Effect of Indicators of Exercise on Sleep Efficiency

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Abstract. Although sleep is important for good health, the number of people suffering from insomnia has increased in recent years, making it important to find ways that can promote sleep. Research has shown that most exercises have a sleep-promoting effect and rarely have a negative impact. In this paper, sleep efficiency is used as a measure of sleep quality to compare and analyse the effects of different intensities of exercise on sleep efficiency, as well as the effects of various exercise indicators, and to conclude how exercise can most effectively improve sleep efficiency. Through ANOVA and linear regression, the study found that exercise in different state may have different preferred patterns which are beneficial to promote sleep efficiency. In general, exercise is better than keep sitting still as the increase in calorie consumption and some other indicators have positive effects on sleep efficiency. Besides, some interaction factors also have significant effects.

Keywords: Linear regression, ANOVA, interaction effect, sleep efficiency, exercise.

1. Introduction

Sleep, as a behavior that takes up a lot of time every day, has a significant contribution to health that is still beyond understanding [1]. Numerous studies claim that sleep has positive impact on both physical health and mental health. For example, sleep may help improve consolidation of one's memory by reactivating neuronal memory representations that are encoded recently before sleep, which happen during slow-wave sleep (SWS), and transform reactivated representations into long-term memory [2]. Replenishment of cerebral glycogen stores, an important part of metabolic functions and energy balance, is the restorative process that also takes place in sleep [3]. There is also evidence that the restorative function of sleep may be achieved by removing potential neurotoxic waste that accumulate in the waking central nervous system [4].

However, more and more people are suffering from insomnia for various reasons. Mental stress, excitement, depression, fear, anxiety, boredom and other mental factors can often cause insomnia; work and study stress, environmental changes, noise, light and air pollution and other social and environmental factors are another important cause; too much dinner, tea and coffee before bedtime and these bad habits can also cause insomnia. Insomnia is also associated with poor sleep hygiene habits, such as reading in bed, watching TV, or drinking alcohol, coffee and tea at night. Poor sleep hygiene can disrupt the normal rhythm of sleep, leading to disruption of sleep patterns and causing insomnia [5].

Long-term sleep deprivation will make the body's immune function low and reduce the ability to resist disease. It may also lead to memory loss and the decline of brain function [6]. One of the most serious risks of chronic insomnia is the increased risk of many diseases, such as heart disease, high blood pressure, dementia, menopausal syndrome, and depression and anxiety disorders [5]. These serious effects that can result from lack of sleep or low-quality sleep make it even more important to find ways to promote better sleep quality.

There are many ways to promote sleep quality, of which exercise is a more effective one with little side effect. Several studies have proved that all kinds of physical activity and exercise can effectively improve sleep quality [7]. A prior study indicates that rope skipping is effective in relieving anxiety and depression for college students, and can significantly improve the sleep efficiency of the subjects [8]. Traditional Chinese exercises such as Tai Chi and Qi Gong can increase energy expenditure, promote the release of endorphins in the brain, speed up metabolism and have a stress-relieving and mood-stabilizing effect, thus contributing to the quality of sleep of older people [9]. Contrary to

common knowledge, experiments have shown that even late-night exercise has no significant negative effect on sleep. [10].

For patients suffering from pulmonary disease, mental illness or other kinds of disease that may make it difficult for them to sleep, exercise also works in improving their sleep quality [11,12]. In the study of relationship between sleep quality and functional exercise capacity in chronic obstructive pulmonary disease (COPD), subjects' conditions of sleep were assessed with Pittsburgh Sleep Quality Index (PSQI) and their exercise capacity is evaluated by 6-min walk distance(6MWD). It turns out that subjects with lower PSQI also tends to have shorter 6MWD, and subjects with worse exercise capacity had worse sleep quality as well [11]. It is also found out that exercise demonstrated comparable efficacy to promoting improvements in sleep amongst people experiencing mental illness [12], while adequate sleep can help people improve their emotional regulation [13]. In this way, physical activities can provide effective treatment for people suffering from mental illness. From these studies, it is able to be found that staying active and maintaining the ability to exercise are both vital to keep the quality of sleep, and that quality sleep plays an important role in recovery from illness and in maintaining health. Therefore, the role of exercise in promoting sleep cannot be underestimated.

In addition, for patients with severe pulmonary and rheumatic diseases and some elderly people, intense and prolonged exercise is difficult, as they may be physically exhausted and the fatigue and pain after exercise is not conducive to good health. Working adults and students may also find it difficult to set aside enough time for exercise. Thus, it's of great importance to find the indicators that are most helpful for the sleep quality, which allows for targeted exercise for those who need it.

In order to solve the problems above, the aim of this study includes: (i) to test whether the quality of sleep improves as the indicators of exercise (distance, calories burnt, etc.) increase; (ii) how much of an increase in each indicator of exercise can have an impact on sleep quality improvement; and (iii) which indicators' increase may have better effects than others; (iv) exercise in which state may have positive effects on sleep efficiency. The findings of the study could help people who have difficulty exercising adequately to improve the quality of their sleep more efficiently.

2. Materials and Methods

2.1. Dataset and Original Variables

The data was collected through a distributed survey conducted by Amazon Mechanical Turk, with a total of 30 eligible Fitbit users agreeing to submit personal tracker data. The data provided included minute-level outputs including physical activity, heart rate and sleep monitoring. The survey was conducted from December 3, 2016 - December 5, 2016, but the tracker data collected were primarily distributed from April to May.

Table 1. Notations of variables used in the research

Variable names	Introduction
TotalSteps	the total amount of steps each subject takes per day
TotalDistance	total distance each subject takes per day (km)
VeryActiveDistance	distances in different states of exercise each subject take per day (km)
ModeratelyActiveDistance	
LightActiveDistance	
VeryActiveMinutes	amount of time in different states each subject spent per day (min)
FairlyActiveMinutes	
LightlyActiveMinutes	
SedentaryMinutes	
Calories	calories consumption of each subject per day (kcal)
TotalMinutesAsleep	the total amount of time each subject slept in minutes (min)
TotalTimeInBed	the total amount of time each subject spent in bed in minutes (min)

Although the dataset includes minute-level, hour-level and daily data, only daily data was used in this study as sleep data was only recorded at most once a day. Notations of variables used in the research and corresponding description are shown in the table below.

2.2. Data Screening and Pre-processing

2.2.1. Preliminary data processing

In the original dataset, the exercise-related data and the sleep-related data were in separate files, so it was necessary to first merge these two types of data. It was observed that some subjects had exercise data but lacked sleep data on that day, so only those observations with both exercise and sleep data were retained. There were 413 observations remaining after screening.

Since the time spent asleep is not an excellent criterion for evaluating sleep quality, the following new variable has been added.

$$\text{sleep_efficiency}=\frac{\text{TotalMinutesAsleep}}{\text{TotalTimeInBed}}. \tag{1}$$

2.2.2. Test of multi-collinearity

Multi-collinearity may lead to the distortion of model estimates or difficulty in estimating accurately due to the presence of exact or high correlations between the explanatory variables in a linear regression model. Therefore, in order to improve the accuracy of the model, variables need to be tested for multi-collinearity and the presence of multi-collinearity needs to be dealt with so as to avoid their presence negatively affecting the regression model as much as possible. The first step is to explore whether any of the variables are strongly correlated by means of correlation plots.

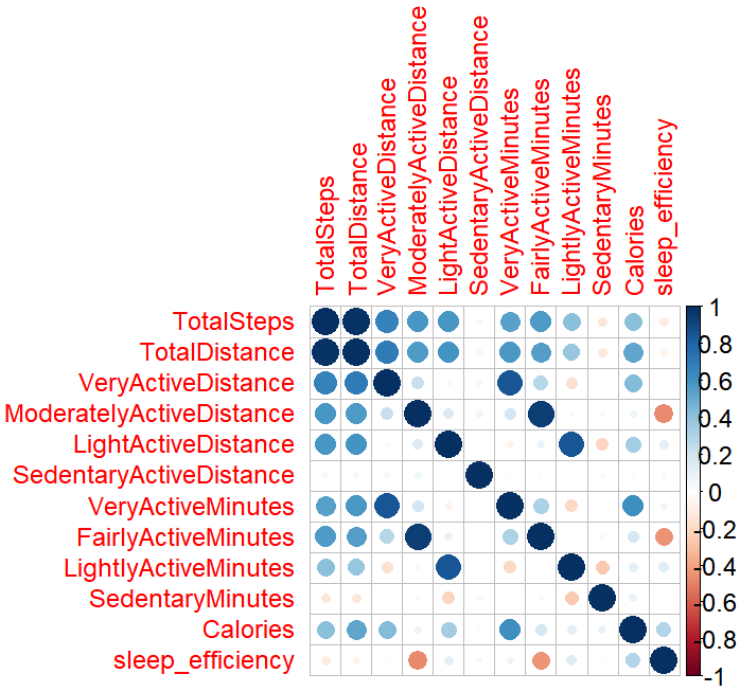


Figure 1. Correlation Plot of Variables

As can be seen from Fig. 1, assumptions are made that 'Total Steps' and 'Total Distance' may have significant positive correlation and the distance under different state and time spent in different state may also be correlated. The test of multi-collinearity is conducted and the assumptions are proved, which indicates the necessity of further adjustments.

2.2.3. Further data processing

In order to retain as much information as possible, the following new variables were first added.

$$\text{step_length} = \frac{\text{TotalDistance}\times 1000}{\text{TotalSteps}} \text{ (meter per step)}, \tag{2}$$

$$\text{veryactivespeed} = \frac{\text{VeryActiveDistance}\times 60}{\text{VeryActiveMinutes}} \text{ (km/h)}, \tag{3}$$

And 'airlyactivespeed' and 'lightlyactivespeed' are derived similarly. In this step, observation with time spent in different state being 0 have to be deleted. Therefore, there 266 observations left for further study. After that, 'TotalSteps', 'TotalDistance' and time spent in different state are eliminated to reduce correlation between variables, while 'SedentaryActiveDistance' is also deleted for its value of most subjects are 0s. In subsequent papers, these variable names are replaced by symbols, and the corresponding VIF values are shown in Table 2.

Table 2. Symbols for Variables and VIF Values

Symbols	Variable Names	VIF values
x_1	VeryActiveDistance	1.845
x_2	ModeratelyActiveDistance	1.096
x_3	LightActiveDistance	2.067
x_4	SedentaryMinutes	1.043
x_5	Calories	5.526
x_6	step_length	3.698
x_7	veryactivespeed	2.213
x_8	fairlyactivespeed	1.554
x_9	lightlyactivespeed	1.893

Most of the VIF values are less than 5 except that of 'Calories', which indicate that there is little multi-collinearity left in the variables other than 'Calories'. However, considering that calorie consumption is an important indicator to evaluate the level of exercise and that the VIF value did not exceed 5 by much, it was not removed.

2.3. Descriptive Statistics

Before in-depth research, basic information about the data is studied. First, distribution of sleep efficiency of all observations is shown in the histogram below.

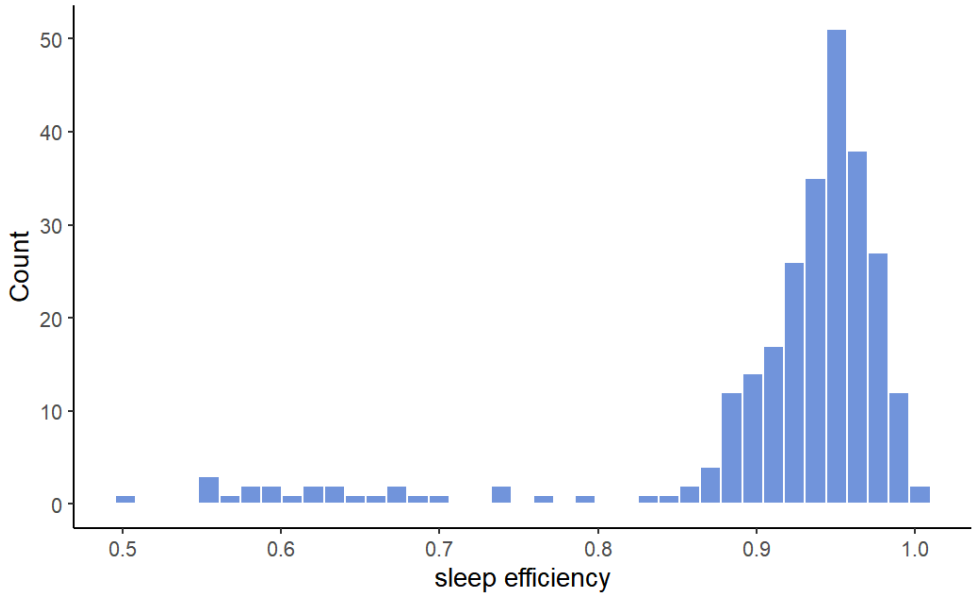


Figure 2. Distribution of Sleep Efficiency

As is shown in Fig. 2, most of the subjects generally have a high sleep efficiency. A small proportion is distributed between 0.5 and 0.8, while the vast majority are in the range of 0.9-1.0.

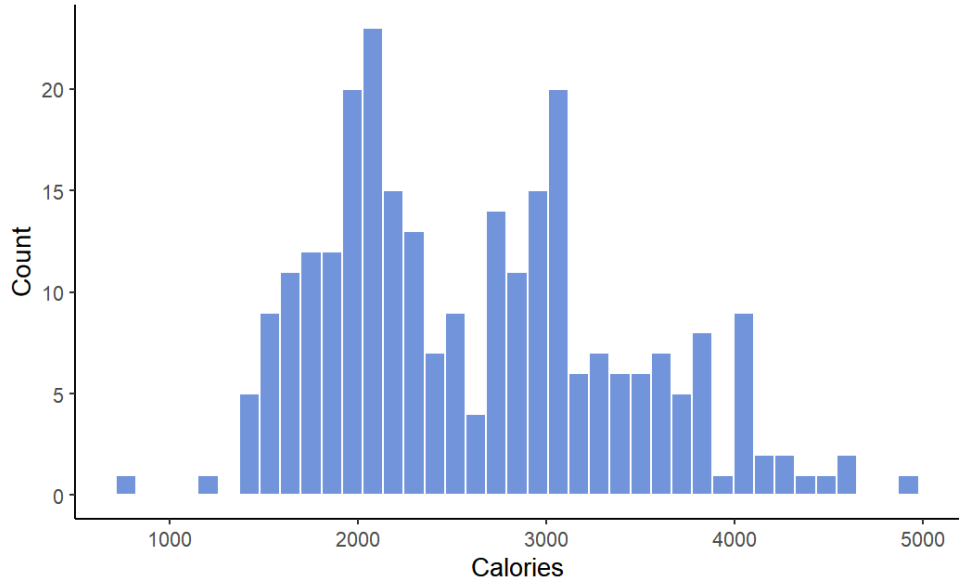


Figure 3. Distribution of Calorie Consumption

Distribution of calorie consumption is also plotted as Fig. 3. Most subjects consume 2000 - 3000 calories each day, with two peaks at around 2000 and 3000 respectively. Besides, comparison between speed of three active level is also concerned, which is presented in the boxplot and table below.

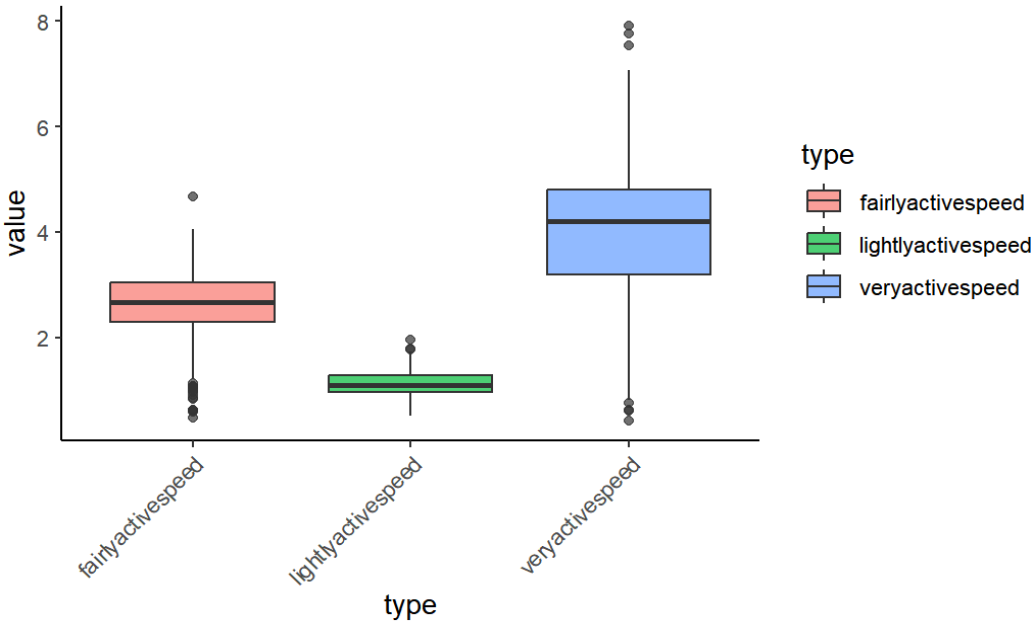


Figure 4. Boxplot of speed in different active level

Table 3. Basic information of speed in different active level

	mean	min	max	median
Veryactivespeed	3.941	0.415	7.911	4.2
Fairlyactivespeed	2.552	0.485	4.667	2.665
Lightlyactivespeed	1.139	0.509	1.955	1.099

According to the Fig. 4 and Table 3., there is indeed a difference in speed between the three levels. The main difference of speed in different active levels mainly appears in the maximum value, which indirectly leads to the difference in the mean and median.

2.4. Methods

2.4.1. Analysis of variance (ANOVA)

ANOVA is a statistical analysis method capable of determining the magnitude of the effects of controllable factors on the results of a study by analyzing and comparing the extent to which the total variance is affected by different factors, and is used to test the significance of differences between the means of two or more samples. Null hypothesis of ANOVA is usually that effect of the factor is not significant. The test statistic of ANOVA for factor A for example, is $F_0 = MS_A/MS_E$, where MS_A represent the mean square of the effects of factor A and MS_E stands for mean square error. The test statistic F_0 will be compared with F_α and when $F_0 > F_\alpha$, we may refuse the null hypothesis.

2.4.2. Multiple linear regression and variable selection

Multiple linear regression is a regression model with two or more independent variables and can be used for estimation and prediction. However, variable selection is required when there are too many variables. Variable selection may have different criterion, and the method used in this study select variables by AIC value. The formula for calculating AIC is as follows.

$$\mathrm{AIC} = 2\mathrm{k} - 2\ln(\mathrm{L}), \tag{4}$$

where k is the number of parameters and L is the likelihood function. With variable selection by AIC, a better model might be found.

3. Results and Discussion

3.1. The Effects of Indicators of Exercise on Sleep Efficiency

Analysis of variance (ANOVA) is conducted to test whether the effects of indicators of exercise on sleep efficiency show statistical significance. Results are presented in the following table 4.

Table 4. Analysis of Variance for Sleep Efficiency

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
VeryActiveDistance	1	0.011	0.011	2.092	0.149
ModeratelyActiveDistance	1	0.623	0.623	123.360	< 2.2e-16***
LightActiveDistance	1	0.144	0.144	28.561	2.01E-07***
SedentaryMinutes	1	0.002	0.002	0.423	0.516
Calories	1	0.165	0.165	32.653	3.05E-08***
step_length	1	0.073	0.073	14.397	0.000***
veryactivespeed	1	0.005	0.005	0.928	0.336
fairlyactivespeed	1	0.046	0.046	9.040	0.003**
lightlyactivespeed	1	0.023	0.023	4.561	0.034*
Residuals	256	1.293	0.005		

The distance passed by subjects in moderately active state or lightly active state, calories consumed, step length and the speed of subjects in moderately active state or lightly active state all have significant effect on sleep efficiency. Effects of the distance passed by subjects in very active state (P=0.149), the corresponding speed (P=0.336) and sedentary time (P=0.516) fail to reach level of statistical significance.

3.2. Multiple Linear Regression of Sleep Efficiency

On the basis of ANOVA, a multiple linear regression model was built for further study of the effect of each factor. Results are in the following table.

Table 5. Multiple Linear Regression Model for Sleep Efficiency

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.06E+00	6.97E-02	15.161	< 2e-16***
VeryActiveDistance	-3.79E-03	2.84E-03	-1.335	0.183
ModeratelyActiveDistance	-4.71E-02	4.48E-03	-10.506	< 2e-16***
LightActiveDistance	8.02E-03	4.05E-03	1.982	0.049*
SedentaryMinutes	-8.02E-06	3.48E-05	-0.23	0.818
Calories	7.72E-05	1.31E-05	5.906	1.11E-08***
step_length	-4.56E-01	1.39E-01	-3.289	0.001**
veryactivespeed	2.39E-03	4.84E-03	0.493	0.623
fairlyactivespeed	2.44E-02	7.12E-03	3.425	0.001***
lightlyactivespeed	-5.06E-02	2.37E-02	-2.136	0.034*

A comparison of Table 4 and Table 5 shows that the factors that are significant in ANOVA still have significant coefficients in the regression model. Both the speed and the distance when subjects are very active fail to reach statistical significance. Sedentary time is also not significant. Calories, step length, distance and speed when subjects are moderately or lightly active have significant coefficients. The adjusted r^2 of the model is 0.4386.

From the estimate of the coefficients, we may learn that sleep efficiency slightly declines as the subjects pass more distance in very or moderately active state. However, increase in distance passed when subjects are in lightly active state may have positive effects on sleep efficiency. To the contrary, increase in speed when subjects are very or moderately active is helpful for sleep efficiency while that of subjects in lightly active state isn't. Increase of step length may have relatively big negative effect on sleep efficiency. Calorie consumption has positive effect on sleep efficiency as well. Sedentary time and step length both have negative effect. Intercept of the model is more than 1, which indicates that most of the subjects' sleep efficiency decreased as a result of their exercise.

3.3. Multiple Linear Regression with Interaction Effects

In the former regression model, interactions of factors are not taken into account. Thus, another regression model is built to study the effects of interactions. Since there are 9 variables in the regression model without interaction, there should be 36 second-order interactions in total, and even more third-order or higher order interactions. According to the principle of effect sparsity, only second-order interaction effects are included. Besides, interaction effects are selected through significance and interpretability. Results are shown in the table below.

The adjusted r^2 of the model is 0.6038, which means that this model may perform better than that without interaction effects. In this model, only the effects of distance passed by subjects in moderately or lightly active state is significant. Main effects of the step length and speed of lightly active state may reach the 0.1 significant level while that of other factors fail to reach a statistically significant level.

Among all significant main effects, only the estimate of the coefficient of light active distance is positive. One more kilometer may lead to an increase of 0.041 on sleep efficiency. However, when the subjects become moderately active, the same increase in distance may lead to a decrease of 0.107 on the sleep efficiency. Estimates of other main effects are relatively small except for that of step length. Besides, estimates of interactions with step length is also relatively bigger than other interaction effects. Simple increase in step length may have negative effect on sleep efficiency, while in the lightly active state there may be a positive effect with a 0.1 level significance.

Table 6. Multiple Linear Regression Model with Interaction Effects

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	1.57E+00	3.53E-01	4.44	1.36e-05 ***
VeryActiveDistance	7.23E-03	8.60E-03	0.841	0.401
ModeratelyActiveDistance	-1.07E-01	1.23E-02	-8.65	6.79e-16 ***
LightActiveDistance	4.07E-02	1.13E-02	3.602	0.000 ***
SedentaryMinutes	-7.62E-06	3.33E-05	-0.229	0.819
Calories	5.02E-05	3.96E-05	1.268	0.206
step_length	-1.08E+00	5.76E-01	-1.868	0.063.
veryactivespeed	4.18E-02	5.46E-02	0.765	0.445
fairlyactivespeed	-5.95E-02	7.44E-02	-0.799	0.425
lightlyactivespeed	-5.50E-01	3.01E-01	-1.828	0.069
VeryActiveDistance: ModeratelyActiveDistance	-4.76E-03	2.41E-03	-1.975	0.049 *
VeryActiveDistance: Calories	-2.43E-06	2.63E-06	-0.922	0.357
ModeratelyActiveDistance: Calories	3.43E-05	5.54E-06	6.194	2.44e-09 ***
LightActiveDistance: Calories	-1.65E-05	4.22E-06	-3.904	0.000 ***
Calories: veryactivespeed	3.57E-05	5.70E-06	6.268	1.62e-09 ***
Calories: fairlyactivespeed	-1.68E-05	1.10E-05	-1.534	0.126
Calories: lightlyactivespeed	-3.77E-05	3.77E-05	-1.001	0.318
step_length: veryactivespeed	-1.90E-01	8.77E-02	-2.163	0.032 *
step_length: fairlyactivespeed	1.71E-01	1.21E-01	1.418	0.158
step_length: lightlyactivespeed	9.02E-01	4.98E-01	1.81	0.071

4. Conclusion

Different from previous studies, the result of this study shows that exercise may have negative effects on sleep efficiency, especially when exercise intensity is moderately high. Distance itself shows significance in the regression model with interaction effects.

Increase of sedentary time and calories both have insignificant effect on sleep efficiency, but the estimates of regression coefficients suggest that more exercise is better than sit for a longer period of time. Besides, calorie consumption reached a statistically significant level in the regression model without interaction effects, suggesting that consuming more calories is indeed beneficial in enhancing sleep efficiency.

Step length and some of its interactions also have significant effect, and the mechanism is complex. In general, small steps are more appreciated with the aim of improving sleep efficiency, especially when one is in very active state. However, if one's physical condition is only at a moderately or slightly active level, step length can be appropriately increased.

Considering main effects and interaction effects of both step length and speed in different state, we may find out the preferred working out pattern. Exercise under very active state with smaller step length is better for improvement of sleep efficiency; when one is moderately active, smaller step length is more appreciated, but distance passed in this state is expected to be shorter; large strides and appropriate speed increases are beneficial when lightly active.

Finally, calories and its interaction effects also show some patterns. Calorie consumption in a very active state is closely related to speed, the greater the speed and the more calories consumed, the more beneficial it is to improve sleep efficiency. In moderately active state, calorie consumption is more related to distance passed in this state. More distance is only preferred when there is a large increase in calorie consumption, or it may lead to a negative impact on sleep efficiency. More distance passed in lightly active state is beneficial as well as more calories burnt, though the interaction has slight negative effect.

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