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A USEFUL METHOD FOR MEASURING DAILY PHYSICAL ACTIVITY BY A THREE-DIRECTION MONITOR

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ABSTRACT. The purpose of this study was to investigate whether a three-direction accelerometer is useful for measuring daily physical activity. Physical activity, being an important part of human behavior, may be related to various aspects of health and disease. In this study, the relationship between the intensity of each action and the three-direction accelerometer (Actigraph) output was compared in 10 healthy subjects under free-living conditions. Subjects wore the Actigraph on their non-dominant wrist and filled out a physical activity check list (self-report) throughout the daytime. Daily physical activities were classified into six categories according to different intensities. The differences of the Actigraph output among each of the six categories were significant by the Kruskal–Wallis analysis ($p = 0.001$). The Actigraph output appeared to correlate highly with the intensity of actions by the Spearman Rank test ($r = 0.95$, $p < 0.05$). The Actigraph output was over-estimated while the subjects were typing, driving and being a passenger in a motor vehicle. The Actigraph was shown to be a useful and convenient device for measuring daily physical activity.

Key words: chronic disease, daily physical activity, physical fitness, self-record method, three-direction monitor.

The measurement of daily physical activity is important for patients with several major chronic diseases and with physical disabilities, such as coronary heart disease, osteoporosis and diabetes. In clinical medicine, the assessment of daily physical activity is useful for advising patients about their lifestyle and designing a rehabilitation program to maintain their physical fitness and optimal physical function. Oxygen consumption is the best parameter to show the intensity of different activities; however, it is almost impossible to measure oxygen consumption without inhibiting the subject's daily routine. Instead of this method, more than 30 easy and convenient methods have been used in population studies (4); however, there are no established methods for individual clinical studies.

The most generally used and well-known methods for this purpose are (a) self-administered quantitative histories or physical activities recall surveys, (b) self-report diaries, and (c) mechanical and electronic monitors. The first two methods provide detailed information on physical activity at a minimal expense to the investigator. However, both of these are subjective and influenced by subject inaccuracies or unwillingness to record every activity (4). Electronic monitors can be classified into two types. One type includes devices that make use of the biological signals from electromyography (EMG) and electrocardiography (ECG). The other type includes devices that assess the quantity of body movement by using the mercury-switch transducer and accelerometer technology. Heart rate monitoring is easy to record under free-living conditions and correlates well with physical activities, except that mental stress may produce heart rate fluctuation (14). If heart rate alone is used to quantify physical activity, it is necessary to assess emotional reactions. The accelerometer is also easy to record. Montoye et al. (7) reported a good correlation ($r = 0.74$) between the integral of absolute value of body acceleration with a two-direction monitor and oxygen consumption measured with a Beckman Metabolic Cart in subjects performing different types of exercise. They suggested that this relationship might even be improved by using a three-direction monitor.

The recent development of an accelerometer is more promising. Three-direction accelerometers that use a piezo-electric transducer allow measurement of acceleration and deceleration caused by movements of the body. These accelerometers have been used for measurements of physical activity in behavioral and biomedical research. There are many studies of relationships between the three-direction monitor and the other methods, such as self-recorded method and heart rate monitoring, showing high correlation (5, 8, 10, 11, 13, 16). However, there is very little information about whether the three-direction monitor can be used for assessing physical activity, and how to make use of its results in clinical medicine.

In present medical devices, some kinds of Rate Responsive Pacemakers are using piezo-electric transducers for measuring body movement (3, 12). Heart rates are controlled corresponding to the body movement in this pacemaker. For example, if a patient with this pacemaker exercises, the patient's heart rate would correct by sensing the body movement. We reported that the motion sensor outputs using this pacemaker showed high correlation (0.73–0.99) with oxygen consumption under different actions in the laboratory (14).

In the present study, the relationship between a three-direction accelerometer measure of physical activity and self-recorded measure of physical activity was compared in each action under free-living conditions. The purpose of this study was to investigate whether a three-direction accelerometer is useful for measuring daily physical activity and to discuss how to make use of its data in clinical medicine.

MATERIAL AND METHODS

Subjects

Ten healthy subjects (8 males, 2 females; mean age 40.8 years old, range 30–66, SD 13.3, mean height 170.3 cm, range 160–182, SD 7.3, mean weight 67.0 kg, range 51–88, SD 9.7) participated in this experiment. They gave informed consent. There were no excessively overweight persons in the subject group. Six subjects fundamentally performed desk-work, three subjects were tourists and the other was a housewife.

In the current study, the Mini Motionlogger Actigraph (Actigraph) pioneered by Ambulatory Monitoring Inc. was used for the measurement of daily physical activity. The Actigraph is a three-direction accelerometer that utilizes a piezo-electric transducer. The Actigraph can translate body movement into an electric signal and interfaces with an IBM-compatible microcomputer for programming and for downloading the data. The data is continually sampled by microprocessor and then stored in 16 K digital memory. The Actigraph is housed in a 1.75L × 1.3W × 0.38H inches (4.4L × 3.3W × 0.95H cm.) aluminium case that weighs approximately 5.6g (similar to a wristwatch). The Actigraph was set so that epoch time is 5 sec and sensitivity is 18. This is the most sensitive setting.

The subjects were instructed in how to fill out the physical activity checklist and the Actigraph was attached to their non-dominant wrist. They then performed their normal daily routine. The duration of this measurement was at least 6 hours, beginning at 10:00 a.m. Daily physical activities were classified into six categories according to intensity, which are defined as follows:

- A = sleeping, lying position.
- B = sedentary activities; rest, reading, talking, thinking, being a passenger, watching TV.
- C = very light activities; desk work, eating, urinating, self-care.
- D = light activities; driving, light house work, washing a dish.
- E = moderate activities; free speed walking, shopping, moderate house work, moving a table, bowling, playing golf
- F = strenuous activities; going up and down stairs, jogging, lifting heavy objects, participating in strenuous sports

The subjects recorded the time, their action and the category number on the checklist whenever they changed their action. For the analysis, each category was assigned the following values: A = 1, B = 1.5, C = 2.5, D = 3.5, E = 4 and F = 5. These values were modified from previous studies, so that low levels of physical activities were classified in detail (2, 9). To assess the test–retest reliability of the Actigraph during the same activities, 4 of the 10 subjects performed the following actions: (1) trunk rotation exercise, (2) body bending exercise in the sitting position, (3) walking exercise at 3 km/h, (4) walking exercise at 5 km/h. These were performed twice in the laboratory, with the walking exercises performed on the treadmill.

RESULTS

The Actigraph output of one subject is shown in Fig. 1. Each value shows the Actigraph output per epoch. The principal activities were obtained from the physical activity checklist. We analysed only the data of the period for which the checklist is completed in detail, because inaccuracy of the checklist may produce a wrong result. The averages and standard deviations of the Actigraph output among the categories are presented in Fig. 2. The differences of the Actigraph output among the categories were significant by the Kruskal–Wallis analysis ($p < 0.05$). This means that the Actigraph recorded the difference in each action under free-living conditions. Especially, the Actigraph could record the differences in the sedentary actions such as in categories A, B, and C. It had been impossible to classify the intensity of sedentary actions with previously used devices such as a pedometer and a two-direction accelerometer. The standard deviations in both B and C were larger than the others. That is why the Actigraph output was overestimated when subjects were in a car as a

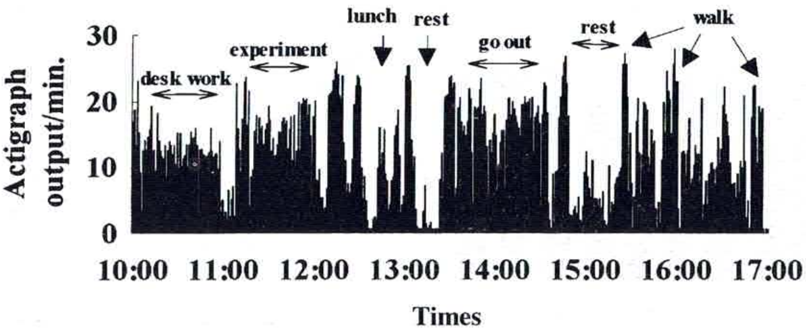

Fig. 1. The Actigraph output in one subject. Each value shows the Actigraph data per 1 epoch. The principal activities were designed from the physical activity check list.

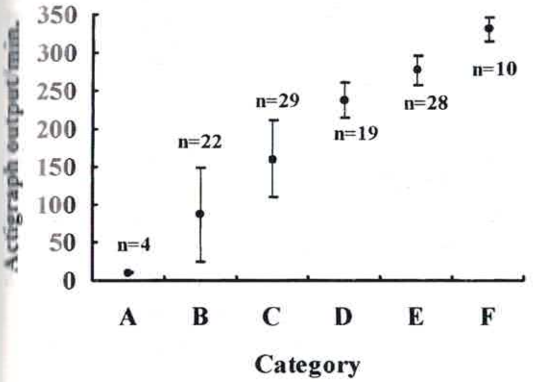

Fig. 2. The average of Actigraph output in each category. The difference among each category was significant by Kruskal-Wallis analysis ($p = 0.001$).

Table I. *Spearman Rank Correlation Coefficients between Actigraph output and intensity of each action in each subject.*

A high correlation was noted in each subject ($p = 0.05$). C.C.; correlation coefficient

Subject	C.C.	Subject	C.C.
1	0.896	6	0.972
2	0.977	7	0.952
3	0.964	7	0.939
4	0.949	9	0.843
5	0.938	10	0.818

passenger and typing on a word processor in comparison with the true intensity of these actions. Category B included two data points whose values were very high, 267.6 and 217.2, while the subjects were passengers. Category C included five data points while the subjects were typing and their values were also very high, 236.4, 264.0, 243.6, 243.4 and 217.2. These seven data points were therefore excluded from the next analysis. The relationship between Actigraph output and intensity in each category in subject 4 is shown in Fig. 3. Actigraph output appeared to correlate highly with the intensity by the Spearman Rank test

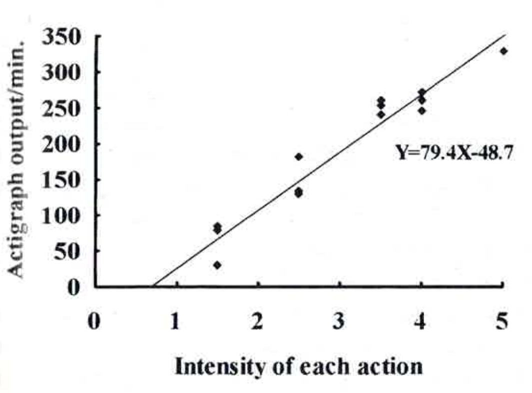

Fig. 3. The relationship between Actigraph output and intensity of each action in subject 4 ($r = 0.94$, $p < 0.05$) .

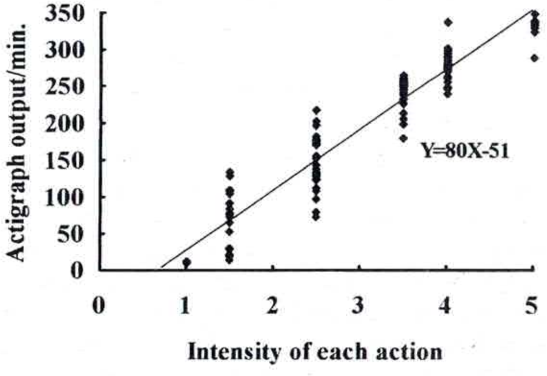

Fig. 4. The relationship between Actigraph output and intensity of each action in all subjects' data. There is significant correlation between them ($r = 0.952$, $p < 0.05$).

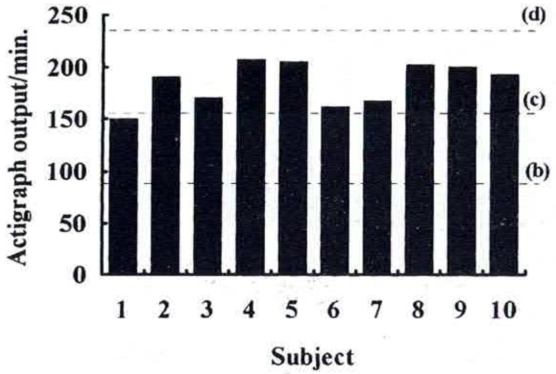

Fig. 5 The average of Actigraph output during each measuring period. Straight line (b); average output of category B. Straight line (c); average output of category C. Straight line (d); average output of category D.

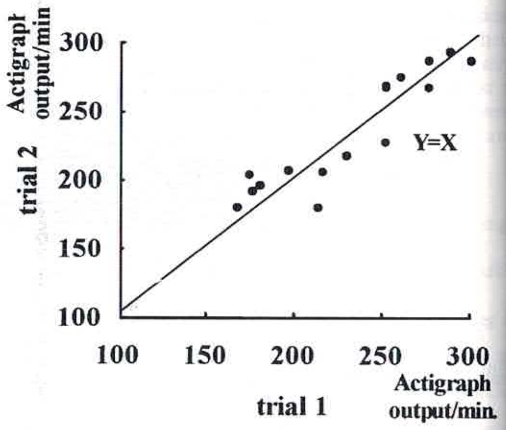

Fig. 6. Scattergram of the Actigraph output from trial 2 vs trial 1 of the test–retest experiment. Test–retest coefficient was high for the various physical activities (ICC = 0.91).

($r = 0.95$, $p < 0.05$). The correlation coefficient in each subject is shown in Table I. All subjects showed correlation coefficients significantly more than 0.8, and 7 subjects showed them more than 0.9. The Actigraph showed appropriate output correspondence to the intensity of each action under free-living conditions in each individual.

The relationship between Actigraph output and intensity in each category, in all subjects, is shown in Fig. 4. There is high correlation between them by Spearman Rank test ($r = 0.952$, $p < 0.05$). The Actigraph output showed high correlation with the intensity, not only in each individual but also between-individuals. The average of the Actigraph output is shown in Fig. 5. Nine out of 10 subjects had Actigraph outputs between category C and category D. This means that the daily physical activity level of each subject was higher than the level of desk-work and less than the level of standing work. Talking of approximate physical activities in each subject from the physical activity check list, subjects 4, 5, 8, 9 and 10, who went out on the measuring day, showed a high level of physical activity. Subjects 1, 3, 6 and 7 who stayed inside, showed a low level of physical activity. In detail, subjects 1, 3 and 7 were the researchers at this institute and did desk-work except for lunch time. The basic tasks of subjects 2, 4, and 8 are desk work too, but they went out for more than 2 hours on the measuring day. Subjects 5, 9 and 10 were tourists. All of them are more than 60 years old and they saw the sights, taking a rest according to their physical strength. Subject 6 is a housewife. She remained at home with activity of only light housework on the measuring day.

The test–retest data of the various activities is presented in Fig. 6. The intraclass correlation coefficient (ICC) (1) between trial 1 and trial 2 had a high value of 0.91.

DISCUSSION

In clinical medicine, especially rehabilitation medicine, the assessment of physical activity is important. It is very useful for designing a rehabilitation program and to advise patients about their lifestyle to maintain their physical fitness and their physical function. Mita et al. (6) reported that a low level of physical activity may lead to a serious decrease in cardiovascular function.

Is the Actigraph useful in clinical medicine?

The following conditions are needed for a useful method to assess physical activity in clinical medicine: (1) a method that can produce accurate data; (2) a method that is easy and convenient; (3) a method that does not inhibit daily activities of subjects; (4) limitations of the measurement that are obvious; and (5) test–retest reliability that is good.

With regard to (1), the difference of the Actigraph output among the categories was significant and there is a high correlation between Actigraph output and intensity of each category. This means that the Actigraph recorded the data corresponding to the intensity of each action under free-living conditions. High correlation coefficients (0.71–0.92) have been reported between accelerometer readings and energy expenditure under different circumstances in the laboratory (5, 10, 16). However, in free-living conditions, the results were different by different researchers (5, 15). Stephen et al. (13) compared the relationship between self-measures of physical activity and monitor measures of physical activity. They reported that it showed low correlation among subjects who made fewer complete self-report entries, but showed significantly higher correlation among subjects who made more frequent entries. In the present study, we compared the Actigraph output per minute during each action and the intensity of its action only for complete parts of self-report. This analysis was less swayed by the accuracy of self-report than that of past studies. It is thought that Actigraph output shows accurate data for assessment of physical activity under free-living conditions.

With regard to (2), the method is very easy, because data input, output and analysis are able to be carried out by IBM compatible personal computer. Additionally, the Actigraph is attached only on the subject's wrist during the measuring period.

With regard to (3), the Actigraph does not inhibit the subject's normal daily routines, because the Actigraph is small and light weight like a wristwatch. Subjects will not feel uncomfortable by having it on their wrists and may even forget about being attached to it.

As for (4), the Actigraph has some obvious limitations. One is that the Actigraph output may be overestimated by vibration caused by a car or a train, Another is that actions using the upper limb repeatedly, such as typing, may also be overestimated. Therefore, the easy self-report should be recorded at the same time for correcting the data, however, this need not be as detailed as in the method of self-report only. The correction of data is easily performed by a computer. This limitation should be investigated in a larger number of subjects and in more kinds of actions.

With regard to (5), test–retest reliability was investigated not under free-living conditions, but during specific actions, because repeating a "normal day's routine" twice in 1 day is impossible. The result of the test–retest analysis for the Actigraph output indicated a very high ICC between trial 1 and trial 2. This demonstrates that the Actigraph has very high test–retest reliability. Stephen et al. (13) reported that Actigraph readings for trial 1 and trial 2 were highly correlated ($r = 0.98$, $p < 0.0001$) in 12 activities.

In conclusion, the Actigraph satisfies the five conditions stated above if self-report is recorded at the same time. It is therefore believed that the Actigraph is a useful and convenient device for measuring daily physical activity in clinical medicine.

How to assess the Actigraph outputs in clinical medicine

It is difficult to concretely advise patients about the level of their daily physical activity and home exercise. In many cases, patients are advised about it without a logical estimation. We suggest assessing the increase and decrease of physical activity by the Actigraph to determine the duration of some specific activity. This will make advice to patients easy and convenient. For example, when a subject was measured for 8 hours on 2 different days, we can compare with physical activities of each day as the duration of walking exercise. If the difference between each day would be 10 values per minute, the difference would reflect the physical intensity as well as when the subjects walk for 17 minutes by the following expression:

$$\frac{10(\text{difference}) \times 60(\text{minute}) \times 8(\text{hour})}{277(\text{average Actigraph output during walking})} = 17$$

The optimal specific activity might be to walk in one case and to jog in another. This should be decided on the basis of the physical condition of each patient. This estimate method is useful when we advise patients about their lifestyle and home physical therapy and easy to understand for patients.

We will actually apply this method for a patient in clinical medicine and discuss the usefulness of this method in the near future. Furthermore, the methodology for a patient with physical disabilities, who needs a wheelchair, will be investigated.

CONCLUSION

The present study demonstrated that a three-direction accelerometer using a piezo-electric transducer, such as the Actigraph, is useful for assessing daily physical activity, if one is aware of the monitor's limitations. It is thought that the best method for this purpose is to record both the Actigraph and the self-report at the same time and to correct the Actigraph data from the result of the self-report if necessary. A sedentary lifestyle may contribute to decline of physical fitness. In clinical medicine, patients will need logical and concrete advice for their lifestyle and home exercise. The evaluation of the increase or decrease of daily physical activity such as walking time is useful for advising patients about their lifestyle and home physical therapy.

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