Field Study

Evaluation of health status of truck drivers by vital sign monitoring using wearable devices: a cross-sectional pilot study

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Abstract

Objectives: Health problems of truck drivers, including cardiovascular and major blood vessel diseases, have long been reported. This study aimed to collect vital signs of truck drivers while working by using commercial wearable devices and to determine the utility of the devices for occupational health. **Methods:** Wearable devices were attached and obtained data from 130 truck drivers working at a single company in Gunma Prefecture in 2020 for 3 continuous working days. Systolic blood pressure (SBP), heart rate (HR) and respiratory rate (RR) were monitored during working hours. The duration and proportion of time at which these parameters exceeded preset upper limits were calculated, as were the frequency and proportion of 10% and 20% increases from previous measurement points. **Results:** The average proportions of time during which SBP, HR, and RR exceeded their preset upper limits were 7.17%, 21.22% and 0.36%, respectively. Also, the average proportions of frequency during which SBP, HR and RR were $\geq 10\%$ increased above previous measurement points were 5.97%, 12.66% and 11.83%, respectively. These results differed slightly from those obtained during regular health checkups. Health guidance should be provided to truck drivers with excess SBP, HR, and RR who were not identified on regular health checkups. **Conclusions:** Wearable devices may be useful in promoting the health conditions of truck drivers.

Keywords: health checkup, occupational health, truck driver, vital sign, wearable device

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Introduction

Worldwide increase in e-commerce, both for individuals and businesses, has resulted in increased cargo shipping by various methods, including trucks, trains, ships, and airplanes¹⁾, with trucking being the most prominent method in Japan²⁾. In 2018, trucking accounted for over \$145 billion (16 trillion yen) in business income and employed over 1,930,000 workers in Japan²⁾.

The average age of truck drivers is gradually increas-

ing³⁾, and their working hours are around 20% greater than workers in other industries²⁾. Under these circumstances, health problems of truck drivers have long been reported. For example, they experience high rates of low back pain because they must maintain a sitting position for a long time⁴⁾. Moreover, sudden death cases among truck drivers are sometimes reported in Japan⁵⁾. These reports led the Japanese government and the Japan Trucking Association to publish guidelines in 2019 to prevent health problems and deaths among truck drivers⁵⁾. These guidelines include daily monitoring and regular health checkups for early detection of health problems, such as major blood vessel and cardiovascular diseases. Moreover, an important task is to monitor the circulation

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dynamics of drivers while operating vehicles to evaluate their actual health conditions. However, evidence regarding circulation dynamics data is scarce in the occupational field, and sufficient data has not been collected or evaluated.

New technologies can help to improve health and safety at the workplace. Industry 4.0 has provided several wearable devices in order to monitor both work environment and workers' health parameters with the goal to reduce injuries and illnesses among the working population⁶⁾. The most used wearable devices to monitor workers' health parameters are wristbands and bracelets. These devices can monitor and collect health data of people while at work, with several available commercially, including Mimamori-gajumaru (<https://www.nttpc.co.jp/service/gajumaru/>) and Silmee (https://product.tdk.com/ja/products/biosensor/biosensor/silmee_w22/index.html) in Japan. Although these packages are used by certain companies to monitor their workers and support health checkups, these data are insufficient because companies will not supply data on individual workers for research studies. In addition, because wearable devices are still under development, little is known about their optimal use or how to evaluate their data. Thus, we hypothesized that if vital data among truck drivers were collected using wearable devices, novel insights may inform guidance to promote the health of drivers. The present study aimed to assess the usefulness of wearable devices for collecting vital signs among truck drivers while working.

Materials and Methods

Study subjects

This study was performed at one trucking company (Vortex Seigun), located in Gunma Prefecture, from June 2020 to March 2021. This company is mainly involved in carrying commercial goods for businesses and uses large trucks for long-distance transportation. The study subjects consisted of 133 truck drivers.

Wearable devices and data collection

Vital signs, including systolic blood pressure (SBP), heart rate (HR), and respiratory rate (RR), were obtained using Helpo wearable devices, from WithUS (Irvine, CA, USA; <https://www.withus-group.com/service/#medical>). The devices measured data as comma separated values (CSV). The measurement of heart rate is based on a method called photoelectric volumetric pulse wave recording (photoplethysmography)⁷⁾, wherein change in blood flow when the heart pumps blood to the periphery is detected by measuring green waveform light absorption by hemoglobin. A light emitting diode transmits the light and a photodiode measures change in the amount reflected to reveal the heartrate. The device in the present study was worn on the wrist. Blood pressure was esti-

mated from the difference between increase and decrease in blood flow detected by the device that measured the heartrate. The respiratory rate was estimated from change in heartrate, where the rate increases during inhalation and decreases during exhalation.

Workers at the study company work 8 hours per day, with truck drivers having flexible working hours. The work schedule of the truck drivers in this study was not fixed between day and night shifts, and shifts of work hours were arranged according to the received work. Each driver checked in before starting to drive and attached the wearable device at that time. The driver transported cargo to its destination, where it was off-loaded and handled; the driver then drove the truck back to the company, and the device was removed at check out. Data, collected for 3 consecutive days, were managed by the occupational health nurse. The nurse assigned an ID number to each driver, deleted identifying personal information, and sent only numerical data to the researcher. The researcher analyzed the data and returned the results to the occupational health nurse. The nurse linked the ID number to the data of each individual and compared these findings with the data obtained at their regular medical health checkups.

Statistical analysis

The measured data were evaluated using two methods to determine drivers' health conditions during working hours.

First, the measured values were directly evaluated from the obtained data. The numbers of points beyond the upper limits of normal ranges were counted at rest for SBP (≥ 130 mm Hg), which is shown in the Ministry of Health, Labour and Welfare medical checkup criteria⁸⁾; HR (≥ 86 beats per minute), which is shown in Japan Society of Ningen Dock judgement classifications⁹⁾; and RR (≥ 25 breaths per minute), which is shown in Japanese Society of Laboratory Medicine's laboratory test guidelines¹⁰⁾. The number of points at which each parameter exceeded the upper limit during working hours was divided by the total number of respective points to determine the frequency at which each parameter exceeded the upper limit.

Sudden fluctuations in blood pressure due to heat shock are associated with high risks of cerebral hemorrhage and myocardial infarction¹¹⁾. To determine the number of sudden fluctuations in SPB, HR, and RR during working hours, the rate of change of each was determined by dividing the parameter obtained at each time point by that obtained immediately prior. Because logarithmic differences are often used to calculate the continuous rate of change of a series data obtained over time¹²⁾, this method was also used in this study. That is, when P_t represents measurement at time t and P_{t-1} represents the parameter at time $t-1$, the rate of change γ_t (%) can be calculated as:

$$\gamma_t = (\log P_t - \log P_{t-1}) * 100$$

Time point “*t*” was set to every 5 minutes, SBP was measured every 5 minutes, and HR and RR were the number of measurements per 1 minute just before every time point. This study counted the numbers of points at which each parameter was $\geq 10\%$ and $\geq 20\%$ higher than at the previous point, with each of these findings divided by the number of total points to calculate the rate.

If the device was not attached properly, data could not be accurately sampled and were classified as missing. In that case, the TSpacage used the spline imputation method. All statistical analyses were performed using R (ver. 4.0.5; R Foundation for Statistical Computing, Vienna, Austria) software.

Ethics

Written informed consent was obtained from all participants. Because the occupational health nurse collected and anonymized all data, only numeric data were available to the researcher. The study aim and protocol were approved by Gunma University Ethics Committee (Study number: HS2020-199).

Results

Among 133 drivers, 130 (97.7%) agreed to participate in the study. The demography of 130 participants were as follows: Their mean age was 49.1 (standard deviation [SD], 10.4) years; 127 drivers (97.7%) were male; 25 (19.2%), 15 (11.5%), and 38 (29.2%) drivers had been diagnosed with hypertension, diabetes, and hyperlipidemia, respectively; and 39 drivers (30.0%) and 52 drivers (40.0%) were obese and smokers, respectively. Among 130 participants, 79 drivers (60.8%) worked some night shifts during the study period, and 51 drivers worked day shifts only (Table 1). Fluctuations in SBP, HR, and

RR over time were plotted for each individual driver. For example, SBP, HR, and RR plotted data of participant ID number 1 is shown in Figure 1. All other participants' data were also plotted, and data points above upper limits were counted. The average proportion of working time during which SBP was ≥ 130 mm Hg was 7.17% (median, 6.97%; range, 0.95–22.74%), the average proportion of time during which HR was ≥ 86 beats per min was 21.22% (median, 19.91%; range, 3.57–58.68%), and the average proportion of time during which RR was ≥ 25 breaths per minute was 0.36% (median, 0.22%; range, 0–2.65%) (Table 2).

To evaluate their rate of change, the difference between the logarithm of each parameter at each time point and at the immediately previous time point was determined. The logarithm transformed data of SBP, HR, and RR of the same participant (ID number 1) are shown in Figure 2. Frequencies of fluctuation in the same participant plotted as a histogram are shown in Figure 3. The average proportions of time during which SBP, HR, and RR were $\geq 10\%$ and $\geq 20\%$ higher relative to the previous measurement point are shown in Table 3. SBP showed a relatively smaller change rate than HR and RR, and HR and RR $\geq 10\%$ change were 12.66% and 11.83%, respectively. Although the frequency of RR above the upper limit was less than that for SBP and HR (Table 2), change rate in RR was higher than that in SBP and similar to that in HR (Table 3).

Comparisons of these SBP, HR, and RR findings for each driver with the results of their general health examinations by the occupational health nurse identified several workers who were high risk according to data obtained during their working hours but not according to data obtained during their general medical examinations. These drivers were provided with additional health guid-

Table 1. Demography of the study participants

Factors		Participants (N=130)	
Age, years, mean (SD)		49.1	(10.4)
Sex	Male	127	(97.7%)
	Female	3	(2.3%)
Hypertension	Yes	25	(19.2%)
	No	105	(80.8%)
Diabetes	Yes	15	(11.5%)
	No	115	(88.5%)
Hyperlipidemia	Yes	38	(29.2%)
	No	92	(70.8%)
Obesity	Yes	39	(30.0%)
	No	91	(70.0%)
Smoking	Yes	52	(40.0%)
	No	78	(60.0%)
Work type	With night shift	79	(60.8%)
	Only day shift	51	(39.2%)

SD, standard deviation.

Fig. 1. Monitoring of SBP, HR and RR over time using a wearable device in a truck driver. Time course changes were observed in respective SBP, HR, and RR data. The data were observed every 5 minutes and obtained on 3 consecutive work days. In this figure, data of participant ID number 1 is shown as an example.

Table 2. Frequency of vital data above upper limit during working time

Factor	Mean (%)	Median (%)	Range (%)
Systolic blood pressure (≥ 130 mm Hg)	7.17	6.97	[0.95–22.74]
Heart rate (≥ 86 beats/minute)	21.22	19.91	[3.57–58.68]
Respiratory rate (≥ 25 breaths/minute)	0.36	0.22	[0.00–2.65]

ance. For example, of the 10 drivers at highest risk, five were asymptomatic for hypertension and four asymptomatic for tachycardia or on electrocardiogram (ECG) findings. Although regular medical examinations found they

did not have severe health problems, they understood the health risks resulting from at-work evaluations and modified their lifestyles accordingly (e.g., meal habit or physical exercise).

Fig. 2. Rate of changes in SBP, HR and RR over time in a truck driver. The reference value was set at 0, increasing when SBP, HR, and RR increased and decreasing when the SBP, HR and RR decreased. Large fluctuations in these factors were accompanied by large fluctuations in range. Data of participant ID number 1 is shown as an example.

Table 3. Frequency of vital data $\geq 10\%$ and $\geq 20\%$ changes during working time

Factor	Mean (%)	Median (%)	Range (%)
Data $\geq 10\%$ change rate			
Systolic blood pressure	5.97	5.73	[1.94–11.28]
Heart rate	12.66	12.40	[6.33–19.17]
Respiratory rate	11.83	11.33	[5.29–22.02]
Data $\geq 20\%$ change rate			
Systolic blood pressure	0.66	0.59	[0.00–2.17]
Heart rate	3.43	3.37	[0.71–7.34]
Respiratory rate	3.21	3.01	[0.82–7.87]

Fig. 3. Histograms showing rate of change of SBP, HR and RR in a truck driver. The proportions of time points at which SBP, HR, and RR were $\geq 10\%$ and $\geq 20\%$ higher relative to previous measurements were counted and shown as histograms. Data of participant ID number 1 is shown as an example.

Discussion

Among truck drivers, at-work health parameters, including SBP, HR, and RR, cannot be evaluated by measuring them at rest during regular health checkups. Therefore, this study was conducted as a pilot study from the perspective of occupational health practice to see if vital sign data could be easily collected using wearable devices in this population and to learn what could be assessed with such devices. As a result, although the

accuracy of the data was limited, in addition to evaluating the frequency at which SBP, HR, and RR exceeded pre-set limits, this study could also evaluate the frequency at which these parameters fluctuated by $\geq 10\%$ and $\geq 20\%$. The results of this study may be utilized practically in healthcare guidance for workers at risk who cannot be identified during regular health checkups.

Currently, workers' health management in Japan is based on the results of health examinations stipulated by the Industrial Safety and Health Act¹³⁾. However, work-

ers' health conditions should be based not only on vital signs at rest but also on vital signs while working. Holter electrocardiogram (ECG) has been used to monitor vital signs, such as physical stress in caregivers¹⁴⁾, and work load in shift-working medical staff¹⁵⁾, providing valuable insight into the chronological development of stress loads during work. However, it is difficult to wear the Holter ECG device for a long time while at work. The problem can be solved using wearable devices. Although wearable devices have been used to evaluate HR in participants who work as drivers, these studies have addressed methods of using these data, not to establish suitable standards. For example, an algorithm is being developed to classify the obtained data using machine learning^{16,17)}. The present study evaluated work-stress-related fluctuations in vital signs while at work. These wearable devices may be utilized to assess the effects of heavy work, long working hours, and high-tension work on workers' vital signs, and thereby inform better work conditions.

Although the use of wearable devices will likely increase, these devices are still being developed, and their accuracy is not high. These devices do not directly measure blood pressure and RR; rather, they are estimated values based on proxy measurements. Despite the difficulties in evaluating the raw data, the rate of change is a relative parameter, suggesting that wearable devices may be suitable for measuring ratios. In contrast, these devices accurately measure HR because they measure pulse directly, suggesting that these wearable devices may be suitable for measuring stress-associated changes in HR. If the accuracy of such devices were improved in the future and the results obtained while working could be compared with those obtained at rest in a medical examination, these issues will likely be resolved. At that time, it will be necessary to conduct another study to evaluate vital signs at work. With such improved devices, it is expected that the health management of truck drivers will advance dramatically and may prevent cardiovascular or major blood vessel diseases in the future.

There are still some issues in terms of working hours for truck drivers in Japan, and there are concerns about the health effects of the workload. The Japanese government revised the Labor Standards Act in 2019, reducing the amount of permissible overtime working hours, including an interval time between continuous working days and expansion of paid holiday rules¹⁸⁾. Application of the overtime work restriction, however, was postponed for 5 years for automobile drivers because some companies using automobile drivers could not immediately implement the decrease in working hours. Thus, despite increases in their workload, it may be difficult to restrict truck drivers' working hours sufficiently to better control their health. Under these circumstances, better ways to manage the health of truck drivers should be considered, and referring to this study results, the use of health

management tools, such as wearable devices, should be promoted.

This study had several limitations. First, since the main focus of this study was to examine the use of wearable devices and how to apply them in practice, we did not evaluate relationships between individual background factors (e.g., gender, age, underlying diseases) and data obtained using wearable devices. Moreover, information about the reliability and accuracy of the devices is lacking. SBP and RR are indirect measurements, so other investigations are needed to compare measurements from the devices with those obtained from direct methods. When the accuracy of the devices is improved and the causality is estimated, the analysis of the association between individual background factors and device data should be considered. Second, because the imputation method was used for missing data, some imputed data were evaluated, which may have affected the accuracy of our findings. Third, this study not only measured data during truck driving itself, but also during cargo handling. Although vital data obtained during driving are suitable for evaluating health problems among truck drivers, it was not possible in this study to separate driving from cargo handling. Future studies may require stratification of workers by type of activity/behavior. Fourth, the observation period was only 3 days. A longer period of time is needed to study changes in the vital signs of drivers during work. This long-term observation is a subject for future research.

Conclusion

This study evaluated the usefulness of wearable devices in evaluating health conditions of truck drivers at work. Some of these drivers showed frequent fluctuations in vital signs, despite the absence of problems during regular health checkups. Therefore, health guidance should be provided to drivers found to be at risk after examining data from wearable devices. Although still under development, wearable devices may have potential to prevent sudden death of truck drivers.

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Conflicts of interest

The research was supported by Vortex Seigun research grant. Matsuda S is a part time employee of Vortex Seigun where the current study was conducted.

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