship Satisfaction and Sexual Functioning Vary as a Function of Their Male Partners' Premature Ejaculation Symptoms? Journal of Sex & Marital Therapy. 2020 Oct 2;46(7):630–8.
11. Burri A, Giuliano F, McMahon C, Porst H. Female Partner's Perception of Premature Ejaculation and Its Impact on Relationship Breakups, Relationship Quality, and Sexual Satisfaction. The Journal of Sexual Medicine. 2014 Sep;11(9):2243–55.
12. Hao ZY, Li HJ, Wang ZP, Xing JP, Hu WL, Zhang TF, et al. The Prevalence of Erectile Dysfunction and Its Relation to Chronic Prostatitis in Chinese Men. Journal of Andrology. 2011 Sep 1;32(5):496–501.

13. Goldstein I, Goren A, Li VW, Tang WY, Hassan TA. Epidemiology Update of Erectile Dysfunction in Eight Countries with High Burden. Sexual Medicine Reviews. 2020 Jan 1;8(1):48–58.
14. Ma C, Cai Z, Xiong J, Li H. History of Prostatitis Is an Independent Risk Factor for Erectile Dysfunction: A Cross-Sectional Study. Khurshid M, editor. BioMed Research International. 2020 Oct 17;2020:1–6.
15. Martins FG, Abdo CHN. Erectile Dysfunction and Correlated Factors in Brazilian Men Aged 18–40 years. The Journal of Sexual Medicine. 2010 Jun;7(6):2166–73.
16. Özkent MS, Hamarat MB, Taşkapu HH, Kılınç MT, Göger YE, Sönmez MG. Is erectile dysfunction related to self-esteem and depression? A prospective case–control study. Andrologia [Internet]. 2021 Feb [cited 2022 Nov 10];53(1). Available from: https://onlinelibrary.wiley.com/doi/10.1111/and.13910
17. Brody S, Weiss P. Erectile Dysfunction and Premature Ejaculation: Interrelationships and Psychosexual Factors. The Journal of Sexual Medicine. 2015 Feb;12(2):398–404.
18. Corona G. Erectile dysfunction and premature ejaculation: a continuum movens supporting couple sexual dysfunction. J Endocrinol Invest. 2022 May 3;45(11):2029–41.
19. Corona G, Rastrelli G, Limoncin E, Sforza A, Jannini EA, Maggi M. Interplay Between Premature Ejaculation and Erectile Dysfunction: A Systematic Review and Meta-Analysis. The Journal of Sexual Medicine. 2015 Dec;12(12):2291–300.
20. Erbay G, Ceyhun G. Is heart rate variability a risk factor for premature ejaculation? Int J Clin Pract [Internet]. 2021 Oct [cited 2022 Nov 16];75(10). Available from: https://onlinelibrary.wiley.com/doi/10.1111/ijcp.14699
21. Turan Y, Gürel A. The heart rate recovery is impaired in participants with premature ejaculation. Andrologia [Internet]. 2020 Jun [cited 2022 Nov 4];52(5). Available from: https://onlinelibrary.wiley.com/doi/10.1111/and.13573
22. Dekker JM, Crow RS, Folsom AR, Hannan PJ, Liao D, Swenne CA, et al. Low Heart Rate Variability in a 2-Minute Rhythm Strip Predicts Risk of Coronary Heart Disease and Mortality From Several Causes: The ARIC Study. Circulation. 2000 Sep 12;102(11):1239–44.
23. Alvares GA, Quintana DS, Hickie IB, Guastella AJ. Autonomic nervous system dysfunction in psychiatric disorders and the impact of psychotropic medications: a systematic review and meta-analysis. jpn. 2016 Mar;41(2):89–104.
24. Xia JD, Han YF, Zhou LH, Xu ZP, Chen Y, Dai YT. Sympathetic skin response in patients with primary premature ejaculation. Int J Impot Res. 2014 Jan;26(1):31–4.
25. Rowland DL. Genital and heart rate response to erotic stimulation in men with and without premature ejaculation. Int J Impot Res. 2010 Sep;22(5):318–24.
26. Ventus D, Jern P. Lifestyle Factors and Premature Ejaculation: Are Physical Exercise, Alcohol Consumption, and Body Mass Index Associated With Premature Ejaculation and Comorbid Erectile Problems? The Journal of Sexual Medicine. 2016 Oct;13(10):1482–7.
27. Yildiz Y, Kilinc MF, Doluoglu OG. Is there any association between regular physical activity and ejaculation. 2018;5.
28. Dhikav V, Karmarkar G, Gupta M, Anand KS. ORIGINAL RESEARCH—EJACULATORY DISORDERS: Yoga in Premature Ejaculation: A Comparative Trial with Fluoxetine. The Journal of Sexual Medicine. 2007 Nov;4(6):1726–32.
29. Kilinc MF, Aydogmus Y, Yildiz Y, Doluoglu OG. Impact of physical activity on patient self-reported outcomes of lifelong premature ejaculation patients: Results of a prospective, randomised, sham-controlled trial. Andrologia. 2018 Feb;50(1):e12799.
30. Rohilla J, Jilowa C, Tak P, Hasan S, Upadhyay N. A comparative study of yoga with paroxetine for the treatment of premature ejaculation: A pilot study. Int J Yoga. 2020;13(3):227.
31. Daniela M, Catalina L, Ilie O, Paula M, Daniel-Andrei I, Ioana B. Effects of Exercise Training on the Autonomic Nervous System with a Focus on Anti-Inflammatory and Antioxidants Effects. Antioxidants. 2022 Feb 10;11(2):350.
32. Ventus D. Daniel Ventus: Diagnosis, Etiology, and Psychobehavioral Treatment of Premature Ejaculation.
33. Brenner IKM, Brown CA, Hains SJM, Tranmer J, Zelt DT, Brown PM. Low-Intensity Exercise Training Increases Heart Rate Variability in Patients With Peripheral Artery Disease. Biological Research For Nursing. 2020 Jan;22(1):24–33.
34. Alansare A, Alford K, Lee S, Church T, Jung H. The Effects of High-Intensity Interval Training vs. Moderate-Intensity Continuous Training on Heart Rate Variability in Physically Inactive Adults. IJERPH. 2018 Jul 17;15(7):1508.
35. Niu C, Wen G, Ventus D, Zhang Y, Jern P, Santtila P. A 2-week high-intensity interval training intervention improves ejaculation control among men with premature ejaculation. Andrology. 2023 Jun 8;andr.13469.
36. Agostini LCM, Netto JMB, Miranda MV, Figueiredo AA. Erectile dysfunction association with physical activity level and physical fitness in men aged 40–75 years. Int J Impot Res. 2011 May;23(3):115–21.
37. La Vignera S, Condorelli R, Vicari E, D'Agata R, Calogero AE. Physical Activity and Erectile Dysfunction in Middle-Aged Men. Journal of Andrology. 2012 Mar 1;33(2):154–61.
38. (Bud) Craig A. Interoception: the sense of the physiological condition of the body. Current Opinion in Neurobiology. 2003 Aug;13(4):500–5.
39. Craig AD. How do you feel? Interoception: the sense of the physiological condition of the body. Nat Rev Neurosci. 2002 Aug 1;3(8):655–66.
40. Azzalini D, Rebollo I, Tallon-Baudry C. Visceral Signals Shape Brain Dynamics and Cognition. Trends in Cognitive Sciences. 2019 Jun;23(6):488–509.
41. Quigley KS, Kanoski S, Grill WM, Barrett LF, Tsakiris M. Functions of Interoception: From Energy Regulation to Experience of the Self. Trends in Neurosciences. 2021 Jan;44(1):29–38.

42. Chen J, Yang J, Xiang Z, Huang X, Lu C, Liu S, et al. Graph theory analysis reveals premature ejaculation is a brain disorder with altered structural connectivity and depressive symptom: A DTI-based connectome study. Eur J Neurosci. 2021 Mar;53(6):1905–21.
43. Berntson GG, Khalsa SS. Neural Circuits of Interoception. Trends in Neurosciences. 2021 Jan;44(1):17–28.
44. Calì G, Ambrosini E, Picconi L, Mehling WE, Committeri G. Investigating the relationship between interoceptive accuracy, interoceptive awareness, and emotional susceptibility. Front Psychol [Internet]. 2015 Aug 24 [cited 2023 Mar 6];6. Available from: http://journal.frontiersin.org/Article/10.3389/fpsyg.2015.01202/abstract
45. Mehling WE, Price C, Daubenmier JJ, Acree M, Bartmess E, Stewart A. The Multidimensional Assessment of Interoceptive Awareness (MAIA). Tsakiris M, editor. PLoS ONE. 2012 Nov 1;7(11):e48230.
46. Price CJ, Hooven C. Interoceptive Awareness Skills for Emotion Regulation: Theory and Approach of Mindful Awareness in Body-Oriented Therapy (MABT). Front Psychol. 2018 May 28;9:798.
47. Wallman-Jones A, Palser ER, Benzing V, Schmidt M. Acute physical-activity related increases in interoceptive ability are not enhanced with simultaneous interoceptive attention. Sci Rep. 2022 Sep 5;12(1):15054.
48. Ferentzi E, Drew R, Tihanyi BT, Köteles F. Interoceptive accuracy and body awareness – Temporal and longitudinal associations in a non-clinical sample. Physiology & Behavior. 2018 Feb;184:100–7.
49. Garfinkel SN, Seth AK, Barrett AB, Suzuki K, Critchley HD. Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness. Biological Psychology. 2015 Jan;104:65–74.
50. Cabrera A, Kolacz J, Pailhez G, Bulbena-Cabre A, Bulbena A, Porges SW. Assessing body awareness and autonomic reactivity: Factor structure and psychometric properties of the Body Perception Questionnaire-Short Form (BPQ-SF). Int J Methods Psychiatr Res. 2018 Jun;27(2):e1596.
51. Li X, Zhang B, Li Y, Antonio ALM, Chen Y, Williams AB. Mental health and suicidal ideation among Chinese women who have sex with men who have sex with men (MSM). Women & Health. 2016 Nov 16;56(8):940–56.
52. Cho MH. Preliminary reliability of the five item physical activity questionnaire (PAQ). J Phys Ther Sci. 2016;28(12):3393–7.
53. Porges SW. Orienting in a defensive world: Mammalian modifications of our evolutionary heritage. A Polyvagal Theory. Psychophysiology. 1995 Jul;32(4):301–18.
54. Wang N, Ren F, Zhou X. Factor Structure and Psychometric Properties of the Body Perception Questionnaire–Short Form (BPQ-SF) Among Chinese College Students. Front Psychol. 2020 Jun 30;11:1355.
55. Mehling WE, Acree M, Stewart A, Silas J, Jones A. The Multidimensional Assessment of Interoceptive Awareness, Version 2 (MAIA-2). Costantini M, editor. PLoS ONE. 2018 Dec 4;13(12):e0208034.
56. Jern P, Piha J, Santtila P. Validation of Three Early Ejaculation Diagnostic Tools: A Composite Measure Is Accurate and More Adequate for Diagnosis by Updated Diagnostic Criteria. Speybroeck N, editor. PLoS ONE. 2013 Oct 15;8(10):e77676.
57. Rosen R, Cappelleri J, Smith M, Lipsky J, Peña B. Development and evaluation of an abridged, 5-item version of the International Index of Erectile Function (IIEF-5) as a diagnostic tool for erectile dysfunction. Int J Impot Res. 1999 Dec 1;11(6):319–26.
58. Rosen RC, Riley A, Wagner G, Osterloh IH, Kirkpatrick J, Mishra A. The international index of erectile function (IIEF): a multidimensional scale for assessment of erectile dysfunction. Urology. 1997 Jun;49(6):822–30.
59. Kolotkin RL, Zunker C, Østbye T. Sexual Functioning and Obesity: A Review. Obesity. 2012 Dec;20(12):2325–33.
60. Hu L, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Structural Equation Modeling: A Multidisciplinary Journal. 1999 Jan;6(1):1–55.
61. MacCallum RC, Browne MW, Sugawara HM. Power Analysis and Determination of Sample Size for Covariance Structure Modeling.
62. Pyke RE. Sexual Performance Anxiety. Sexual Medicine Reviews. 2020 Apr;8(2):183–90.
63. Kolacz J, Chen X, Nix EJ, Roath OK, Holmes LG, Tokash C, et al. Measuring Autonomic Symptoms with the Body Perception Questionnaire Short Form (BPQ-SF): Factor Analysis, Derivation of U.S. Adult Normative Values, and Association with Sensor-Based Physiological Measures [Internet]. Psychiatry and Clinical Psychology; 2022 Apr [cited 2023 Sep 9]. Available from: http://medrxiv.org/lookup/doi/10.1101/2022.04.27.22274391

Tables

Table 1

Description and Correlations between Age, BMI, Body Awareness, Parasympathetic Reactivity, Interoceptive Awareness, Physical Activity, and Sexual Dysfunction.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. CHEES (Premature Ejaculation)													
2. IIEF-5 (Erectile Function)	-.580**												
3. Control Problems	.920**	-.560**											
4. Age	-.076**	.056*	-.039										
5. BMI	.077**	-.121**	.071**	.037									
6. Physical Activity	-.327**	.258**	-.331**	.112**	-.041								
7. Body Awareness	.164**	-.173**	.106**	-.137**	-.007	.019							
8. Supradiaphragmatic	.061**	-.102**	.015	-.092**	-.070**	.052*	.816**						
9. Subdiaphragmatic	.026	-.085**	-.001	-.085**	-.025	.049*	.649**	.757**					
10. Noticing	-.249**	.275**	-.270**	.103**	-.057*	.369**	-.019	.001	.016				
11. Not-worrying	-.295**	.171**	-.235**	.039	.013	.129**	-.188**	-.098**	-.042	-.045*			
12. Self-regulation	-.386**	.336**	-.388**	.146**	-.074**	.398**	.070**	.128**	.134**	.629**	.112**		
13. Body Listening	-.359**	.307**	-.366**	.102**	-.109**	.440**	.111**	.193**	.184**	.618**	.056*	.752**	
N	1976	1976	1796	1976	1975	1976	1976	1976	1976	1976	1976	1976	1976
Mean	9.396	21.826	5.896	31.543	24.555	33.161	49.497	19.089	7.539	3.031	2.502	3.313	3.156
SD	2.800	2.592	1.740	5.259	5.635	11.825	12.894	6.655	3.133	0.985	0.792	0.959	1.107

*Note.*Higher values of CHEES suggest more premature ejaculation problems. Higher values of IIEF-5 suggest better erectile function. *p< .05,**p< .01.

Table 2

Direct Effects of Physical Activity on Body Awareness, Parasympathetic Reactivity and Interoceptive Awareness and Direct Effects of Body Awareness, Parasympathetic Reactivity and Interoceptive Awareness on Sexual Dysfunctions Before and After Controlling for Age and BMI.

	Physical Activity (Independent) (Free Time)			CHEES (Dependent) (Premature Ejaculation)			IIEF-5 (Dependent) (Erectile Function)			Control Problems (Dependent) (Ejaculation Control)		
Variables	*β*	*SE*	*p*	*β*	*SE*	*p*	*β*	*SE*	*p*	*β*	*SE*	*p*
Before Controlling												
Body Awareness	.019	.021	.373	.326	.040	< .001	-.249	.041	< .001	.234	.048	< .001
Supradiaphragmatic	.052	.019	.007	-.140	.046	.002	.091	.050	.068	-.136	.045	.002
Subdiaphragmatic	.049	.021	.019	-.063	.021	.061	-.005	.039	.904	-.042	.033	.213
Noticing	.369	.021	< .001	.003	.029	.908	.094	.029	.001	-.037	.035	.292
Not-worrying	.129	.024	< .001	-.244	.022	< .001	.139	.024	< .001	-.178	.022	< .001
Self-regulation	.398	.021	< .001	-.204	.037	< .001	.166	.035	< .001	-.264	.064	< .001
Body Listening	.440	.020	< .001	-.123	.033	< .001	.069	.036	.056	-.011	.100	.911
After Controlling												
Body Awareness	.018	.021	.400	.315	.040	< .001	-.232	.039	< .001	.231	.047	< .001
Supradiaphragmatic	.051	.019	.008	-.127	.048	.008	.066	.049	.179	-.129	.044	.003
Subdiaphragmatic	.049	.021	.017	-.067	.035	.058	.001	.039	.981	-.043	.033	.194
Noticing	.369	.021	< .001	.003	.029	.921	.095	.029	.001	-.038	.035	.277
Not-worrying	.129	.023	< .001	-.245	.021	< .001	.141	.025	< .001	-.179	.022	< .001
Self-regulation	.398	.022	< .001	-.203	.036	< .001	.166	.038	< .001	-.269	.064	< .001
Body Listening	.439	.020	< .001	-.118	.034	.001	.057	.037	.124	-.006	.100	.953

Note. Higher values of CHEES suggest more premature ejaculation problems. Higher values of IIEF-5 suggest fewer erectile problems.

Table 3

Indirect Effects of Physical Activity on Sexual Dysfunction via Body Awareness, Parasympathetic Reactivity and Interoceptive Awareness.

	CHEES (Premature Ejaculation)			IIEF-5 (Erectile Function)			Control Problems (Ejaculation Control)		
	Indirect Effect	*SE*	95% CI	Indirect Effect	*SE*	95%CI	Indirect Effect	*SE*	95% CI
Body Awareness	.006	.007	-.008, .019	-.004	.005	-.014, .005	.004	.005	-.005, .014
Supradiaphragmatic	**-.007**	.004	-.015, -.001	.003	.003	-.001, .011	**-.007**	.003	-.014, -.001
Subdiaphragmatic	-.003	.002	-.008, 0	0	.002	-.005, .004	-.002	.002	-.006, .001
Noticing	.001	.011	-.020, .021	**.035**	.011	.014, .057	-.014	.013	-.040, .011
Not-worrying	**-.032**	.006	-.045, -.021	**.018**	.004	.010, .027	**-.023**	.005	**-**.034, -.014
Self-regulation	**-.081**	.015	-.112, -.055	**.066**	.016	.037, .097	**-.107**	.026	**-**.160, -.061
Body Listening	**-.052**	.015	-.081, -.023	.025	.016	-.006, .059	-.003	.043	-.073, .077

Note. Higher values of CHEES suggest more premature ejaculation problems. Higher values of IIEF-5 suggest fewer erectile problems. The significant indirect effects are shown in bold.

Figures

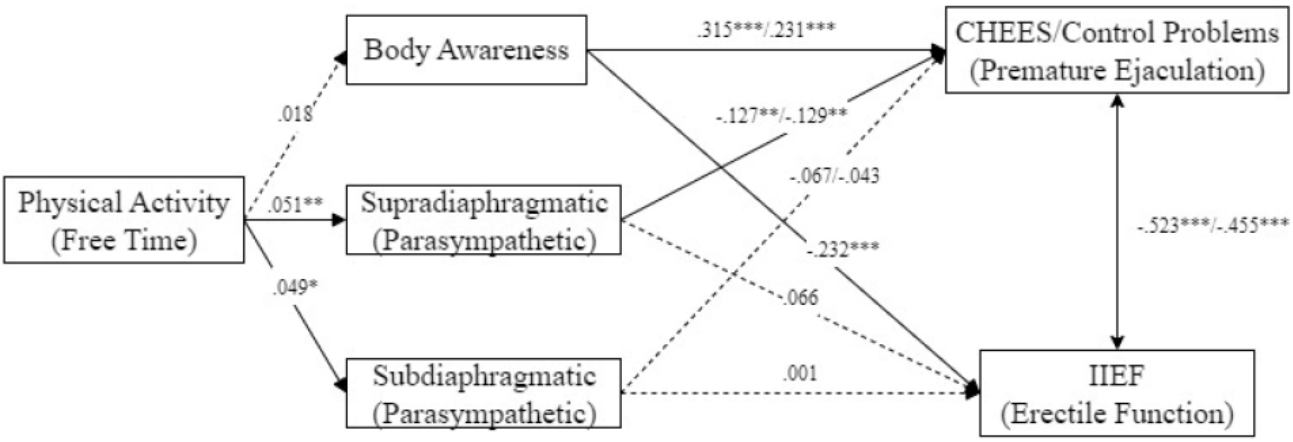

Figure 1

Mediation Effects of Body Awareness and Parasympathetic Reactivity during Sex on the Association between Physical Activity and Sexual Dysfunction.

Note. Higher values of CHEES suggest more premature ejaculation problems. Higher values of IIEF-5 suggest fewer erectile problems. The parameter estimates before and after the slash (/) means the scale of CHEES and Control Problems. The direct effects of physical activity on the CHEES/Control Problems and IIEF were significant.

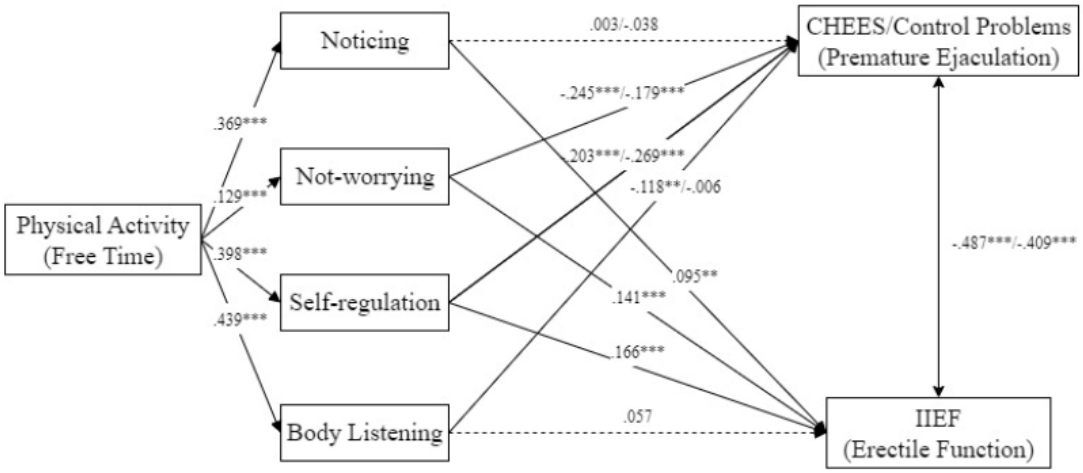

Figure 2

Mediation Effects of Interoceptive Awareness on the Relationship between Physical Activity and Sexual Dysfunction.

Note. Higher values of CHEES suggest more premature ejaculation problems. Higher values of IIEF-5 suggest fewer erectile problems. The parameter estimates before and after the slash (/) means the scale of CHEES and Control Problems. The direct effects of physical activity on the CHEES/Control Problems and IIEF were significant.