Effects of sleep restriction and exercise deprivation on somatic symptoms and mood in healthy adults

J.N. Ablin[1], D.J. Clauw[2], A.K. Lyden[2], K. Ambrose[2], D.A. Williams[2], R.H. Gracely[3], J.M. Glass[2]

[1]*Institute of Rheumatology, Sourasky Medical Center, Tel Aviv, and Tel Aviv University faculty of Medicine, Israel;* [2]*University of Michigan, Ann Arbor MI, USA;* [3]*University of North Carolina, Chapel Hill, NC, USA.*

Jacob N. Ablin, MD
Daniel J. Clauw, MD
Angela K. Lyden, MS
Kirsten Ambrose, MS
David A. Williams, PhD
Richard H. Gracely, PhD
Jennifer M. Glass, PhD

Please address correspondence to:
Jacob N. Ablin MD,
Institute of Rheumatology,
Tel Aviv Soourasky Medical Center,
Weizmann St. 6,
Tel Aviv, Israel.
E-mail: ajacob@post.tau.ac.il

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ABSTRACT

Objective. *Exposure to acute "stressors" (e.g. infections, pain, trauma) often results in altered sleep habits and reductions in routine activity. In some individuals, these behavioural responses to acute stressors may contribute to the development of chronic somatic symptoms such as widespread pain, fatigue, memory difficulties and mood disturbances, much like those associated with "functional somatic syndromes" (FSS) such as fibromyalgia or chronicfatigue syndrome.*

Methods. *Eighty-seven healthy young adults who reported sleeping between 7 and 9 hours nightly and exercising regularly were randomised to one of four groups: exercise cessation, sleep restriction (6 hours nightly), both, or neither. Symptoms of pain, fatigue, cognitive dysfunction and negative mood were measured before and after the 10-day restriction period.*

Results. *Sleep restriction was a potent contributor to the development of somatic symptoms. Exercise cessation was less influential leading only to fatigue. There were no significant interactions between exercise cessation and sleep restriction, except that males were much more likely to develop somatic symptoms when deprived of both sleep and exercise than one or the other. Women were generally much more likely to develop somatic symptoms than men.*

Conclusion. *This study supports previous research suggesting that both sleep and exercise are critical in "preventing" somatic symptoms among some individuals. Furthermore, to our knowledge, this is the first time there is data to suggest that women are much more sensitive to decrements in routine sleep and exercise than are men.*

Introduction

Sleep is a vital function. Sleep restriction or deprivation leads to decrements in performance and in some individuals, the development of pain, fatigue, negative mood and somatic symptoms (1-3). Likewise, cessation of regular exercise in individuals who exercise regularly can lead to negative mood and fatigue (4, 5). Both sleep and exercise may function to buffer the effects of stress, diminish pain sensitivity, and maintain alertness and vigilance (6, 7). Various forms of physical activity, including dancing have been shown to be effective in the management of fibromyalgia (8). Individuals with chronic conditions such as fibromyalgia and chronic fatigue syndrome (functional somatic syndromes; FSS) often report having disordered sleep and barriers to regular exercise. It is common for such individuals to report an active premorbid history (9, 10); thus we hypothesise that a lifestyle of regular sleep and exercise habits may buffer FSS, until some stressor disrupts exercise or sleep, resulting in FSS in susceptible individuals (5, 11, 12).

This prospective study was designed to examine the hypothesis that restriction of sleep and/or exercise is capable of promoting unwanted symptoms across several domains: pain, fatigue, negative mood, somatic symptoms and cognition. Demonstration of these effects in healthy men and women provides one line of evidence that this mechanism can mediate symptoms in FSS. Participants were healthy men and women who exercised regularly and reported sleeping between 7 and 9 hours per night. Although it is known that total sleep deprivation (24-36 hours awake) as well as selective sleep stage disruption (*e.g.* REM or slow wave deprivation) can lead to increased symptoms of pain and somatic complaints, less is known about the effects of partial sleep restriction that mimic naturally occurring disruptions of sleep

(1, 2, 13, 14). Similarly, exercise deprivation has been shown to increase feelings of fatigue and negative mood, but its effects on other symptom domains have not been investigated thoroughly. Moreover, the combined effect of sleep restriction and exercise deprivation are not known. This study is unique as it used a real-life analogue of extended sleep restriction (six hours of sleep per night for ten days) and exercise deprivation that may be experienced by otherwise healthy individuals during a time of personal crisis. Since most FSS are more common in women (*e.g.* fibromyalgia (FM)), we hypothesised that women would be more sensitive to the effects of sleep and or exercise disruption.

Methods

Participants

The participants were asymptomatic, healthy active adults who reported running at least five days per week as well as sleeping at least 7–9 hours per night. Individuals diagnosed with chronic medical disorders or taking chronic medications (not including birth control) were excluded. The study was approved by the Institutional Review Board of the University of Michigan and each participant gave written informed consent. Ninety-four individuals, including 57 females and 37 males were randomised, and 87 participants completed the study. The mean age was 27.2 (SD-5.6). Participants reported performing an average of 5.14 hours of running weekly, with a range of 2–15 hrs.

Study design

The participants were randomly assigned to one of four groups: (1) control (un-modified exercise and sleep), (2) exercise deprivation (*i.e.* no running permitted), (3) sleep restriction (*i.e.* 6 contiguous hours in bed per night), and (4) both exercise and sleep restriction. The deprivation period lasted 10 days. To ensure compliance with the treatment assignment, participants wore activity monitors throughout the baseline and treatment periods and completed sleep and activity diaries. The activity monitors allowed assessment of time asleep as well as activity during the day. Participants underwent assessment at baseline and again near the end of the 10-day deprivation period.

Measures

Assessments consisted of both self-report measures and neuropsychological evaluation. Domains of assessment included inventories chosen to capture symptoms in various domains associated with the FSS: pain, fatigue, negative mood, dyscognition (perceived cognitive problems), somatic complaints and performance on a test of attention and vigilance.

Pain. The VAS from the short-form McGill Pain Questionnaire (MPQ) was used to assess current clinical pain intensity (15).

Fatigue. The Multidimensional Fatigue Inventory (MFI) was used to quantify different facets of fatigue (16). The MFI is a 20-item survey organised into five fatigue categories (general fatigue, physical fatigue, mental fatigue, reduced motivation and reduced activity). It has been used previously in CFS and FM patients (17).

Negative mood. Sub-diagnostic *affective status* was assessed using several instruments. The Center for Epidemiological Studies Depression Scale (CES-D)(18) is a 20-item self report questionnaire that assesses symptoms of depression in non-psychiatric adults and has strong association with other measures of depression. The Perceived Stress Scale (PSS) is a 10-item self-report questionnaire that assesses symptoms of stress. Symptoms of anxiety were assessed using the trait anxiety subscale of the State-Trait Personality Inventory (STPI) (19). The Profile of Mood States (POMS) is another measure of affect that assesses tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment (20). We chose to include this additional instrument because it has been sensitive to sub-clinical mood changes associated with exercise withdrawal (4, 21-23).

Dyscognition. Perceived cognitive difficulties were assessed using the Multiple Ability Self-Report Questionnaire (MASQ), a brief questionnaire comprised of 5 cognitive domains: language ability, visual-perceptual ability, verbal memory, visual memory and attention (24).

Somatic symptoms. Sensitivity to somatic symptoms was assessed using the Modified Somatic Perceptions Questionnaire (MSPQ) (25). This 22-item questionnaire assesses the degree to which individuals report a number of common somatic sensations as problematic.

Attention and vigilance. In addition to the self-report measures described above, participants were also administered the Psychomotor Vigilance Task (PVT). In this computerised task, participants monitor a "counter." Once the counter starts timing, the participant must press a key to stop the counter as quickly as possible. The counter then resets automatically, and after a randomly selected time interval (2, 4, 6, 8, or 10 seconds) it starts timing again. This sequence repeats for the duration of the 10-minute task. The metric derived from this task is the number of lapses (*i.e.* defined as responses greater than 500 ms.). The PVT is highly sensitive to sleep restriction, showing decrements in performance as fine grained as shifting from 9 to 8 hours of sleep (13, (26). This measure is highly reliable and is not affected by repeated administrations (27).

Data analysis

Given the large number of measures used in this study, several steps were taken to reduce the number of comparisons and to simplify presentation of the results. First, for symptom domains evaluated by a number of instruments, or when the instruments provided several sub-scales (fatigue, negative mood, and dyscognition) the measures were averaged to produce one measure for each symptom domain. Principal component analyses provided strong support for averaging the measures in all cases. Second, the summary scores for each domain were averaged to create one omnibus symptom change variable. The primary analysis was then carried out on the omnibus variable. If significant effects occurred on the omnibus variable, secondary analyses were conducted to examine effects on each individual symptom domain.

Symptom domain scores

Prior to analyses, all scores were scaled using the entire range possible for that particular measure, thus the measures range from 0 to 1. This allowed for easy comparison and averaging of the individual measures. The PVT number-of-lapses measure was excluded from this scaling procedure. This method of scaling was used instead of normalising the measures to z-scores. Z-scores are based on sample means, and we expect the means to increase post-intervention. Therefore, using z-scores would diminish our ability to detect post-intervention change in our measures. To calculate change scores, the scaled baseline scores were subtracted from the scaled post-intervention scores. For ease of presentation, all analyses of variance were conducted using change scores. However, the same pattern of results was obtained using repeated measures analysis of variance with time (baseline versus post-intervention) as the repeated measure.

Results

Effects of sleep restriction, exercise deprivation and sex

Baseline levels of exercise (miles run per week) and sleep (hours per night) are presented in Table I. As indicated in the table, there was no significant difference in level of exercise (miles run per week), in number of baseline sleep hours or is baseline sleep quality (MOS sleep adequacy subscale) between male and female participants.

Total symptoms. An ANOVA using Total Symptoms Change indicated significant main effects of sleep restriction ($F(1, 79) = 23.44$, $p<0.001$) and sex ($F(1, 79) = 7.77$, $p=0.007$). Sleep restriction was associated with an increase in symptoms. Women were more likely to report increased symptoms overall. Examination of Figure 1 shows that men were more likely to report *decreased* symptoms in the control and exercise deprivation groups, whereas women were more likely to report *increased* symptoms in the sleep restriction and the exercise and sleep restriction groups. Exercise deprivation did not significantly change symptoms, and none of the interactions between sleep restriction, exercise deprivation or sex were significant. Post hoc analyses of the sex differences for each sleep by exercise condition showed that men reported fewer symptoms in each group, except for the combined sleep restriction/exercise deprivation group where there were no differences between men and women.

Following the significant results with the omnibus variable, the effects on each individual symptom domain were examined in separate ANOVAs.

Table I. Baseline levels of sleep, sleep adequacy and exercise in study groups.

Group	Average exercise (miles per week ± SD	Sleep at baseline (hours per night))	MOS sleep adequacy subscale
Exercise deprivation	26.3 ± 12.0	7.6 ± 0.6	68.5 ± 17.8
Sleep restriction	29.3 ± 8.8	7.6 ± 0.6	71.0 ± 18.2
Exercise & sleep restriction	25.2 ± 2	7.9 ± 0.6	73.7 ± 22.8
Normal activity	28.1 ± 8.8	7.7 ± 0.5	70.0 ± 18.5
Males (total, n=48)	28.6 ± 10.7*	7.7 ± 0.6**	72.0 ± 17.9***
Females (total, n=44)	25.9 ± 7.0*	7.7 ± 0.6**	68.7 ± 19.9***

*p=0.17; **p=0.73; ***p=0.46.

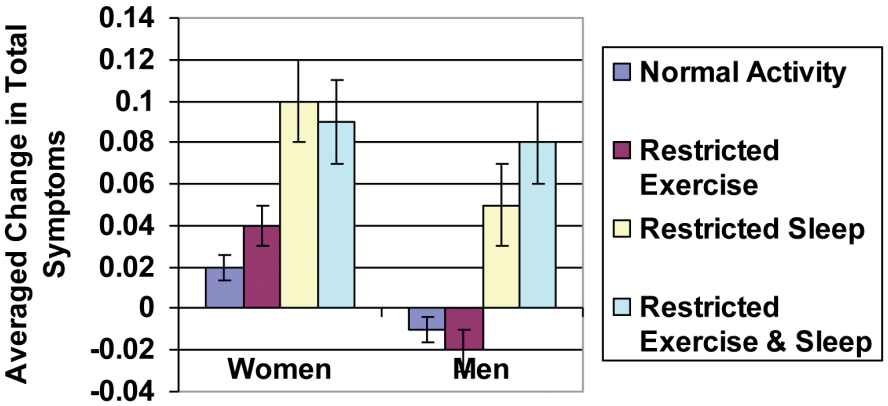

Fig. 1. Change (post-intervention minus baseline) in total mean symptoms by sex and intervention group.

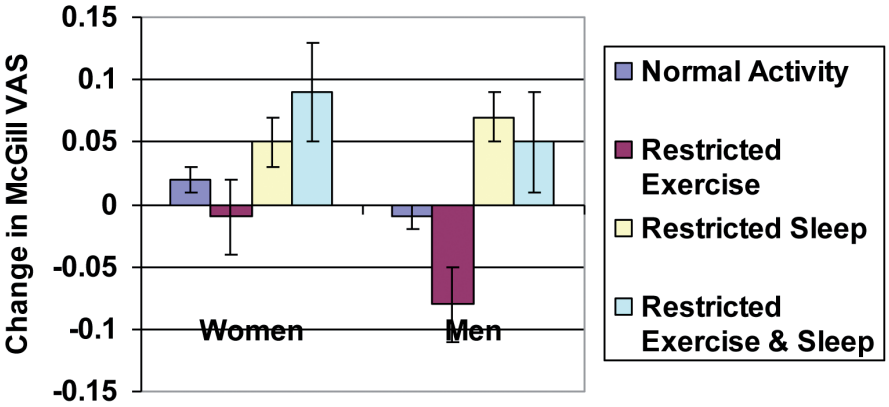

Fig. 2. Change (post-intervention minus baseline) in pain (McGill visual analog score) by sex and intervention group.

Self-reported pain

A significant effect of sleep restriction ($F(1,76) = 7.33$, $p=.008$) was found for the McGill VAS. There were no other significant effects. Figure 2 shows that pain increased in both restricted sleep groups in both men and women.

Fatigue

Significant effects of sleep restriction ($F(1, 77) = 17.29$, $p<0.001$) and exercise deprivation ($F(1, 77) = 5.53$, $p=0.021$) were found for fatigue along

with an interaction between sex, sleep restriction, and exercise deprivation (F (1, 77) = 4.19, p=.044). As seen in Figure 3, for women, restricting either exercise or sleep resulted in increased symptoms of fatigue. For men, increased symptoms of fatigue were observed for only the combined sleep restriction/exercise deprivation group.

Negative mood. Significant effects of sleep restriction (F (1, 78) = 17.59, p<0.001) and sex (F (1, 78) = 3.86, p=0.053) were found for the combined negative mood measure. Figure 4 shows that women were more likely to have increased symptoms of negative mood and that sleep restriction was most likely to increase symptoms, whether alone or with exercise deprivation. No other effects or interactions were significant. A very similar pattern was observed for the POMS total mood disturbance score (Fig. 5): sleep restriction (F (1, 68) = 14.92, p<0.001), sex (F (1, 68) = 6.63, p=0.012). Additionally, there was a trend for an interaction between sex, sleep restriction and exercise deprivation (F (1, 68) = 2.95, p=0.090). For women, sleep restriction resulted in increased symptoms whether or not exercise deprivation was present. For men, increased symptoms were only observed in the combined sleep restriction/exercise deprivation group.

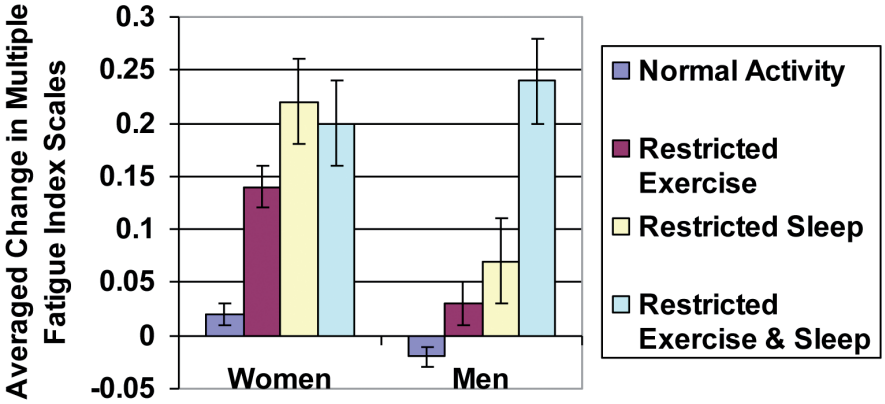

Fig. 3. Change (post-intervention minus baseline) in fatigue (mean Multiple Fatigue Index scales) by sex and intervention group.

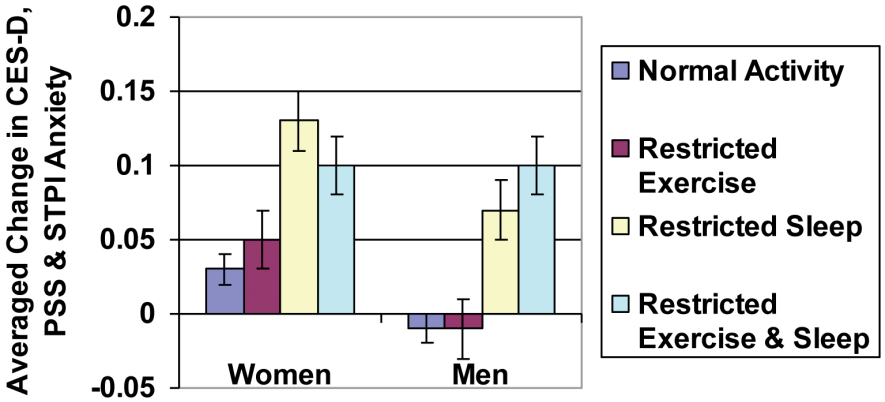

Fig. 4. Change (post-intervention minus baseline) in negative mood (mean Center for Epidemiological Studies Depression Scale, Perceived Stress Scale, State-Trait Personality Inventory-Anxiety subscale) by sex and intervention group.

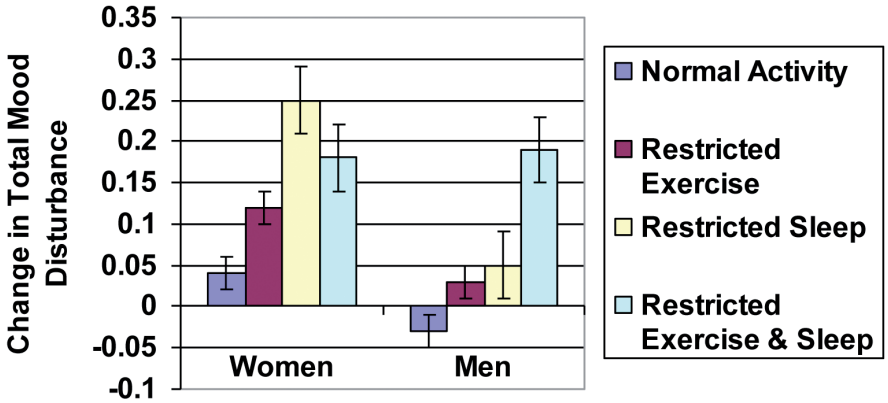

Fig. 5. Change (post-intervention minus baseline) in total mood disturbance (Profile of Mood States) by sex and intervention group.

Dyscognition

Significant effects of sleep restriction (F (1, 68) = 6.62, p=0.012) and sex (F (1, 68) = 6.65, p=0.012) were found for the MASQ combined measure. Figure 6 shows that women were more likely to have increased symptoms of dyscognition, and that sleep restriction was most likely to increase symptoms, whether alone or with exercise deprivation. No other effects or interactions were significant.

Somatic complaints

Significant effects of sleep restriction (F (1, 74) = 8.13, p<0.006) and a marginal effect of sex (F (1, 74) = 3.90, p=0.052) were found for the MSPQ. Figure 7 shows that women were more likely to report more intense somatic sensations (*e.g*. stomach pains, muscle aches, tense feelings across the forehead, etc.) and that sleep restriction was most likely to increase these sensations. No other effects or interactions were significant.

Attention and vigilance

Data from one subject were excluded due to extremely long reaction times (more than 3 s) and number of lapses in baseline testing. Significant effects of sleep restriction (F (1, 76) = 4.66, p<0.034) and a sex by exercise deprivation interaction (F (1,74) = 7.67, p=0.007) were found for the number of lapses in the PVT. Figure 8 shows that in both men and women sleep restriction resulted in increased lapses. However, for men, exercise depriva-

tion appeared to reduce the number of lapses regardless of sleep restriction.

Correlations between symptom domain change scores

To examine whether there is a tendency for individuals who have increased symptoms in one domain to also have increased symptoms in other domains, we conducted a partial correlation analysis using the change scores from each domain with baseline Averaged Total Symptoms as the control variable. Participants from the control condition (normal sleep and exercise) were excluded from this analysis. Results (Table II) show significant positive correlations between each domain, with the exception of pain and negative affect. This suggests that individuals with increased symptoms in one domain are likely to experience increased symptoms in other domains as well.

Discussion

In the current study, we observed that healthy young individuals faced with short-term sleep restriction that might occur in response to a variety of naturally occurring life stressors reported significant increases in pain, fatigue, negative mood, dyscognition, somatic symptoms and vigilance. These results are notable because in this study, the sleep restriction was not severe – participants could sleep up to six hours per night – yet the effects were observable. Sleep disorders including non-restorative sleep are an integral clinical component of the fibromyalgia syndrome and are considered to be consistent with the concept of central sensitisation underlying this condition (28, 29). In fibromyalgia (as well as in other conditions associated with chronic pain) sleep quality has been associated with levels of pain, fatigue and depression (30).

In the current study, sleep restriction appeared to be a much more potent stressor than was exercise deprivation, since exercise deprivation did not result in significant changes in the composite symptom score in this particular sample. The effects of exercise deprivation were limited to increased fatigue. Prior research on exercise cessation has focused on changes in fatigue and mood (4). The present results partially replicate these findings since fatigue was increased with cessation of exercise. However, we failed to replicate the large increase in negative mood observed previously. One possible reason for the attenuated response to exercise deprivation in our study was that we allowed individuals to maintain daily living activities, which may have included walking to school or work. Ten days of more profound inactivity may have produced markedly different results.

The hypothesis that exercise deprivation and sleep restriction together would have multiplicative effects on symptom development was not sup-

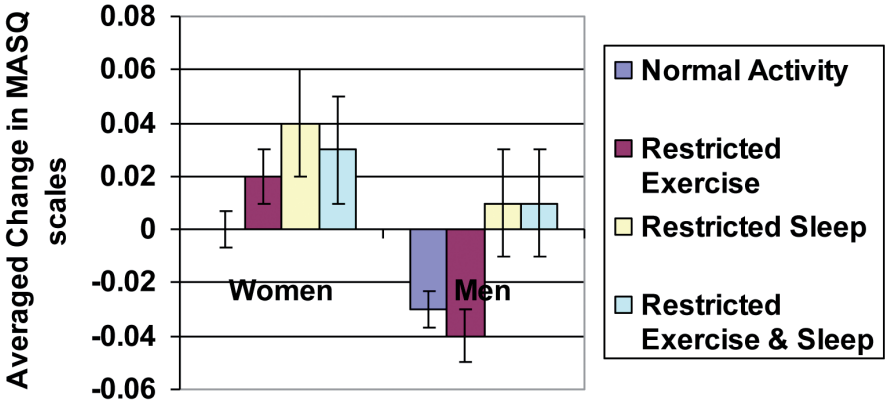

Fig. 6. Change (post-intervention minus baseline) in dyscognition (mean Multiple Abilities Self-Report Questionnaire scales) by sex and intervention group.

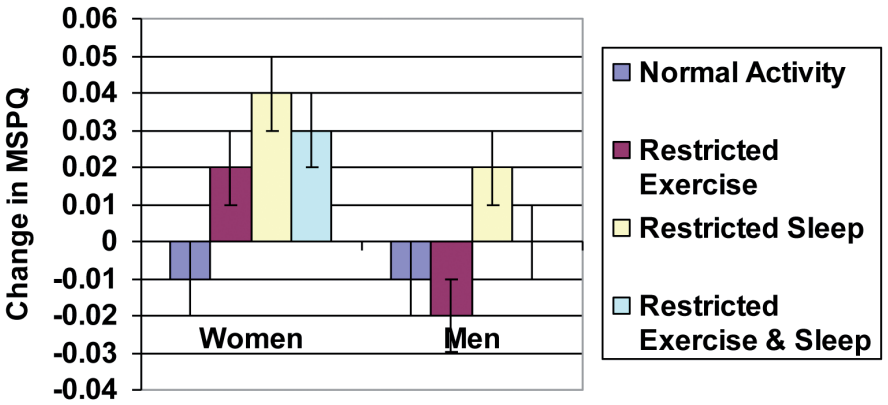

Fig. 7. Change (post-intervention minus baseline) in somatic symptoms (mean Modified Somatic Perceptions Questionnaire) by sex and intervention group.

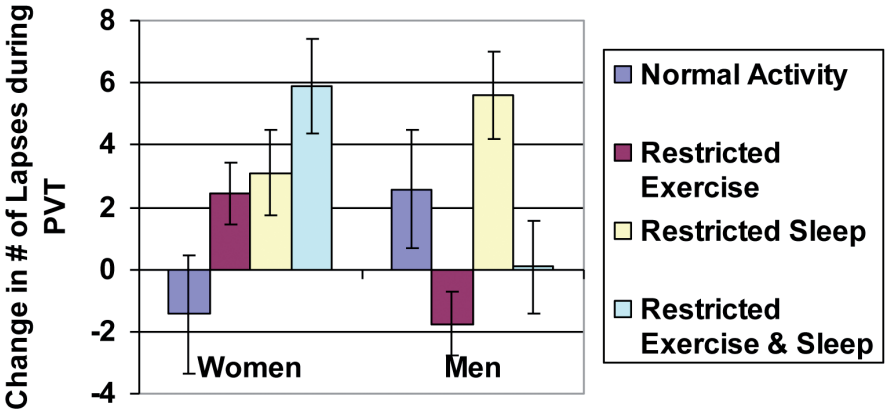

Fig. 8. Change (post-intervention minus baseline) in attention and vigilance (number of lapses in the Psychomotor Vigilance Test) by sex and intervention group.

Table II. Partial correlations among change scores after controlling for baseline average total symptoms.

	Fatigue	Negative Mood	POMS-TMD	Dyscognition	Somatic Complaints
Pain	0.489***	0.261	0.432**	0.397**	0.485***
Fatigue		0.518***	0.605***	0.650***	0.537***
Negative mood			0.648***	0.313*	0.364*
POMS-TMD				0.510***	0.394**
Dyscognition					0.553***

***p<0.001; **p<0.01; *p<0.05

ported in the analysis of Total Symptom Change. However, for measures of fatigue, there appeared to be an important sex difference. On average, men did not experience increased fatigue unless sleep restriction was combined with exercise deprivation. A similar trend was observed for negative mood measured with the POMS total mood disturbance.

In addition to the pervasive effects of sleep restriction, we also noted a consistent influence of sex. In the analysis of Total Symptom Change, women were more likely to report increased symptoms than men in the exercise deprivation treatment group and in the sleep restriction group. In the combined exercise deprivation/sleep restriction group, men and women had similar increases in symptoms. Thus women were more sensitive to the influences of sleep restriction and exercise deprivation than were men. This pattern of increased sensitivity in women was observed in negative mood, dyscognition, and somatic symptoms. The reason for the difference between women and men in these aspects is not readily evident. Notably, men and women participating in the study did not differ significantly in baseline measures of sleep (quantity and quality) or in levels of exercise, thus indicating that the observed results reflect a true gender – based difference. Theoretically, intense excersice might have a negative effect on sleep quality which could improve with exercise restriction, but this would still not explain the difference between men and women with similar baseline levels of exercise. Thus, further research into the gender differences relating to the response to exercise restriction is called for.

One other study has reported sex differences in the effects of sleep deprivation in a cognitive estimation task (*e.g.*, how many seeds are in a watermelon?) such that women, but not men, had impaired performance after 46 hours of sleep deprivation (31).

Additionally, we found that individuals reporting an increase in one somatic symptom following sleep or exercise restriction were generally more likely to report increases in many or all other symptoms. Thus it is entirely possible that the results of this study have relevance to factors that may promote the development of FSS, where (especially over the course of their lifetime) individuals will meet criteria for many of these symptoms and syndromes rather than just one (32, 33).

Finally, we observed individual variation in the development of symptoms, which can be seen by examination of the standard error bars in all graphs. The concept which has emerged from our preliminary results (5) and which is corroborated by the current results and earlier studies of sensitivity to sleep deprivation (3) is that some healthy individuals possess an underlying "diathesis" which, under a particular set of stressors, may lead to the development of FSS-like symptoms. As implied above, this diathesis probably reflects the variability in genetic predisposition to experiencing chronic somatic symptoms. Genetic markers such as the variants (haplotypes) of the gene encoding catecholamine-O-methyltransferase (COMT), which has been shown to influence pain sensitivity and the risk of developing chronic pain (34), would appear to be possible candidate for mediating such a diathesis. The intriguing concept that exercise deprivation and sleep restriction invoke increased pain and other symptoms may well explain why particular individuals faced with forced inactivity and disrupted sleep resulting from either physical trauma or other medical disorders (*e.g.* infections) may be prone to lapse into pain. Further, it suggests that some individuals may actually learn to "self–medicate" with regular exercise or sleep, as a means of preventing the development of unpleasant symptoms.

In the current study, symptoms of dyscognition were significantly increase by sleep restriction while exercise restriction appeared to increase such symptoms only among women. Cognitive symptoms are increasingly recognised as a major complaint impairing the quality of life of patients suffering from functional somatic syndromes such as fibromyalgia (35) and have been incorporated into the updated diagnostic criteria of that syndrome (36). Thus, understanding the interaction between dyscognition and other symptoms, as well as triggers, of the FSS is an important issue; our results may shed some light on the way in which gender – specific reaction to stressors may impact on the propensity to develop FSS-like symptoms.

The results of this study have implications not only for the management of FSS, but for primary prevention as well. Patients with FSS should be mindful to plan their exercise and sleep patterns accordingly, resisting the urge to automatically curtail activity during a "stressor" and to continually practice good sleep hygiene. Likewise, those in the general population who "self-medicate" can be taught awareness to ensure continued participation in adequate exercise and sleep behaviours.

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