Effects of Daily Physical Activity Level on the Degree of Sympathetic Tone

Eiji Ino-Oka¹, Hiroshi Sekino¹, Yasuaki Ohtaki² and Hikaru Inooka³

Abstract

Background Exercise is recommended for the treatment and prevention of cardiac disorders. Relaxation of the sympathetic nervous system has been considered to be one of the therapeutic mechanisms. However, the means by which the level of daily physical activity affects sympathetic activity remains unclear.

Objective To evaluate the effects of daily physical activity on autonomic nervous tone.

Methods Daily physical activity was measured for 5 or more days in 26 patients with various cardiac disorders of NYHA class 1 or 2 and in 6 healthy individuals using an intelligent calorie counter. Recumbent resting ECG was recorded for 3 minutes immediately before waking up and after going to bed using a digital ECG. Low- (Lf; 0.03-0.15 Hz) and high- (Hf; 0.15-0.45 Hz) frequency components were calculated by frequency analysis of the R-R interval, and Lf/Hf ratio was calculated as an index of sympathetic tone.

Results The average values of energy expenditure and time were 145±93.6 kcal/day and 47.8±24.3 min/day, respectively. The morning Lf/Hf ratio decreased following an increased physical activity level the day before, but increased with subsequent increase in the activity level in 65.6% of subjects. A negative correlation was observed in 34.4% of subjects, which suggested that an appropriate level of physical activity led to relaxation of sympathetic tone.

Conclusion The daily level of physical activity affects sympathetic tone, and an appropriate level results in sympathetic relaxation. The results of this study provide a useful index to enable patients with cardiac disorder to perform exercise without overloading.

Key words: physical activity, autonomic nerve tone, energy expenditure, ambulatory ECG

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Introduction

Exercise therapy is widely recommended for the rehabilitation of patients with chronic heart disease, for those with lifestyle-related diseases, such as diabetes mellitus, hypertension, and obesity, and in the prevention of the recurrences of these diseases. The effectiveness of this therapy has been widely recognized. Exercise therapy is usually performed under supervision at specific facilities because of the risk of adverse effects due to overloading. It is important to continue exercise therapy over a long period, and to that end, patients are expected to incorporate physical activity into their daily lifestyle or habits. However, it is difficult to determine how much exercise is performed in daily activities or the effectiveness of that exercise. For this purpose, simple and accurate monitoring of the level of exercise is necessary to evaluate whether the targeted level of physical activity has been achieved and whether the level of exercise is excessive. Various activity meters have been utilized for monitoring the level of physical activity (1-6), however, most of these meters can not be evaluated due to structural limitations.

We devised a calorie counter (Intelligent Calorie Counter; ICC) appropriate for this purpose (7-9) and examined its utility in monitoring the effects of physical activity in daily life on sympathetic tone and in determining an appropriate level of physical activity. Our expectation was that while ef-

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Figure 1. Typical wave forms of accelerator, air pressure, and estimated behavior and energy expenditure while various activities. In the first part of the left panel (time, 11.3 hours), the accelerator signals (left, upper) oscillated moderately, while the air pressure (left, middle) was unchanged. The ICC judged this as representing level walking (right, upper) with low energy expenditure (right, middle). At 11.32 hours, the air pressure showed upward and downward variations but the accelerator recorded no change. The ICC judged this as representing vehicle (elevator) down and vehicle (elevator) up with no energy expenditure. Next, the accelerator signals barely oscillated (11.34-11.38 hours), but the air pressure showed upward and downward variations. The ICC judged this as representing stair descent and stair ascent. Energy expenditure was of a moderate to high level. These data suggest that the ICC can differentiate human responses correctly.

Effective exercise might reduce the sympathetic nervous tone, over-exercising might stimulate it.

**Methods**

**Measurement of daily physical activity**

The level of physical activity in patient’s daily lives was monitored using our newly developed calorie counter (ICC) for 5 or more days. This calorie counter includes a barometer with acceleration sensors and has the following characteristics: the level of movement in an upward and a downward direction can be measured at a precision of 20 cm/s, various movement types, such as walking on flat ground, climbing up or down a slope or steps, and moving on an elevator or escalator can be differentiated and oxygen consumption can be estimated automatically from an equation describing the relationship between exercise intensity and oxygen consumption. The equation was formulated based on a database of oxygen consumption values measured by a portable expired gas analyzer (Anima kk, Tokyo, Japan) in volunteers of different ages while walking on level ground, and while ascending and descending steps at various levels of intensity (Fig. 1). The activity pattern in daily life, walking count, and oxygen consumption were recorded on the ICC. The final level of physical activity was calculated by collecting the value obtained during excess post-exercise oxygen consumption (EPOC) (10-15). Thus, the errors in the level of physical activity were reduced to about 10% compared with the actual measurements.

**Evaluation of sympathetic nerve tone**

On each day during this period, bipolar ECG from leads on the right finger and left pre-cordial region (corresponding to the V5 lead) were recorded continuously for 3 minutes on a digital memory card at a sampling rate of 128 Hz using a portable electrocardiograph (modified HCG801, Omron kk Kyoto, Japan). ECGs were performed immediately before subjects awoke in the morning and immediately after going to bed at night while maintaining a decubitus position. Frequency analysis of the R-R interval was performed on the ECGs. Low- (Lf, 0.03-0.15 Hz) and high- (Hf, 0.15-0.45 Hz) frequency components were extracted, and their ratio (Lf/Hf) was calculated as an index of sympathetic tone. The following cases were excluded from the analysis: 1) those in which normal sinus rhythm could not be recorded continu-
ously for 2 minutes or longer with compensatory pauses follow-
ing episodes of extra-systole during the 3-min period; 2) those showing rhythms other than the sinus rhythm, such as atrial fibrillation; 3) those showing marked baseline drift due to technical reasons; and 4) those in which stable records were interrupted for 20 seconds or longer due to noise.

Protocol and subjects

During the study, the subjects were asked to continue their routine daily activities, as much as possible, and to perform vigorous short periods of exercise if they could. The subjects who consented to participate in this study included 26 patients and 6 healthy individuals. The patients group included 8 subjects with paroxysmal atrial fibrillation or paroxysmal atrial tachycardia combined with hypertension, 4 with ischemic heart disease, 6 with diabetes mellitus, and 8 with chronic kidney disease (end-stage severe renal failure) with cardiac disorder. All were in a stable condition and were considered to be appropriate candidates for exercise therapy. Their mean age was 62.9±10 years (mean ± SD), and the male/female ratio was 15/17 (Table 1).

Medications that were being administered before the study were continued during the study. All data are presented as mean ± SD and statistical analysis was performed by Student's t test.

Table 1. Patient Profile

<table>
<thead>
<tr>
<th>Background of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paroxysmal Atrial Fibrillation/Tachycardia</td>
</tr>
<tr>
<td>Paroxysmal Atrial Fibrillation + Diabetes Mellitus</td>
</tr>
<tr>
<td>Ischemic Heart Disease</td>
</tr>
<tr>
<td>Diabetes Mellitus + Ischemic Heart Disease</td>
</tr>
<tr>
<td>Chronic Kidney Disease (Hemodialysis) + CHF</td>
</tr>
<tr>
<td>Chronic Kidney Disease (Hemodialysis) + DM</td>
</tr>
<tr>
<td>Chronic Kidney Disease (Hemodialysis) + IHD</td>
</tr>
<tr>
<td>Healthy Volunteer</td>
</tr>
</tbody>
</table>

Age (Mean±SD) and Gender(F/M): 62.9±10yrs (15/17)

Table 2. Results of Physical Activity and Lf/Hf Ratio

<table>
<thead>
<tr>
<th></th>
<th>All Cases</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Cases</td>
<td>32</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>Age</td>
<td>62.9±10</td>
<td>61.7±11.1</td>
<td>66.8±5.0</td>
</tr>
<tr>
<td>Physical Activity (kcal)</td>
<td>145.0±83.6</td>
<td>135.8±81.8</td>
<td>162.1±119</td>
</tr>
<tr>
<td>Maximum</td>
<td>253.2±160.9</td>
<td>247.4±159</td>
<td>274.6±175.8</td>
</tr>
<tr>
<td>Minimum</td>
<td>62.6±48.7</td>
<td>59.4±36.7</td>
<td>70.4±66.2</td>
</tr>
<tr>
<td>Optimun</td>
<td>163.8±110.9</td>
<td>183.8±110.9</td>
<td>153.8±110.9</td>
</tr>
<tr>
<td>Activity Time</td>
<td>47.8±24.3</td>
<td>45.2±22.2</td>
<td>53.8±28.8</td>
</tr>
<tr>
<td>6 Met&gt;</td>
<td>2.5±4.5</td>
<td>2.1±2.8</td>
<td>3.4±6.7</td>
</tr>
<tr>
<td>3-6 Met&lt;</td>
<td>30.8±18.2</td>
<td>29.4±15.7</td>
<td>34.7±22.9</td>
</tr>
<tr>
<td>3 Met&lt;</td>
<td>14.5±7.7</td>
<td>13.7±7.9</td>
<td>15.7±7.7</td>
</tr>
<tr>
<td>Running Walk Count</td>
<td>8.3±22.2</td>
<td>10.6±35</td>
<td>1.1±3</td>
</tr>
<tr>
<td>L/H (Morning)</td>
<td>2.13±1.17</td>
<td>1.97±1.1</td>
<td>2.46±1.3</td>
</tr>
<tr>
<td>L/H (Night)</td>
<td>1.89±1.38</td>
<td>1.76±1.32</td>
<td>2.11±1.56</td>
</tr>
<tr>
<td>Body Weight</td>
<td>60.6±12</td>
<td>60.1±10.8</td>
<td>58.8±11.6</td>
</tr>
<tr>
<td>Height</td>
<td>160.7±8.6</td>
<td>160.2±8.4</td>
<td>160.0±8.3</td>
</tr>
<tr>
<td>BMR</td>
<td>1286.8±271.7</td>
<td>1277.2±236.5</td>
<td>1232.7±260.6</td>
</tr>
</tbody>
</table>

Group A: The relationship between physical activity on the previous day and Lf/Hf the following morning showed a biphasic pattern in which Lf/Hf reached a nadir. Group B: The relationship between physical activity on the previous day and Lf/Hf the following morning showed an inverse relation. Data are presented as mean±standard deviation.

Units of O2 consumption: kcal, Activity time: min.
Optimum: O2 consumption at nadir in Group A

The average number of days of physical activity recorded was 8.3±2.8 days. ECG measurements were obtained immediately before waking up in the morning 7.6±2.9 times/subject. After excluding records in which frequency analysis was impossible due to the occurrence of arrhythmia or baseline drift data from 6.3±2.5 measurements were analyzed for each subject. The level of physical activity was a minimum of 62.5±48.7 kcal/day and a maximum of 253.2±150.9 kcal/day, on average 145.0±93.6 kcal/day. The duration of exercise was 47.8±4.3 min/day. The duration of intense exercise (≥Mets) was 2.5±4.5 min/day; moderate exercise (3-6 Mets) was 30.8±8.2 min/day; and mild exercise (≤Mets) was 14.5±7.7 min/day. The Lf/Hf ratio was 2.13±1.17 and 1.89±1.38 immediately before waking up and immediately after going to bed, respectively (Table 2).

Examples of the analysis are presented in Fig. 2. The left panel of Fig. 2 is the record of a subject with paroxysmal supraventricular tachycardia that was obtained while the attacks were completely controlled. In this case, the level of physical activity was 70-300 kcal/day (mean 257.9±191.6 kcal/day), and the duration of exercise was 58.5±36.6 min/day. The durations of intense, moderate, and mild exercise were 5.9±12.4, 33.4±19.4, and 18.0±16.4 min/day, respectively. The level of physical activity on the previous day (X-

Table 3. Clinical Characteristics and Drug Intervention of Each Group

Clinical Characteristics of each Type

<table>
<thead>
<tr>
<th>Underlying Disease</th>
<th>Type A</th>
<th>Type B</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paroxysmal Atrial Fibrillation</td>
<td>6</td>
<td>3</td>
<td>ns</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>5</td>
<td>2</td>
<td>ns</td>
</tr>
<tr>
<td>Chronic Kidney Disease</td>
<td>5</td>
<td>3</td>
<td>ns</td>
</tr>
<tr>
<td>Congestive Heart Failure</td>
<td>4</td>
<td>2</td>
<td>ns</td>
</tr>
<tr>
<td>Ischemic Heart Disease</td>
<td>3</td>
<td>2</td>
<td>ns</td>
</tr>
<tr>
<td>Premature Ventricular Arrhythmias</td>
<td>1</td>
<td>0</td>
<td>ns</td>
</tr>
<tr>
<td>Neurocirculatory Asthenia</td>
<td>1</td>
<td>0</td>
<td>ns</td>
</tr>
<tr>
<td>Normal Healthy Volunteers</td>
<td>4</td>
<td>2</td>
<td>ns</td>
</tr>
</tbody>
</table>

Administered Drugs

- Ca-Channel Blocker 10 2 ns
- Beta Blocker 8 2 ns
- RAS Inhibitor 7 6 p<0.001
- Statins 6 3 ns
- Antiarrhythmic Drugs 5 3 ns
- Nitrate 3 1 ns

Paroxysmal atrial fibrillation in 2 paroxysmal atrial tachycardia.
Each complication was counted as one disease, then the numbers of disease over the number of patients. RAS inhibitor includes both angiotensin II-converting enzyme inhibitor and angiotensin II receptor blocker.

axis) was correlated with the Lf/Hf ratio immediately before waking up the next morning (Y-axis). As plotted in the scattergram, the Lf/Hf ratio showed biphasic changes that decreased after increases in the physical activity level up to 150-200 kcal, and increased following a subsequent increase in the level of physical activity. The right panel of Fig. 2 shows the record of a subject with paroxysmal supraventricular tachycardia who had no attacks for about 6 years after bepridil administration. The level of physical activity was 94.6-16.6 kcal (mean 50.6±26.2 kcal/day), and the Lf/Hf ratio continued to decrease following increases in the physical activity level, showing a consistent negative correlation with no increasing phase.

Biphasic changes, as shown in the left panel of Fig. 2, were observed in 21 subjects (65.6%; Group A), and a negative correlation, as shown in the right panel of Fig. 2, was observed in 11 subjects (34.4%; Group B). Average values of age, energy expenditure, and Lf/Hf in each group are also listed in Table 2. The clinical characteristics and drug interventions for each group are shown in Table 3. There were no significant differences in clinical characteristics, average value of physical activity, basal metabolic rate or drug intervention between subjects in Group A and B with the exception of frequent use of rennin-angiotensin system (RAS) inhibitors use, such as angiotensin-converting inhibitors and/or angiotensin II receptor blockers which was more common in group B.

Discussion

For exercise therapy to be performed safely and effectively as a component of a patient’s daily physical activity, monitoring of the activity and detecting excessive exercise at an early stage using a defective index are necessary. Various measures, including exercise at 60% of the maximum oxygen consumption, aerobic exercise (16, 17), Borg’s scale for perceived exertion (18), or Karvonen’s heart rate reserve method (19) have been used as indices of effective and safe exercise intensity for patients with heart disease. However, no method has been identified that can be used routinely to
check whether the targeted level of physical activity has been achieved and whether the level of exercise is excessive. We calculated the number of steps by connecting a pedometer to a Holter ECG instrument, and alternatively using an accelerometer incorporated in a Holter ECG instrument as an index of the level of physical activity. We then determined the incidence of over-exercising from the presence or absence of asymptomatic ischemic attacks or the relationship of physical activity level to heart rate (20-22). However, the effectiveness of such attempts has been limited, because monitoring has been limited to a period of 24 hours and it is impossible to represent the level of physical activity accurately by the number of walking steps alone.

Due to such circumstances, we developed a new device that provides accurate measurement of physical activity level and proposed that the sympathetic nervous tone the next morning be used as an index of effective physical activity. Our device has two important characteristics. First, it evaluates height-related changes, such as climbing up steps or a slope which is considered a primary factor leading to errors in activity measurement. Second, it considers the physiological phenomenon of EPOC, which is defined as the excess oxygen consumed during recovery from exercise as compared with resting oxygen consumption. Other instruments devised to date appear to have been designed with little consideration of these phenomena. In contrast, our instrument was designed with these two points in mind. These innovations enabled measurement of the level of physical activity to be improved to a level of precision that warrants clinical application (i.e., errors within ±10%).

In the present study, which was conducted to evaluate the effects of differences in the level of physical activity on autonomic nerve tone and various disorders, and to estimate the optimal amount of physical activity for each individual, the level of physical activity on the previous day was found to affect the Lf/Hf ratio of the next morning.

These findings suggest that the level of physical activity affects sympathetic tone. Piepoli et al (23) and Iellamo et al (24) have suggested that optimal exercise therapy might mitigate sympathetic hyperactivity. Further Taylor-Tolbert et al (25), Park et al (26) and Nami et al (27) have also reported that exercise therapy reduces blood pressure due to an improvement in balance between sympathetic and parasympathetic tone. However, these reports are based on comparisons with the results before and after exercise therapy that had been conducted during a set time period. Our results generally agreed with these findings, and further suggest that such beneficial effects of physical activities differ on a daily basis and that the accumulation of such short-term effects leads to favorable results.

However, it remains an open question whether the effects differ with the amount, intensity and type of exercise, or whether a certain amount of exercise in daily life is necessary for the rehabilitation of patients with heart diseases (28, 29) and that the blood pressure lowering effect is related more to the intensity of moderate to severe exercise rather than the total exercise level (30), emphasizing the need for vigorous exercise. However, other reports have maintained that vigorous exercise is not always necessary (31), that a blood pressure lowering effect was observed even by walking for 40 min/day and that both the blood pressure lowering and sympathetic relaxation effects were increased by repeated bouts of exercise of short duration rather than by “one shot” exercise (32). These findings suggested that physical activity in daily life is sufficient to produce a blood pressure lowering effect.

The findings in the present study showed that the exercise level in 11 subjects fulfilled the minimum requirement of 1,500 kcal/week at mean value and 16 subjects at maximum value, which suggests that physical activity in daily life without a specialized exercise program provides the necessary level of activity to produce desirable effects.

Further, the sympathetic tone on waking up was affected by the level of physical activity on the previous day. Sympathetic tone was mitigated following increases in the physical activity level to a certain point, but intensified beyond this point. Because an abnormal increase in blood pressure or an excessive response of the pulse has been reported as an indication of overloading in exercise tests, and the changes in these parameters are considered as a marker of the exercise cessation, this reversal of the effect of exercise on sympathetic tone is considered to be due to overloading. It is widely known that overexertion is a factor in the exacerbation of heart failure and that there is a high risk of inducing acute lethal arrhythmia or acute heart failure by overloading in aggressive exercise therapy. However, there are no data clarifying whether the level of free daily activities or, in particular, whether the continuation of excessive exercise, leads to the exacerbation of heart failure, myocardial ischemic attacks or induction of arrhythmia. A reversal increase in the Lf/Hf ratio might serve as a warning of excessive exercise. On the other hand, there was no reversal in the Lf/Hf ratio in daily activities in 34.4% of the subjects, and the possibility exists that vigorous exercise is more effective without adverse effects in such individuals. No significant differences in physical activity or clinical characteristics were noted between the two groups in this study, but the frequency of RAS inhibitor use was higher in group B than in Group A, which suggests the effectiveness of these agents in maintaining a patient’s physical capabilities. However, further evaluation is required to determine whether the preceding effects differ among patients with various forms of heart disease, diabetes mellitus, chronic kidney disease and obesity, as compared with healthy individuals and also whether the level of physical activity that resulted in a minimum Lf/Hf ratio is associated with a good prognosis.
References


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