The Relationship between Ambulatory Blood Pressure and Physical Activity in Young and Older Shiftworkers

A Quantitative Assessment of Physical Activity Using a Microcomputer with Acceleration Sensor

Iwao Kuwajima, M.D., Akihiko Hamamatsu, M.D., Yasuko Suzuki, M.D., and Kizuku Kuramoto, M.D.

SUMMARY

We studied the relationship between physical activity and ambulatory blood pressure (BP) in young and older shiftworkers by simultaneous recordings of activity, blood pressure and pulse rate (PR). Activity was assessed using Activetracer, a self-contained microcomputer with an acceleration sensor, attached to a waist belt. Ambulatory BP was monitored every 30 minutes for 48 hours with a TM2421.

Three types of hemodynamic responses were noted in relation to the physical activity. The balance type, in which both BP and PR increase with physical activity, was observed in 5 of 10 young cases (50%) but only in 1 of 7 older cases (14.3%). The BP response type, in which the BP increases with no change in the PR, was observed in 6 of the 7 older workers (86%) but only in 3 cases in the young group (30%). The PR response type, in which only the PR increase correlated with activity, was observed in 2 cases in the young group (20%) and none in the older group.

The difference in systolic BP between periods of activity and rest in the older shiftworker was significantly larger than that in the young group (15.9±6.4 vs. 5.9±6.6 mmHg, p<.01), although no significant difference was observed in diastolic BP. In contrast, the increase in pulse rate after movement was significantly higher in the young group (4.4±4.0 vs. 9.0±4.8 bpm, p<.05). Thus, the fluctuation of the systolic BP was more dependent on physical activity in the older group, whereas PR variations correlated with the physical activity in the young group. (Jpn Heart J 34: 279–289, 1993)

Key Words:
Blood pressure variability   Blood pressure monitoring
It is well known that there is a diurnal pattern of blood pressure (BP) variation, which rises in the morning and falls during the night. However, there has been some dispute as to whether this BP rhythm represents an intrinsic circadian rhythm or whether it is synchronized to the usual daily cycle of daytime activity and nighttime sleep. \(^1,2,3\) Mann et al.\(^1\) noted that there was a diurnal rhythm in which BP increased during the day and fell at night in hospitalized patients kept on bed rest. However, there are several recent reports supporting the notion that BP variation related to physical activity overcomes that related to day-night rhythm. First, the high BP period in shiftworkers was reported to coincide with working time.\(^2\) In addition, if physical activity is minimized, the daytime BP profile becomes relatively flat, as observed in orthopedic patients who were immobilized by plaster casts.\(^3\) However, physical activity-related BP fluctuation is possibly dependent upon the age of the subjects because moment-moment variability of BP has been known to be greater in elderly than in younger subjects.

Regardless of the important contributing factors to the circadian rhythm of BP, physical activity has not been widely considered in most studies of ambulatory BP, primarily due to a technical inability to obtain an accurate quantitative record of physical activity.

In the present study, we used a new device equipped with an accessory sensor to monitor physical activity in young and older shiftworkers. We hypothesized that the relationship between physical activity and ambulatory BP or pulse rate responses would differ between the two groups due to structural and functional changes of the cardiovascular system associated with the aging process. We chose nurses and guards, working during the period from midnight to early morning as subjects of the study for two reasons. One is that the nature of the work during night in both groups is physiologically similar. That is, the main work of both groups was dynamic exercise rather than isometric work or mental desk work. Another reason was to avoid the synchronization of physical activity-related BP increment to the intrinsic rise of BP during daytime.

**Subjects and Methods**

Ten young (mean 25.3 years) and 7 older (mean 63.5 years) shiftworkers who work from midnight to early morning, were recruited for the study. The two groups consisted of nurses (young group) and gatekeepers or guards (older group) whose shift started at midnight of the first day and ended at 0800 AM on the second day, followed by a holiday. Informed consent for the study was obtained from each subject. All subjects were healthy and cases with hypertension were excluded from the study. The average office blood pressure was 112.5 mmHg
systolic, 77.2 mmHg diastolic in the young group and 131.7/82.1 mmHg in the older group.

Ambulatory BP was measured by the oscillometric method every 30 minutes for 48 hours with a TM 2421 (A&D Comp, Inc., Tokyo). The features and accuracy of the TM 2420, which is a prototype of the TM 2421 have been reviewed by Tochikubo et al. Essentially, it is comprised of a sphygmomanometer cuff containing two microphones to distinguish Korotokoff sounds from extraneous noise and a compact battery-driven BP/pulse recorder capable of making approximately 300 measurements per battery charge and of storing up to 600 measurements in memory. In the TM 2421, simultaneous measurements of BP by the oscillometric and Korotokoff methods can be made. The accuracy of measurements at rest and during exercise has been confirmed by Imai et al. The measurements of BP and pulse rate in the present study were made in an unrestricted state in all subjects.

Physical activity was monitored with Activetracer (GMG Inc., Tokyo) which was attached to a waist belt. The simultaneous measurements of ambulatory BP, pulse rate and physical activity were conducted for 48 hours beginning in the evening on the day of nightwork.

Activetracer is a self-contained microcomputer housed in a 74×52×21 mm-sized lightweight aluminum case. Technical aspects of Activetracer have been described by Redmond and Hegge. The unit interfaces with a NEC-compatible microcomputer for operator selection of patient identification, start time, length of accumulation period and for downloading of data. The device is sensitive enough to detect small movements and can record the frequency of movement in two spatial axes (up-down and right-left direction). A piezoelectric flexible element translates body movement into an electrical signal. The instrument was adjusted to detect g forces more than 0.05 g which was considered to be reasonable sensitivity to distinguish physical movement from background noise. It recorded and counted the duration of movements greater than 0.05 g and the frequency of movements accumulated over a minute. The data were stored continuously for up to 2 days in cumulative units of 1 minute. In order to assess the relationship between BP fluctuation and physical activity, the correlation coefficient between the averaged active counts for 5 minutes just before BP measurements and the corresponding BP or pulse rate were calculated in all subjects. Resting BP and pulse rate were all included in the analysis for the correlation. All subjects were classified into 3 categories according to their BP and pulse rate response to activity. When activity significantly correlated with either systolic or diastolic BP but not with pulse rate, the subject was referred to as a BP type. If activity significantly correlated with pulse rate, but not with BP, the subject was considered a Pulse type. If both the BP and the pulse rate significantly correlated
with activity, the subject was considered a Balance type.

Activity during the 48 hour period was divided into active time and resting time according to the averaged active counts for 5 minutes before BP measurements. When the averaged active counts were 50 or more counts per minute it was classified as active time and when it was 49 points or less it was classified as resting time. The mean BP and pulse rate during active time and resting time for each case were calculated.

All data are expressed as mean±standard deviation. The significance of differences in means between groups was determined by unpaired t test. A p value <0.05 was considered significant.

RESULTS

Figure 1 shows a graphic record of 48-hour activity and BP of a working 25 year old female. Systolic BP and pulse rate fluctuations are shown in the upper panel and activity counts are shown in the lower panel, where each spike represents a 1 min. cumulative total. The BP clearly rises when the subject moves during working hours and decreases during sleep after nightwork. The pulse rate also fluctuates in accordance with the activity score variations in this case.

Figure 2 demonstrates the three response types observed in the correlation
Fig. 2. The three representative types of correlation between physical activity and BP or pulse rate are shown. SBP = systolic blood pressure; DBP = diastolic blood pressure; PR = pulse rate. See text for details.

between the subject’s activity score and BP or pulse rate. In case 1 (Fig. 2a), the activity count significantly correlated with the systolic and diastolic BP, but was not related to the pulse rate. This case was classified as the BP response type. In case 2 (Fig. 2b), the activity score correlated with pulse rate but not with systolic or diastolic BP and she was classified as the pulse rate (PR) response type. In case 3 (Fig. 2c), all three monitored responses increased as the activity increased and she was classified as the Balance type.

Table I lists the correlation coefficients calculated between the activity count and BP or pulse rate measured in each case, and their classified response. The Balance type of response was observed in 5 of 10 cases in the young group (50%) but only in 1 of 7 cases in the older shiftworkers (13.4%). The PR response was seen in only 2 cases in the young group (20%). The BP response type was observed predominantly in the older group of workers since 6 of 7 cases (86%) demonstrated this response as compared to only 3 cases in the young group (30%).
Table I. Correlation Coefficients Calculated between the Activity Count and BP or Pulse Rate in Each Case and the Classified Response Type

<table>
<thead>
<tr>
<th>Age (in years)</th>
<th>Sex</th>
<th>SBP r (p value)</th>
<th>DBP r (p value)</th>
<th>PR r (p value)</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Young group)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>F</td>
<td>.41*(.001)</td>
<td>.53*.001</td>
<td>.42*.001</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>F</td>
<td>.39*.001</td>
<td>.32*.003</td>
<td>.03*.78</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>F</td>
<td>.12 (.247)</td>
<td>.20 (.061)</td>
<td>.44*.001</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>F</td>
<td>.05 (.604)</td>
<td>.05 (.627)</td>
<td>.27*.001</td>
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<tr>
<td>5</td>
<td>23</td>
<td>F</td>
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<td>.30*.008</td>
<td>.07*.521</td>
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<tr>
<td>6</td>
<td>28</td>
<td>F</td>
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<td>.50*.001</td>
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<tr>
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<td>F</td>
<td>.30*.003</td>
<td>.46*.001</td>
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<td>24</td>
<td>F</td>
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<td>.29*.005</td>
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</tr>
<tr>
<td>10</td>
<td>26</td>
<td>F</td>
<td>.11 (.331)</td>
<td>.29*.012</td>
<td>.08 (.507)</td>
</tr>
</tbody>
</table>

| (Older group) |     |                |                |                |      |
| 1             | 65  | M              | .43*.001       | .16 (.113)     | .01*.982 | BP     |
| 2             | 69  | M              | .47*.001       | .53*.001       | .29*.006 | BALANCE |
| 3             | 63  | M              | .28*.006       | .16 (.116)     | .10*.327 | BP     |
| 4             | 68  | M              | .27*.018       | .35*.002       | .1 (.367) | BP     |
| 5             | 61  | M              | .47*.001       | .28*.016       | .17*.154 | BP     |
| 6             | 69  | M              | .36*.001       | .34*.001       | .02*.848 | BP     |
| 7             | 63  | M              | .24*.032       | .42*.001       | .19*.058 | BP     |

Number in parenthesis represents p value determined by an analysis of variance table. Asterisk represents a significant correlation (p value less than 5%). SBP=systolic blood pressure, DBP=diastolic blood pressure, PR=pulse rate, M=male, F=female.

Table II. Differences in BP, Pulse Rate and Activity Counts between Resting Time and Active Time in Both Groups.

<table>
<thead>
<tr>
<th>n</th>
<th>Young</th>
<th>Older</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- SBP (rest) mmHg
- SBP (active) mmHg
- Incr. SBP mmHg
- DBP (rest) mmHg
- DBP (active) mmHg
- Incr. DBP mmHg
- PR (rest) bpm
- PR (active) bpm
- Incr PR bpm
- ACT (rest) counts
- ACT (active) counts
- Incr ACT counts

Asterisk represents a significant value (p less than 5%).

Table II represents BP, pulse rate and activity score during resting time and active time in both groups. The difference in activity score between resting time and active time was 207.0±40.1 counts in the young group and 201.4±80.5 counts in the older group, representing comparable physical activity in both
groups. The frequency of active time was 51.1±6.7% in the young group and 48.5±6.6% in the older group, and these were comparable. In each group, systolic BP during active time was significantly higher than that during resting time.

Figure 3 shows the increase in systolic and diastolic BP during activity (the difference between active time and resting). The increase in systolic BP in the older shiftworker group was 15.9±6.4 mmHg and it was significantly larger than the 5.9±6.6 mmHg seen in the young group (p<.01), although no significant difference was observed in diastolic BP changes. In contrast, the increase in pulse rate during active time in the young group was 9.1±4.8 beats per minute and it was significantly higher than the 4.4±4.0 bpm seen in the older group (p<.05). (Fig. 4, Table II).

Significant correlations between BP during rest time and the increase observed during active time were not observed (r=0.29, p=0.26 for systolic; r=0.16,
p=0.54 for diastolic). The correlation between pulse rate during rest time and increase during active time was also not significant (r=0.43, p=0.09).

**Discussion**

In the present study, the relationship between physical activity and ambulatory BP or pulse rate was evaluated in young and older shiftworkers. Activity was monitored with a new device which is capable of objective and quantitative assessment of physical activity and it was shown that BP fluctuations were more closely correlated to physical activity in the older group as compared to the young group.

Although many investigators have noted that physical activity is an important factor contributing to the circadian rhythm of BP, there have been few attempts to make a quantitative analysis of the effect of activity on BP.

Clark et al. analyzed the effects of activity on BP in 461 hypertensive patients using a diary-computer system and noted that there was no significant diurnal BP rhythm independent of activity. Van Egeren and his group developed a computer assisted diary (CAD) for standardization and quantification of the behavioral information. However, diary systems in general disrupt the subject's routine activity, lack objectivity in data collection, and require subject compliance.

The Activetracer used in the present study is a modified version of the original Actigraph, which was manufactured by precision control design (PCD). The technical aspects of the device have been described by Redmond and Hegge. The device provides objective quantitative information of physical movements without interrupting the action of the subject. Activetracer senses 2 directional movements, although the original Actigraph is capable of sensing movement in 3 dimensions. Van Egeren noted that restriction to two axes of movement need not be problematic by proper orientation of the Actigraph on the body.

For people who usually work during the daytime and sleep at night, BP rises during the daytime and falls during the nighttime. However, it was recently reported by Chau et al. that this circadian rhythm was disturbed when day-night activity patterns changed. They noted that the high BP period in shiftworkers appeared to coincide with working time. In the present study of subjects with reversed day-night activity, it was shown that the relation of BP changes to physical activity was stronger in the elderly group compared to the young group. Although BP during rest time in the older group was significantly higher than in the young group, the increase in systolic BP during active time was not correlated with that during rest time. Therefore, the augmented systolic BP change during
active time in the older group was not explained by the higher BP during rest time in this group.

The results of the present study are consistent with previous reports which noted the differences in hemodynamic response to exercise between young and elderly populations. Sidney et al.\textsuperscript{9}, Granath et al.\textsuperscript{10} reported that elderly populations have higher systolic and diastolic BP responses during submaximal or maximal exercise compared to the younger populations. Miyawaki\textsuperscript{11} also noted that the increase in systolic and diastolic BP after 50w dynamic exercise on a bicycle ergometer was significantly larger in the elderly than in the young.

In the present study, there was no quantitative difference between the two groups as indicated by comparable activity scores in both groups (207 vs. 201 counts).

As most work during the night in both groups consisted of dynamic exercise such as walking or running rather than isometric exercise or mental desk work, the qualitative difference in work between the two groups seems to be negligible. An increased fluctuation in BP has also been reported in the elderly with a normal daily lifestyle. Drayer\textsuperscript{12} measured 24-hour BP noninvasively in young and elderly populations and noted that BP variations were significantly larger in the elderly group relative to the young group. Such an augmented BP response could be explained by the structural and functional changes associated with the aging process.

First, decreased elasticity due to age-related thickening of large arteries and an increased pulse wave velocity would augment BP elevation in response to increased ventricular ejection during exercise.\textsuperscript{13,14} Second, impaired baroreceptor function might possibly contribute to the larger fluctuation of BP in the elderly. Shimada et al.\textsuperscript{15} noted that carotid baroreceptor function is impaired in the elderly and we have reported disturbed cardiopulmonary baroreceptor function in the elderly.\textsuperscript{16} Thus, the impaired buffer effect of baroreceptor function augments the blood pressure fluctuation during physical activity. Third, increases in plasma norepinephrine levels with aging might also contribute to the enhanced BP response.\textsuperscript{17} Since the $\alpha$-adrenoceptor sensitivity of resistance vessels is preserved in the elderly in contrast to the decreasing $\beta$-adrenoceptor effects seen with the aging process,\textsuperscript{18} increased norepinephrine level during exercise might be involved in the augmented BP response in the elderly.\textsuperscript{22}

The reason for the lower correlation between pulse rate and physical activity in the older group is not clear, but this finding is similar to the result of the Baltimore Longitudinal Study which noted a lower heart rate at given levels of exercise in older subjects compared to younger subjects. Lakatta\textsuperscript{19} also reported a decreased heart rate response to maximal exercise with aging, while systolic and diastolic BP responses increased. The decreased $\beta$-adrenoceptor responsive-
ness in the sinus node associated with aging might be involved.19)

In the present study, the relationship between physical activity and BP was examined in night workers whose physical activity was not synchronized to the usual day-night BP cycle which rises during the daytime and falls at night. We expect that monitoring physical activity using the Activetracer and the resultant objective data collection will enable similar quantitative studies of ambulatory BP changes in a variety of populations, including the day working population.

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REFERENCES