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WORKLOAD ANALYSIS OF REBAR WORKER USING WEARABLE WRISTBAND IN HONG KONG 6-DAY CYCLE BUILDING CONSTRUCTION

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ABSTRACT

In Hong Kong, the building workers are pressurised to deliver the tight 6-day cycle construction schedules on time. Therefore, the workloads of rebar workers are heavy to meet the project deadline. Although the salaries are considerably high, the young workers are not willing to join the industry due to heavy workload. With the development of wearable health devices that are equipped with biosensors, such as wearable wristband equipped with heart rate (HR) sensors, the health status of construction workers can be smartly monitored. The wristbands can be worn by the workers without causing much site work interruption. Based on the HR data, the heart rate reserve percentage (%HRR) can be calculated to quantify the workers' physical demand and workload when performing site activities. Wristbands have been proven to be a feasible tool for measuring workers' physical demands. However, no research has investigated the 6-day cycle workloads of rebar workers on site. As such, this research study proposed a 5-step method to measure the physical demand based on %HRR of rebar workers using wearable wristbands. The steps are: (1) Select suitable wearable wristband devices; (2) Identify suitable workers; (3) Prepare data collection; (3) Collect and store sensor data; and (5) Analyse workers' physical demand based on %HRR. A practical case study is used to demonstrate the application of the proposed method. The results show that the workloads are different among the rebar workers and among the work cycles. As a result, this approach shows the potential of quantifying and monitoring workers' workload on site for planning workload among available workforce.

Keywords: workload analysis, physical demand, wearable wristband, heart rate, rebar worker.

1. INTRODUCTION

During the past decades, concerns of workers' health and safety have arisen in construction due to the labour-intensive nature of executing the site activities that may cause excessive physical demands beyond workers' physical capability (O.Abbe *et al.*, 2010). According to the statistics published by the Census and Statistics Department (C&SD) in Hong Kong (C&SD, 2018)，the workers face the highest risk of illnesses and accidents, compared to other sectors. In general, the site works are physically demanding, and workers' motions are frequently repetitive. As such, the workers' workload can be heavy and their energy expenditure can be excessive.

In Hong Kong, the bar benders and fixers, form workers, and concretors are considered as three main trades suffered from excessive workloads. According to C&SD (2007), the wages of construction workers were increased tremendously over the past decade. However, still, in 2007, the longest-running strike in Hong Kong history occurred to protest the unaffordable heavy workload and lengthy working time of rebar workers. Nevertheless, the report given by C&SD in 2018 (C&SD, 2018) shows that the number of workers engaged on construction site dropped 11.4% compared to the one in 2017, and the job opportunities of construction workers reached to 52%. The workers are not willing to join and stay in the industry. Apart from the economic factors, the workers are often pressurised by the tight 6-day cycle construction schedules. To meet the project deadline, they may accelerate the work progress by intensively performing the activities which are physically demanding. To maintain and monitor workers' health and safety, the workload of site workers should be quantified without causing any work interruption.

Heart rate (HR) has been proved as a reliable approach for monitoring workers' cardiovascular and physiological loads when the workers are delivering field work. In particular, the percentage of heart rate reserve (%HRR) is a widely accepted physical demand measurement indicator which normalises the individual difference between workers (Hwang and Lee, 2017a). This approach was applied to estimate the intensive physical demand work in construction (Lee and Migliaccio, 2016). However, there is no research focused on profiling the health and workload of rebar workers using the %HRR data captured by wristbands throughout the 6-day work cycle. This research provided a method and made the first attempt to profile workers' health and workload for benchmarking the workers' workloads in Hong Kong building construction.

In this regard, this research study investigates the changes of %HRR of rebar workers for one complete cycle of a concrete work (i.e., six days) in Hong Kong. A new 5-step method is proposed to collect the HR data from site workers on site using wristbands (i.e., Apple Watch), followed by analysing and comparing the %HRR data between weeks and among workers. Conclusions are given by discussing the feasibility of monitoring the workers' %HRR data continuously for the benefits of workers' health in construction.

2. LITERATURE REVIEW

2.1 Workload assessment method based on subjective judgement

Self-report-based workload assessment method focuses on workers' subjective feelings and uncomfortable physiological self-assessments. For example, NASA-TLX (Task Load Index) established six dimensions to assess workloads such as mental demand and physical demand. Subjective Workload Assessment Technique (SWAT) is a subjective rating technique that to assess workload in three levels (low, medium, high). Based on these methods, Workload Profile (WP) has been proposed as a new multidimensional subjective workload assessment instrument, which portends to be a technique with an elevated diagnosticity (Rubio *et al.*, 2014). Questionnaires and interviews are the primary data collection approaches, such that the data collection process is time-consuming and inefficient yet the collected data can be subjective.

2.2 Workload assessment method based on observations

Observation-based methods are another kind of well-accepted methods for assessing the workload. Many estimation methods based on visual investigations of the work being undertaken and the corresponding performance of workers (i.e., work posture, external load, and duration). These methods include, but are not limited to, OCRA (Occupational Repetitive Actions), RULA (Rapid Upper Limb Assessment), OWAS (Ovaka Working Posture Analyzing System), and REBA (Rapid Entire Body Assessment). Although these methods are feasible to implement and can assess the workload roughly, the safety staff is required to make their subjective judgement. Additionally, these methods assess the workload from different perspectives (e.g., the work are repeated or not). Therefore, the same workload assessed by different approaches may lead to different results (Malchaire, 2011).

2.3 Workload assessment method by mounting sensors on human body

Recent advancements of wearable health devices provide opportunities to measure workers' physical demands by virtue on body sensor-base equipment, in which the errors in assessment due to the subjective nature of the responses could be potentially avoided. For example, Yang *et al.* proposed an in-suit mobile sensing system using inertial measurement units (IMUs) to investigate the safety and health of ironworkers (Yang *et al.*, 2016), and Yu *et al.* proposed a computer vision and smart insole-based joint-level ergonomic workload calculation methodology and wristband-type wearable biological sign capture devices, for detecting the physical health of the subjects (Yu *et al.*, 2018). To study the physical demand and workload, the light-weight and comfortable wristband-type health devices (e.g., smart watches and fitness trackers) can be used to measure physical demand on-site continuously without interfering workers' site works. Furthermore, the wristband devices provide the %HRR data of the site workers continuously (Thiebaud *et al.*, 2018). This approach can be used to assess the work types (e.g., walking, lifting and bending etc.), action postures (e.g., back turned and twisted), activity duration and occurrence rate, environmental factors (e.g. humidity, temperature), regardless of the factors of individual workers (Hwang and Lee, 2017a). However, most of the research endeavours collected the HR data in a laboratory setting for a short time period (e.g., four to eight working hours for only one day) for demonstration purpose. The benchmark may not be suitable for profiling the health and workload for the workers who perform the works repetitively. In particular, the repetitive heavy workload suffered by the workers in high-rise building construction is worth benchmarking.

There are limited research studies focused on the investigation of the accumulated effects of excessive physical demands over time by analysing the workload using waistband. Thus, this research study proposed a new 5-step approach for recording and analysing the %HRR data for a complete work cycle, in collaboration with the steel workers on a construction site in Hong Kong. As such, this research study proves the feasibility and reliability of using wristband devices to measure the workers' (excessive) workload in construction.

3. PROPOSED METHODOLOGY

Figure 1 depicts the flowchart of the proposed workload evaluation method for construction workers. The whole study was completed with the following steps. Step 1: Select suitable wearable wristband devices; Step 2: Identify suitable workers; Step 3: Prepare the data collection; Step 4: Collect and store the sensor data; and Step 5: Analyse the physical demand of workers based on %HRR.

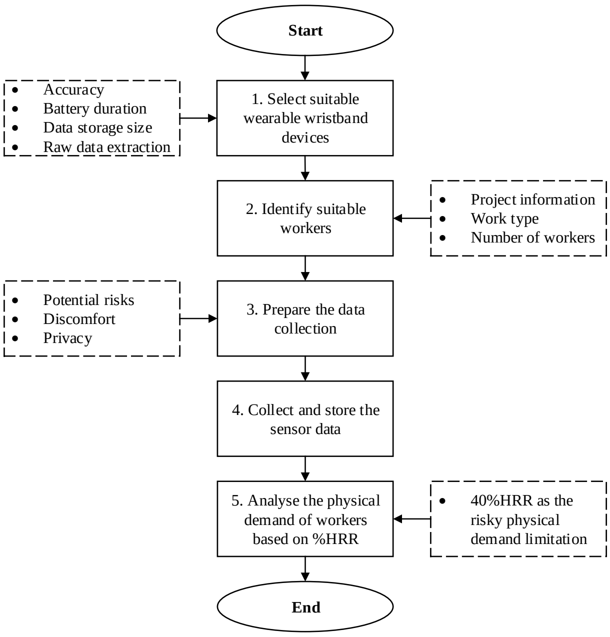

Figure 1: A flowchart showing the steps of the proposed method

Step 1: The accuracy of the wristband measurement data is the most critical factor in determining the suitability of the wristbands. The battery lasting duration should be greater than four to five hours to ensure a full day data collection. The memory size should be sufficiently large for storing data efficiently. The raw data should be able to extract from the wristbands for data analysis.

Step 2: The type of workers who are performing heavy works should be targeted. The number of workers should be determined in order to make comparisons of the workloads from the perspectives of different work cycles and work activities.

Step 3: The potential risks should be well informed to all the participated workers to protect their safety during the data collection period.

Step 4: The wristband should be worn tightly on worker' dominant hand to collect HR data during a whole day. The worker privacy and data security cannot be ignored.

Step 5: Based on the recorded HR data, %HRR can be calculated by Equation (1) to describe the physical demands of workers (Kirk and Sullman, 2001).

$$\%HRR = \frac{HR_{\text{working}} - HR_{\text{resting}}}{HR_{\text{maximum}} - HR_{\text{resting}}} \times 100\% \tag{1}$$

where HR_{rest} is equal to the resting heart rate [bpm]; HR_{working} means the average value of working heart rate [bpm]; and HR_{maximum} describes the maximum heart rate estimated by ($220 - age$) [bpm] (Pengemudi and Transjakarta, 2017).

It is recommended to measure the resting heart rate during the sleeping time of the subject. However, (Hwang and Lee, 2017a) found that low-level HR measured during 10 to 15 minutes from the beginning of the rest time can be used as an approximate resting heart rate. As such, resting heart rate can be measured when the workers took a rest for more than 20 minutes.

The indicators of worker health problem were evaluated with respect to the work duration and the %HRR. That means, the workers should be alerted if their %HRR is over a certain threshold continuously for a certain time period. For example, Wu and Wang (2002) suggested that 30%HRR can last for eight hours, 40%HRR can last for 30 to 60 minutes. Nevertheless, the time limits associated with %HRR were not determined in construction.

4. PRACTICAL CASE STUDY

A practical case study is conducted to show the practical application of the proposed approach. The HR data were collected from two rebar workers during one cycle of concrete work (6 days) at a residential building project located in Hong Kong.

Step 1: We have considered to use the chest-mounted instruments, however, it caused uncomfortable wearing experience and increased potential heatstroke due to the inability of dissipating the workers' chest heat. Thus, wristband-type HR recorded devices were selected. Apple Watch Series 4 was used to collect site data (Figure 2a). Notably, the accuracy of HR data collected through Apple Watch was promising (Abt *et al.*, 2018). However, the battery duration can last for only 4 to 5 hours. Therefore, the strategy of charging Apple watches for an hour during workers' lunch time at noon was adopted so as to collect the data for a whole day. Since Apple Watch does not provide the function of exporting the raw data, a data connector has developed (Its details are out-of-scope of this research study). The storage space of Apple Watch was sufficient because the HR data for ten months maximum can be recorded. Cardiogram App was used to extract the HR data of 5-second interval.

Figure 2a: Apple Watch Series 4 used for capturing heart rate of workers

Figure 2b: Steel workers wearing Apple Watch when working on site

Step 2: The HR data were collected from two rebar workers (Worker A, Worker B) during one cycle of concrete work (6 days) at a residential building project in Hong Kong. The working area is 53,700 ft^2. Note that one rebar worker participated in data collection for two weeks (Table 1).

The data associated with Worker A was collected from Day 1 to Day 11. Worker A worked for 2 cycles. The data associated with Worker B was collected from Day 6 to Day 11. These two workers were healthy (no health issues such as cardiovascular disease). On site, they were asked to wear an Apple Watch on their dominant hand for collecting the HR data for a whole day. Once they completed their work, the Apple Watch was returned.

Table 1: Details about rebar workers

Worker number	Data collection period	Age
A	Day 1—Day 5 (Week 1)	40
A	Day 6—Day 11 (Week 2)	40
B	Day 6—Day 11 (Week 2)	31

Step 3: We carefully considered for any potential risks, physical discomfort, and privacy concern for our subjects. They were fully informed of any potential risks when collecting the data. The workers were allowed to stop the collection process if they felt any discomfort when wearing Apple Watch.

Step 4: One Apple Watch was given to one worker. The data privacy was guaranteed, as long as the collected data would be kept anonymous, and the data would be securely stored at a network attached server in The Department of Building and Real Estate, The Hong Kong Polytechnic University.

Step 5: We defined a threshold of 40%HRR with 30-60 minutes as a risky physical demand for investigating the %HRR patterns associated with each worker.

Table 2 shows the collected HR data. The data includes the resting HR, estimated maximum HR, average working HR, average %HRR, and average %HRR for direct work. Notably, the HR data for a day associated with Worker A contains a lot of noises. Thus, we decided to remove the data for more accurate analysis. The average values of %HRR per day are ranged from 4.17 to 48.34%HRR. Figure 3 demonstrates the %HRR for Worker A in Day 5 from 8:20:00 am to 17:02:08 pm.

Table 2: Overview of subjects' physical demand measurement

Worker	**Week**	**Day**	**Resting HR (BPM)**	**Estimated Max HR (BPM)**	**Average working HR (BPM)**	**Average %HRR**	**Average %HRR for direct work**
A	Week 1	1	60	180	85.00	4.17	4.17
		2	68		83.50	**14.00**	**13.84**
		3	70		92.29	19.90	20.78
		4	69		84.47	11.93	12.58
		5	79		101.90	22.22	23.03
A	Week 2	6	64	180	86.78	**16.26**	**15.68**
		7	60		120.97	40.83	48.34
		8	63		129.59	12.57	12.57
		9	66		83.33	17.40	18.55
		10	64		73.70	8.42	8.42
		11	60		73.64	6.21	8.58
B	Week 2	6	55	189	80.44	15.26	15.26
		7	83		121.85	32.56	43.14
		8	65		80.20	11.98	12.86
		9	66		83.85	14.96	15.11
		10	60		74.57	7.55	10.96
		11	79		84.68	5.20	5.84

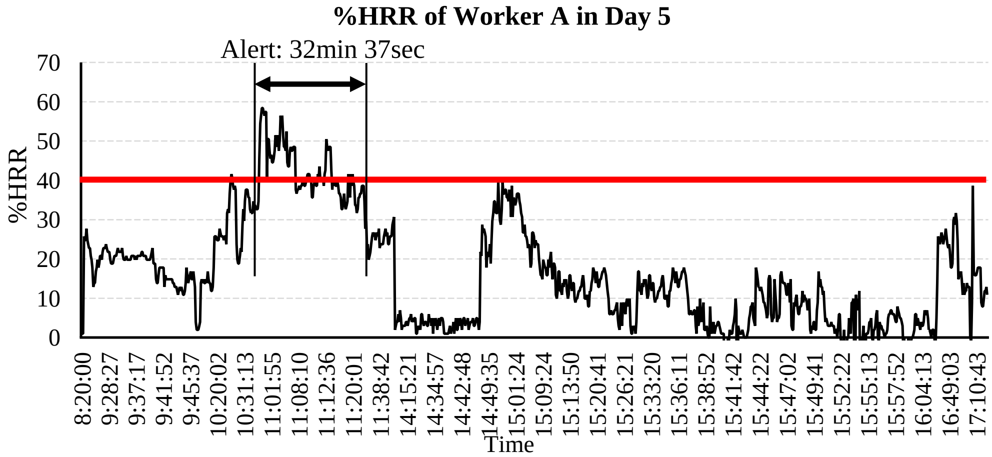

Figure 3: %HRR of Worker A in Day 5

Error! Reference source not found.(a-c) illustrates the %HRR data associated with Worker A and Worker B. **Error! Reference source not found.**(a-c) illustrates the percentage of total data points over 40%HRR associated with Worker A and Worker B.

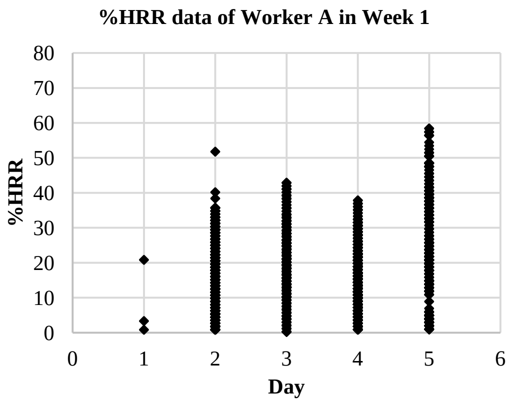

Figure 4a

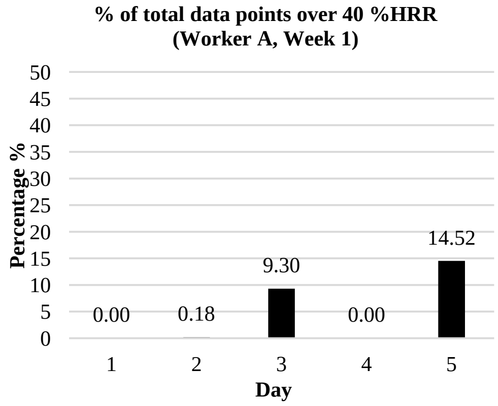

Figure 5a

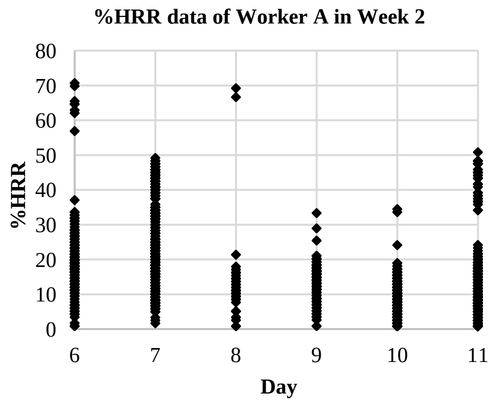

Figure 4b

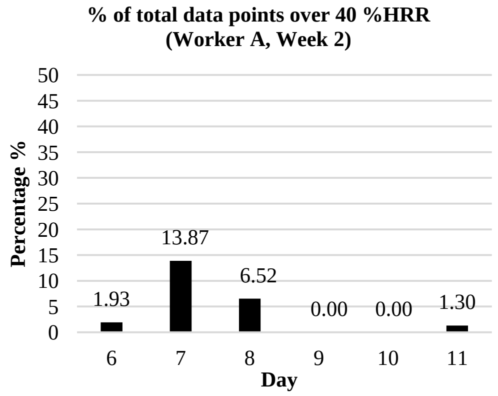

Figure 5b

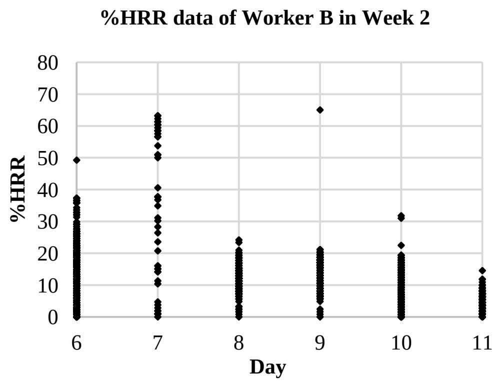

Figure 4c

Figure 4: %HRR data of workers

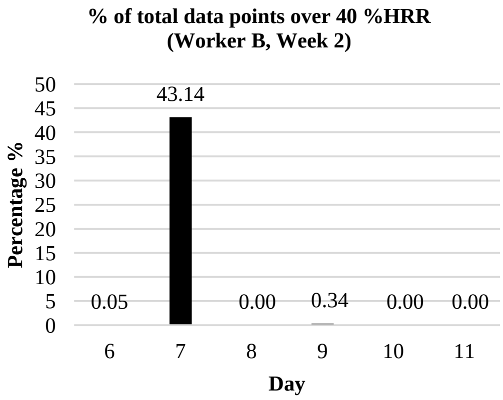

Figure 5c

Figure 5: Percentage of total data points over 40% HRR

5. DISCUSSIONS

5.1 Workload assessment for rebar workers

Error! Reference source not found. shows daily %HRR data associated with Workers A and B. As the data were collected from the 6-day cycle of concrete work. Basically, they performed the same types of work. However, the data shown in Figure 4a and 4b (same workers worked for different week) demonstrated a significant difference while data shown in Figure 4b and 4c (different workers for the same week) looked similar. As mentioned, the probability of worker health and safety problems due to the heavy workload is dependent on both %HRR and duration of %HRR intensity. In particular, the averages %HRR for Worker A and Worker B in Day 7 were both over 40%. The duration of physically demanded activities performed should be longer than 30 to 60 minutes. However, although the %HRR was averaged as below 40%, the %HRR was recorded as over 40% for an abnormal period of 32 minutes 37 seconds (**Error! Reference source not found.**). The results of average %HRR for rebar workers were lower than the one for electricians and mason workers reported by Hwang and Lee (2017). The rebar workers performed the upper limb movements (such as tying the rebars), in contrast with the electricians performed (frequent ladder climbing) and mason workers (laying blocks). Nevertheless, the results proved the feasibility of quantifying the heavy workload of workers on site based on the proposed method.

5.2 Workload comparisons between cycles and among workers

Worker A helps to collect the HR data for two 6-day cycles. The data of %HRR and excessive percentage of workload indicated some variances and similarities for these two cycles. The differences between these two cycles were obvious: (i) The workloads over the day between cycles were different implied that the activities engaged by Worker A were different; (ii) The workloads over the weeks between cycles were different, because most of the data points in Week 2 have the %HRR data below 20% in contrast with the fact that most of the data points in Week 1 had over 40%HRR; (iii) The workloads of the same day between cycles were different, for instance, the percentage of total data points over 40%HRR for Worker A in Week 2 Day 7 (13.87%) was much higher than that in Week 1 Day 2 (0.18%), which implied that Worker A delivered the tasks with more physical demand in Day 7 compared to the task assigned to this worker in Day 2. Worker A and Worker B help to collect the HR data when they performed the site work at the same time for one 6-day cycle. Their HR and %HRR data shared similarities in the cycle from the prespectives of the pattern of data and the intensities of excessive workload. (i) The two workers both demonstrated abnormal high values of %HRR in Week 2 Day 7, and the percentages of total data points over 40%HRR were the highest among the days in the cycle. (ii) The %HRR data of Worker A and Worker B in Day 8, Day 9, and Day 10 were almost all below 20%, and the percentages of total data points over 40%HRR were extremely low. The differences of HR and %HRR data among Worker A and Worker B were significant. (i) In Week 2 Day 7, the %HRR data and the total data points over 40%HRR associated with Worker B were quite high. This illustrated that Worker B suffered from heavy workload on that day. Such heavy workloads could adversely affect his safety and health. (ii) In Week 2 Day 8, the percentage of total data points over 40%HRR for Worker A (6.52%) was higher than Worker B (0%) but they shared similar patterns of %HRR data. It is because two %HRR points with high values (more than 60%) were recorded when Worker A performed the work. Based on above observations, even though the rebar workers worked in the same trade, we proved that the daily physical demands of the rebar workers can be largely varied attributed to the different site works assigned between days and the weekly physical demands of the rebar workers can be varied attributed to the different site works assigned between cycles.

5.3 Validation of the small sample size

This research collected data from two workers for two weeks, the small sample size of workers and work trades should be justified to draw the scientific conclusion about the difference of workloads among the rebar workers and among the work cycles. In this session, student t-test was used to illustrate the difference between idling HR and non-idling HR, which validate the small specimen size can be accepted for making conclusions. According to the video from the GoPro that were equipped in front of the chest of Worker A and Worker B, the sub-activity of rebar fixer was investigated. By dividing activities into idling and non-idling these two types, the independent t-test can be used to estimate the differences of these two kinds of HR. For Worker A in Week 1 and Week 2, the p-value of HR in t-test is 4.42e-10, which is much less than 0.05 (95% confidence level), in this regard the null hypothesis (the mean values of work and non-work HR are the same) should be reject and the non-idling and idling HR are varies significantly. For Worker B in week 2, the p-value is 0 that much smaller than 0.05, so that the opposite hypothesis should be accepted. The results from t-test demonstrate the workers' HR are significant different depending on their status, which means according to HR and %HRR index, the physical demand of workers can be investigated even though the sample size is considerably small. In the long run, this research can be extended to other trades to help understanding the physical demand from construction work.

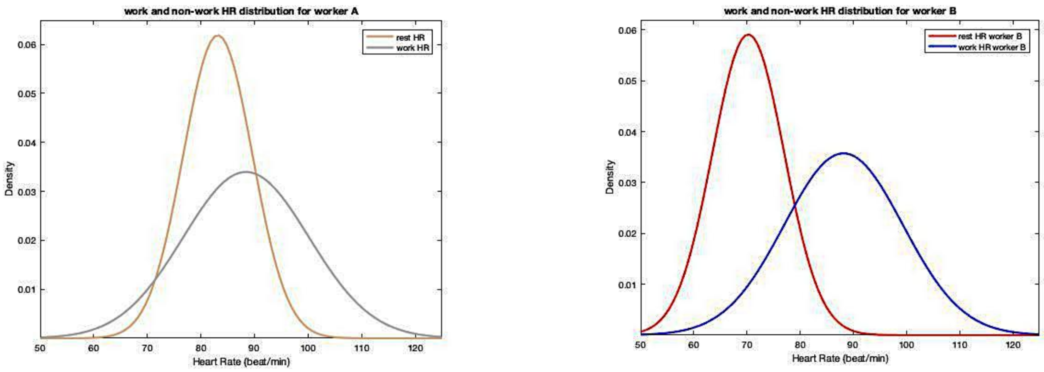

Figure 6: Work and non-work HR distribution for Worker A and Worker B.

6. CONCLUSIONS

This research proposed a new 5-step method for profiling the health and workload of rebar workers using wearable wristbands (Apple Watch) in Hong Kong building construction. Previous studies by Hwang and Lee (Hwang and Lee, 2017) have validated that %HRR is significantly correlated with workers' physical demands from work, reflecting working patterns, individual (e.g., ages) and environmental (e.g., temperature) factors. Based on the findings from the previous study, this paper tested the usefulness of a long-term HR-based physical demand monitoring for understanding workload variations between working days, weeks and workers during 6-day cycles of rebar work. The data collected from two workers for two weeks showed meaningful variations that can be used to understand work allocation issues (e.g., unbalanced work assignment during a cycle, change of workloads between work cycles) during cyclic construction tasks. For example, the results showed that "the patterns of %HRR data" and "the percentages of total data points over 40%HRR" between different cycles can be different (i.e., most of the data points in Week 2 have the %HRR data below 20% in contrast with the data points in Week 1 reached over 40%HRR). Furthermore, we examined the HR and %HRR data associated with Worker A and Worker B who worked at the same time (in the same cycle) (i.e., the patterns of %HRR data were similar while Worker B in Week 2 Day 7 illustrated the highest percentage of total data points over 40%HRR).

Workload information from HR data can help the project managers in assigning the site works without overloading the workers. In Hong Kong, the wages of rebar workers are the highest among all other construction trades. However, the youngsters are not willing to be the rebar workers due to the heavy workloads. If the highly intensive workload can be evenly distributed, it may attract the young workers to be the rebar benders and fixers such that the labour shortage problem can be potentially alleviated. Through this new approach for quantifying the workload, the health and safety of rebar workers can be ensured. Even though the data was collected from two workers for two weeks, the data showed meaningful variations of physical demands that imply productivity and work allocation issues at construction sites. However, the small sample size of this study, and the data from only rebar work may hinder the generalization of results for other construction tasks. In future, further data collection and analysis considering demographic differences among construction workers and diverse types of construction tasks would be needed. In the long run, this research study can be extended for benchmarking the HR and %HRR by collecting the wristband data as per different trades and activities to better understand between-subject and within-subject variations in physical demands from construction work, suggesting possible intervention strategies such as reasonable arranging for “work-rest schedules” and “work-rest cycles”.

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