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Original Article

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Development of algorithm for work intensity evaluation using excess overwork index of construction workers with real-time heart rate measurement device

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ABSTRACT

Background: The construction workers are vulnerable to fatigue due to high physical workload. This study aimed to investigate the relationship between overwork and heart rate in construction workers and propose a scheme to prevent overwork in advance.
Methods: We measured the heart rates of construction workers at a construction site of a residential and commercial complex in Seoul from August to October 2021 and develop an index that monitors overwork in real-time. A total of 66 Korean workers participated in the study, wearing real-time heart rate monitoring equipment. The relative heart rate (RHR) was calculated using the minimum and maximum heart rates, and the maximum acceptable working time (MAWT) was estimated using RHR to calculate the workload. The overwork index (OI) was defined as the cumulative workload evaluated with the MAWT. An appropriate scenario line (PSL) was set as an index that can be compared to the OI to evaluate the degree of overwork in real-time. The excess overwork index (EOI) was evaluated in real-time during work performance using the difference between the OI and the PSL. The EOI value was used to perform receiver operating characteristic (ROC) curve analysis to find the optimal cut-off value for classification of overwork state.
Results: Of the 60 participants analyzed, 28 (46.7%) were classified as the overwork group based on their RHR. ROC curve analysis showed that the EOI was a good predictor of overwork, with an area under the curve of 0.824. The optimal cut-off values ranged from 21.8% to 24.0% depending on the method used to determine the cut-off point.
Conclusion: The EOI showed promising results as a predictive tool to assess overwork in real-time using heart rate monitoring and calculation through MAWT. Further research is needed to assess physical workload accurately and determine cut-off values across industries.

Keywords: Heart rate; Overwork; Working time; Prediction

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Abbreviations

AUC: area under the curve; EOI: excess overwork index; HR: heart rate; MAWT: maximum acceptable working time; OI: overwork index; PSL: appropriate scenario line; ResHR: resting heart rate; RHR: relative heart rate; ROC: receiver operating characteristic.

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Competing interests

The authors declare that they have no competing interests.

Author Contributions

Conceptualization: Lee J; Data curation: Lee JH, Lee J; Formal analysis: Park JY; Funding acquisition: Kim HR, Lee J; Investigation: Lee J; Methodology: Park JY, Jang TW, Kim SY; Project administration: Lee JH, Lee J; Resources: Lee JH, Kim SY; Supervision: Kang MY, Jang TW, Kim HR, Kim SY, Lee J; Validation: Kang MY, Jang TW, Kim HR; Visualization: Park JY; Writing - original draft: Park JY; Writing - review & editing: Kang MY, Jang TW, Kim HR, Kim SY, Lee J.

BACKGROUND

Construction workers are particularly susceptible to health risks due to factors such as dust, noise, and high physical workload.[1,2] Fatigue related to overwork in construction workers has been linked to accidents and injuries,[3] cerebrovascular disease risk[4] and chronic fatigue syndrome.[5] To prevent these health effects, it is essential to assess physical workload in the workplace and manage workers appropriately. However, subjective questionnaires and interviews are inconvenient and prone to recall bias.[6] Therefore, previous studies have utilized physiological metrics such as heart rate (HR), heart rate variability, skin temperature, electromyography, and jerk metrics to evaluate workload,[7] as well as combinations of these indicators.[8-10] Among these, HR measurement can be easily performed with a wristwatch-type device.[11] Hwang et al.[12,13] reported the results of a feasibility study on HR monitoring of construction workers using PPG sensor technology built into a wristband-type activity tracker. In particular, relative heart rate (RHR), which will be further discussed later in this paper, has been widely used to assess physical workload.[14-17]

Another approach to fatigue management is maximum acceptable working time (MAWT), which refers to the maximum time that an individual can perform tasks of a given intensity without fatigue, given their ability, such as cardiovascular function. If a worker works longer than the MAWT, there is a limit to the body's ability to supply the necessary oxygen for physical activity from work. In a 2002 study, Wu and Wang[14] calculated biomarkers and MAWT for adult volunteers according to increased physical load. In their study, the boundary value of MAWT was determined using oxygen intake and RHR. In short, working at a high RHR gives less MAWT, meaning that more rest is needed. By using their equation, we can have a better estimation of cumulative workload by weighting RHR, rather than simply monitoring RHR. However, to the best of our knowledge, no previous study has developed a real-time fatigue monitoring system utilizing RHR and MAWT.

In this study, we will propose a scheme to predict overwork. First we will define an overwork index (OI) based on RHR and MAWT, which can be measured in real time. Using receiver operating characteristic (ROC) curve analysis, we will provide optimal cut-off values for overwork prediction. Since HR monitoring devices have not only recorded HR information in real time, but also used communication technologies such as Bluetooth and LTE to transmit information collected in real time to servers to immediately utilize it for early intervention in case of overwork (that is, break during work).

METHODS

Participants

From August to October 2021, we measured the working time HRs of construction workers at a residential and commercial complex construction site in Seoul. The study participants were limited to workers of Korean nationality. After an on-site safety training conducted from 6 a.m. to 7 a.m. every day, we explained the study to workers and recruited volunteers. Participants wore real-time HR monitoring equipment. After completing a preliminary questionnaire and obtaining informed consent, workers were provided with an explanation about the device. We used 5 to 10 units of the devices daily. Due to the fact that construction workers have no fixed number of people, those who worked in the morning changed daily. As a result, new research participants were recruited every day with the same protocol, resulting in several duplicate participants. In the case of duplicated study subjects, the last measured result was used as the main result to ensure compliance with the measurement.[18]. Results of the first measurement and all measurements with duplication were used for sensitivity analyses. In total, 66 workers participated in the study.

HR monitoring

We measured the HR from the start of work to the end of work using Polar M430. We started measurements of HRs at 7 a.m. when they started working. After finishing work between 3 p.m. and 4 p.m., we collected devices and transferred the data to the researcher's PC and saved it.

RHR

To calculate the RHR, we evaluated the minimum and maximum HRs. The HR measured together with blood pressure measurement was considered as the minimum HR after making the target worker rest before starting the measurement. For workers who had multiple measurements, the minimum value of the HR measured was selected. However, if this value was higher than the minimum HR during work, the 1st centile value of the HR measured during work was used as the minimum HR. This value could rule out erroneous measurements and provide a better estimation of the resting HR.

The maximum HR was calculated with [208 − 0.7 × (Age)],[18-20] which has been widely used in the previous studies.[13,21]

The RHR was calculated using the following equation (1) using the minimum HR and the maximum HR:

$$RHR = \frac{Heart\ Rate\ - Minimal\ Heart\ Rate}{Maximal\ Heart\ Rate - Minimal\ Heart\ Rate} \quad (1)$$

However, in this study, instead of calculating the RHR using the average HR during work day, the RHR was evaluated in units of 1 second using the measured HR per second.

MAWT

According to a previous study by Wu and Wang[14] that measured the MAWT for young adults, MAWT can be estimated using RHR with the following the equation (2):

$$MAWT = 26.12 \times e^{-4.81 \times RHR} \qquad (2)$$

The workload can be calculated as the reciprocal of MAWT multiplied by worked time (3).

$$Workload = \Sigma \frac{1}{MAWT} \times Working\ Time\ (3)$$

The justification of this formula will be discussed later. The calculation of the workload might vary depending on the unit of evaluation time. As the time unit is divided finely, the amount of work calculated generally increases.

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Definition of overwork

Previous studies have no agreement on the workload limit based on RHR for an 8-hour workday. For example, 24.5% for cyclists,[14] 30% for teachers, construction workers,[17,22] 1.5 MAWT, roughly corresponds to 33% of RHR, for Korean workers[4] and construction workers,[18] 30%–40% for construction workers.[13] For this study, we defined overwork as a workday in which RHR for workday is more than 30% following some of the previous studies.[17,23] To develop an index that monitors overwork in real time, we define new concepts as follows. First, we evaluated the workload by evaluating the MAWT on a per-second basis and defined the OI as the cumulative workload evaluated with the MAWT (4).

$$OI = \Sigma \frac{1}{MAWT} \times Working\ Time = \Sigma \frac{1}{MAWT} \times \frac{1}{60 \times 60} \quad (4)$$

We schematized indicators calculated based on the HR measured for each worker. An example is shown in **Fig. 1**. The purple graph is the RHR and the blue line represents the OI. To evaluate the degree of overwork in real time, an appropriate scenario line (PSL) was set as an index that can be compared to the OI. The PSL is a straight line that increases from 0 to 1 over 9 hours based on an 8-hour work and 1-hour break as a cumulative workload indicator (green straight line in **Fig. 1**). Using the difference between the OI (blue) and the PSL (green), the excess overwork index (EOI) was evaluated in real time during work performance (red line in **Fig. 1**).

$$EOI = OI - PSL \qquad (5)$$

It is this EOI value that we performed ROC curve analysis to find the optimal cut-off value for classification of overwork state. Among many methods to calculate the optimal cut off value,[24] we applied Youden index,[25] Concordance Probability method[26] and the closest to (0, 1) criteria, which had been widely used in the previous studies.

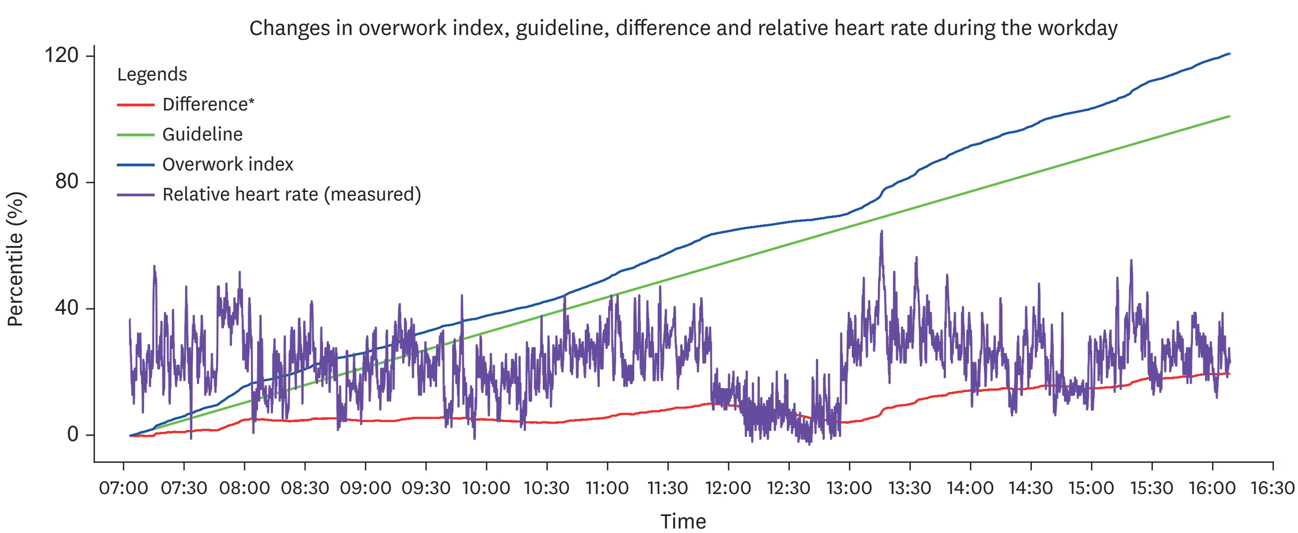

Fig. 1. An example of real-time records of heart rate and indices to predict overwork during working time.

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Statistical analysis

It was tested whether there were differences in covariates defined above between the overwork group and the non-overwork group. We used a chi-square test for nominal variables and a t-test for continuous variables. The statistical significance level was set at p-value < 0.05. All statistical analyses were performed using R version 4.2.2. For ROC curve analysis, R package 'cutpointr' was used.

Other variables

Participants recorded demographic variables such as age, gender and job. They also recorded variables that could affect HR in self-report format, including subjective work intensity and amount of smoking and coffee intake of the day. Measurements were made from August to October, which included the hottest period in Korea. We evaluated the degree of heat wave by date by heat index and recorded it in conjunction with the measurement date.[27] We interviewed three experienced experts related to the construction industry and divided the intensity of the job. Management, electricity work and the operation of tower crane were evaluated as jobs with low work strength. Other jobs were evaluated to have high work strength.

Ethics statement

The present study protocol was exempted from review by the Institutional Review Board of the Catholic University College of Medicine (approval no. KC21OISI0501). Informed consent was obtained from all participants of the study.

RESULTS

Out of the 66 participants, six were excluded from the analysis due to errors in the device or incomplete measurements of HR. The remaining 60 participants were analyzed according to the method described in the methods section, where a workday RHR exceeding 30% was defined as overworked. Among the participants, 28 were classified as overworked, accounting for 46.7% of the total.

There were no significant differences between the overwork and non-overwork groups in terms of age, workload classification by job, subject feeling of work intensity, and number of coffee cups or cigarettes consumed during the workday, which could affect HR. However, the overwork group had a higher ratio of extreme caution for the heat index on the workday, and they consumed more coffee and cigarettes on average. Age also showed a nonsignificant difference, with a relatively higher proportion of individuals aged 60 or older in the overwork group (**Table 1**).

Table 2 summarizes the HR measurements of construction workers by job classification. The mean RHR was lowest for Tower crane operators, and highest for concrete workers, waterproofers, and electric workers. **Fig. 2** illustrates the accumulative working time spent for a given RHR interval by job classification, sorted by the order of RHR. The S-shaped curve shifts rightward when the subject works longer on a higher RHR, indicating a greater physical workload. **Fig. 3** shows the same data for normal weather, excluding data obtained during caution or extreme caution heat index conditions.

The overwork and non-overwork groups showed clear differences in HR and overwork indicators. The average OI value of the overwork group was significantly higher than that of

Table 1. Demographic characteristics of study population divided by overwork with assessment using last measurements of heart rate

Variables	Non-overwork (n = 32)	Overwork[a] (n = 28)	*p*-value[b]
Sex			0.156
Male	28 (87.5)	28 (100)	
Female	4 (12.5)	0 (0.0)	
Age (years)			0.062
< 40	4 (12.5)	5 (17.9)	
≥ 40 and < 50	7 (21.9)	0 (0.0)	
≥ 50 and < 60	12 (37.5)	11 (39.3)	
≥ 60	9 (28.1)	12 (42.9)	
Hypertension medication			1.000
Yes	3 (9.4)	3 (10.7)	
No	29 (90.6)	25 (89.3)	
Workload classification according to job			0.783
Low	5 (15.6)	3 (10.7)	
High	25 (15.6)	25 (89.3)	
No answer	2 (6.3)	0 (0)	
Heat index of the workday			0.055
Normal	19 (59.4)	15 (53.6)	
Caution	9 (28.1)	3 (10.7)	
Extreme caution	4 (12.5)	10 (35.7)	
Subjective feeling of work intensity			0.235
Affordable	4 (12.5)	8 (28.6)	
Acceptable	25 (78.1)	16 (57.1)	
Overburdened	2 (6.3)	2 (7.1)	
No answer	1 (3.1)	2 (7.1)	
Number of cigarettes in the workday			0.157
Mean ± SD	6.2 ± 6.8	8.9 ± 7.2	
Median [Min, Max]	4.5 [0, 20.0]	10.0 [0, 25.0]	
No answer	2 (6.3)	2 (7.1)	
Number of coffee cups in the workday			0.055
Mean ± SD	1.0 ± 1.2	1.9 ± 1.9	
Median [Min, Max]	1.0 [0, 5.0]	1.0 [0, 5.0]	
No answer	1 (3.1)	2 (7.1)	

Values are presented as number (%) unless otherwise indicated.
[a]Overwork is defined as the average of relative heart rate during the workday exceeds 30%.
[b]*p*-values from tests for nominal variables and *t*-tests for continuous variables.

the non-overwork group (2.3 vs. 1.1, *p*-value < 0.001). The average maximum HR was also significantly higher in the overwork group than in the non-overwork group (142 bpm vs. 128 bpm, *p*-value < 0.001). However, the average minimum HR showed no significant difference between the two groups (60.2 bpm vs. 63.5 bpm, *p*-value = 0.261, **Table 3**). This trend was observed not only in the analysis based on the last measurement but also in the first measurement (n = 60) and all measurements (n = 180) (**Supplementary Tables 1** and **2**).

To determine the cut-off value for classifying overwork when the EOI increased above a specific value, we plotted the ROC curve, and the area under the curve (AUC) was 0.824 (**Supplementary Fig. 1**). The distribution of the predictor, EOI, was also plotted (**Supplementary Fig. 2**). **Table 4** presents optimal cut-off values, accuracy, sensitivity, and specificity for each data source and method used to determine optimal cut-off points. When last measurements were used as a data source, the optimal cut-off points of the EOI were 24.0% for Youden index, 24.0% for Concordance probability method, and 21.8% for the closest to (0.1) criteria. All three models showed similar tendencies in AUC, accuracy, sensitivity, and specificity.

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Table 2. Overview of HR measurements of construction workers by Job

Job	No.	Estimated resting HR[a]	Maximum HR[a]	Mean HR[a]	RHR[a]
Bricklayers	16	59.2 (10.7)	127.3 (15.4)	86.7 (13.7)	26.6 (6.9)
		52 [52,77]	126.5 [106,156]	82.5 [70.6,109.4]	25.1 [17.5,40.7]
Carpenters	5	77.6 (1.3)	133.8 (2.2)	103.1 (2)	25.4 (2.2)
		77 [77,80]	135 [130,135]	103.9 [100.2,105]	26.5 [22.8,27.5]
Concrete workers	9	69.6 (10.7)	145.8 (8)	104.3 (10.4)	36.9 (6.8)
		71 [50,85]	146 [132,158]	106 [87.4,117]	36.6 [26.7,48.8]
Electric workers	20	55.4 (12.9)	142.2 (8.1)	99.4 (6.8)	33.7 (9.6)
		64 [37,65]	142.5 [125,152]	100.4 [82.2,109.6]	34 [14.5,47.1]
Equipment mechanics	26	65.0 (9.9)	133.3 (7.2)	93.7 (8.1)	26.8 (5.6)
		61 [51,85]	132.5 [120,147]	91.8 [82.7,112.2]	26.5 [17.5,38.2]
Insulation workers	3	69 (17.3)	134.3 (1.5)	100.6 (4.2)	27.1 (8)
		59 [59,89]	134 [133,136]	100 [96.8,105.1]	30.3 [18,32.9]
Laborers	15	70.3 (8.3)	136.6 (13.2)	100.5 (11.8)	30.8 (10.2)
		66 [62,90]	134 [113,163]	99.1 [81.7,119.3]	28.3 [16.6,50.1]
Plasters	24	55.5 (9.7)	131.2 (16.7)	87.7 (9.8)	27.7 (6.5)
		62 [42,66]	127.5 [100,177]	89.5 [69.3,101.7]	26 [19.1,44.6]
Project managers	13	54.3 (18.6)	135.6 (9.4)	95.2 (12.2)	30.2 (8.7)
		70 [35,72]	132 [126,155]	94.1 [69.2,118]	30.8 [16.3,41.3]
Tower crane operators	3	49.0 (0)	126.7 (3.5)	78.8 (2.7)	22.8 (2.1)
		49 [49,49]	127 [123,130]	77.3 [77.2,81.9]	21.7 [21.6,25.2]
Waterproofers	14	56.9 (4)	130.1 (11.4)	94.2 (11.5)	35.8 (10.7)
		56 [53,65]	131.5 [112,148]	93 [75.8,113.4]	35.9 [20.4,54.3]
Other	32	58.8 (5.2)	130.9 (18)	90.9 (10.7)	30.1 (9.5)
		57 [55,76]	126.5 [108,190]	90.1 [71.3,114.1]	29.5 [13,52.1]

HR: heart rate; RHR: relative heart rate.
[a]For each variable, average (standard deviation), median [minimum, maximum] is shown.

DISCUSSION

Construction workers often have high physical workloads, especially in hot and humid environments, which can lead to overwork. Early-warning systems have been proposed in previous studies to prevent overwork.[8,9] In this study, we propose a scheme to assess overwork and provide advance warning based solely on HR, which can be measured using a wrist-type device during work with minimal inconvenience. This approach requires little health information about the worker in advance, making it useful in situations where many workers are temporary.

Our study demonstrates that the EOI can be used as a predictive tool to assess overwork in real-time, based on HR monitoring and calculation through the MAWT. By monitoring EOI instead of real-time HR, the workload can be estimated more accurately by weighting high RHRs. Our study found that the EOI value cut-off ranged from 15.4% to 29.3%, depending on the method used to find the optimal cut-off value.

Overall, our scheme based on HR monitoring and MAWT calculation could enable real-time monitoring of physical workload and help prevent overwork before it occurs in construction workers.

In our basic analysis comparing overwork and non-overwork groups, we did not observe significant differences in age, heat index, smoking, and coffee intake, which are known to potentially affect HR. Previous studies have shown that age[18] and hot weather conditions[28] are associated with higher RHR. Smoking is also known to increase the resting heart rate (ResHR),[29] while nicotine intake can cause a rapid increase in HR within 15 minutes.[30]

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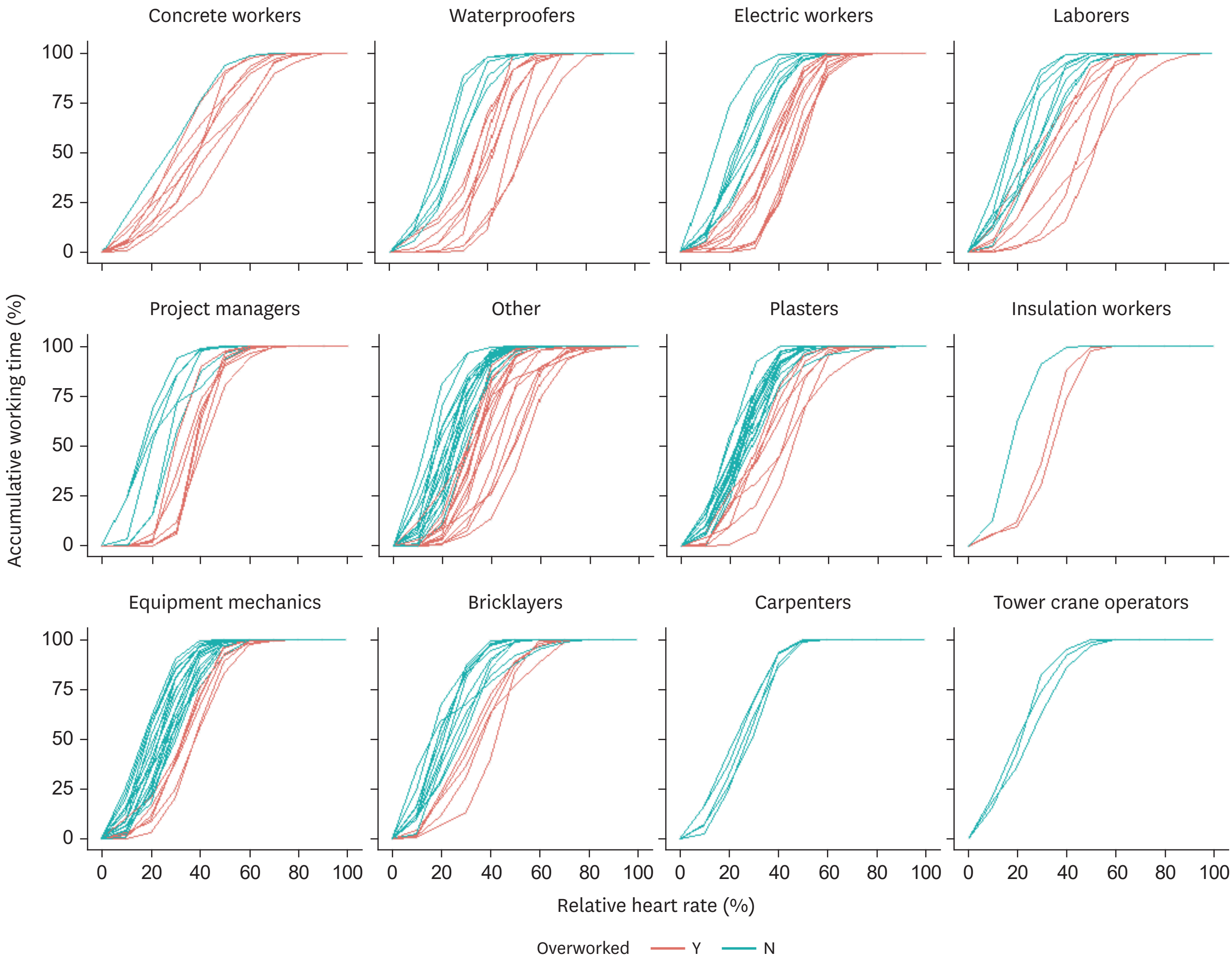

Fig. 2. Workload patterns of relative heart rate with the cumulative time of construction workers by job including duplicated cases.

Therefore, the high ResHR recorded in smokers could complicate the interpretation of our EOI estimation, depending on the correlation between RHR, MAWT, and EOI. However, we could not exclude participants who smoked because smoking is prevalent among construction industry workers.

Similarly, the effect of coffee intake on HR is difficult to interpret. Acute coffee intake has little impact on HR,[31] while habitual coffee intake might lower HR.[32] The overwork group in our study may have had more breaks during work, leading to more coffee intake. We also did not observe significant differences in the subjective feeling of work intensity and workload classification by job. Previous studies have questioned the reliability of self-reported work intensity due to recall bias.[6] We also note that hot weather conditions may have affected our results, as taking more breaks in hot weather could have decreased the subjective feeling of work intensity.

Disease and medication can change HR. One limitation of this study was that it did not investigate angina, arrhythmia, or thyroid dysfunction. However, the prevalence of these

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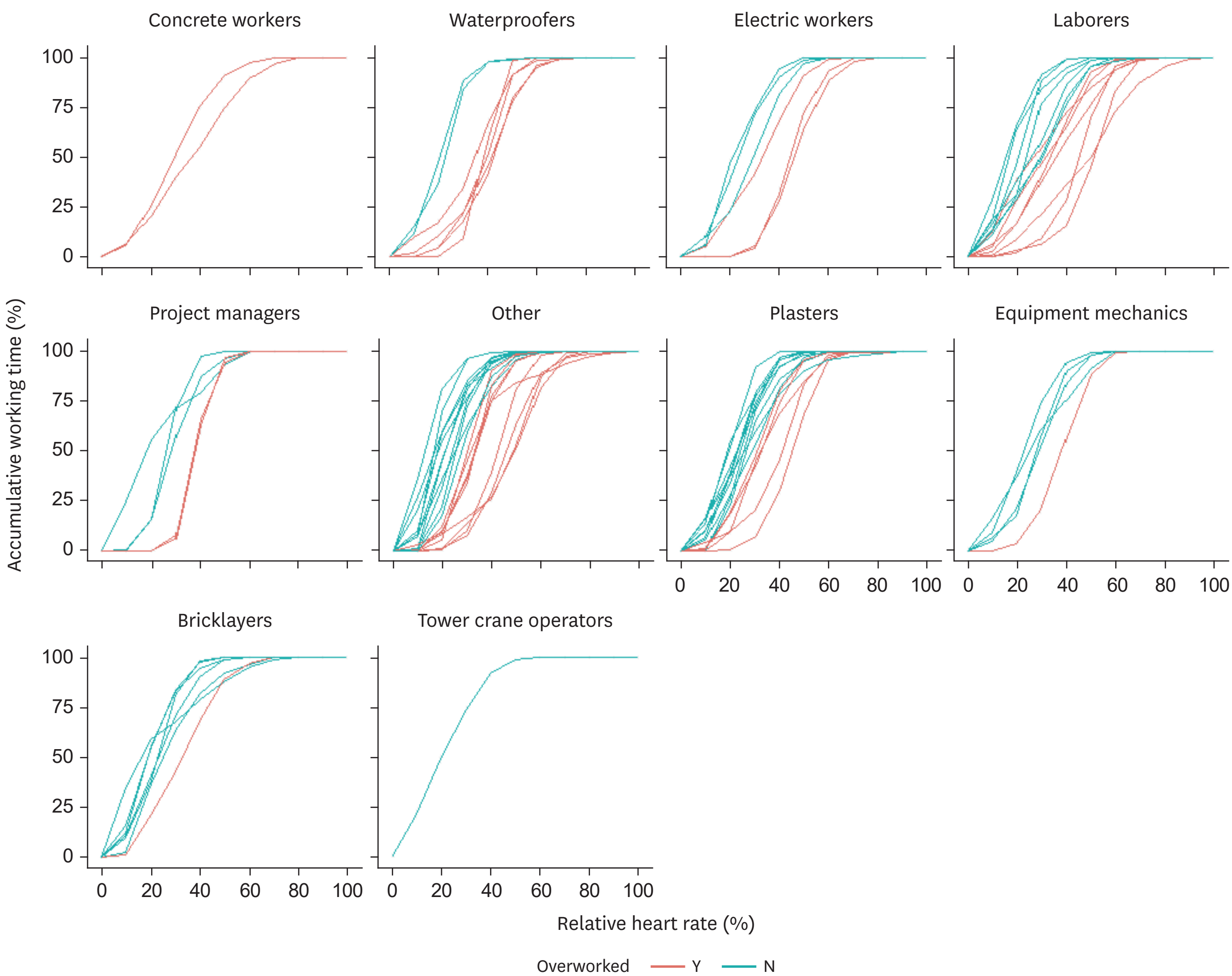

Fig. 3. Workload patterns of relative heart rate with the cumulative time of construction workers by job including duplicated cases in normal weather condition only.

Table 3. Overwork index and heart rates of study population divided by overwork with assessment using last measurements of heart rate

Variables	Non-overwork (n = 32)	Overwork[a] (n = 28)	*p*-value[b]
Overwork Index			< 0.001
Mean ± SD	1.1 ± 0.3	2.3 ± 0.9	
Median [Min, Max]	1.1 [0.6, 1.6]	2.0 [1.3, 4.8]	
Maximal heart rate			< 0.001
Mean ± SD	128 ± 11.1	142 ± 9.9	
Median [Min, Max]	132 [100, 150]	141 [126, 166]	
Minimal heart rate			0.261
Mean ± SD	60.2 ± 12.0	63.5 ± 11.1	
Median [Min, Max]	60.5 [36.0, 81.0]	66.5 [35.0, 81.0]	

[a]Overwork is defined as the average of Relative heart rate during the workday exceeds 30%.
[b]*p*-values from *t*-tests.

conditions is not expected to be high in our study population, which is characterized by high labor intensity. Additionally, the study included some participants who were taking antihypertensive medications. A sub-analysis comparing the average daily RHR and EOI values between participants who were taking antihypertensive medications and those who

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Table 4. Relevance indices of models by heart rate resources to predict overwork

Variables	Heart rate resource		
	Last records (n = 60)	First records (n = 60)	Full records (n = 180)
Youden index			
Optimal cut-off point	24.0%	29.3%	26.5%
Accuracy	75.6%	77.0%	80.0%
Sensitivity	69.2%	67.9%	71.2%
Specificity	81.2%	88.7%	86.7%
Concordance probability method			
Optimal cut-off point	24.0%	29.1%	26.2%
Accuracy	75.6%	77.0%	80.0%
Sensitivity	69.2%	68.0%	71.4%
Specificity	81.2%	88.6%	86.4%
The closest to (0,1) criteria			
Optimal cut-off point	21.8%	15.4%	21.8%
Accuracy	75.2%	77.5%	78.5%
Sensitivity	70.7%	79.3%	74.8%
Specificity	79.2%	75.2%	81.3%
AUC	0.824	0.871	0.862

AUC: area under the curve.

were not found that the latter group had higher values for both. However, this difference was not statistically significant.

Table 2 presents HR measurements by job classification. Overall, our RHR levels are higher than in previous studies,[18] similar to some[13,33] and lower than others.[21] In our study, operators showed the lowest mean RHR, consistent with a previous study.[33] However, bricklayers and carpenters did not exhibit high RHR, unlike in a previous study.[18] Among jobs with low work strength, management and electrical work (excluding tower crane operators) showed high RHR. We note that this may be due to weather conditions, as the data for overwork cases in management and electrical work were mostly obtained during caution or extreme caution heat index levels, as shown in **Figs. 2** and **3**.

The study conducted by Wu and Wang[14] focused on young adults in their 20s and 30s and aimed to determine MAWT. Other studies have also verified MAWT using the same theory on healthy adults aged 20-35 without any history of hypertension, heart surgery, cardiovascular, or respiratory diseases.[34,35] However, the subjects used in Wu and Wnag's study[14] for calculating MAWT were different from actual construction workers, as revealed by the Korea Safety and Health Agency's (KOSHA) 2019 general health examination results; the proportion of workers in the construction industry was 8.9% for those under 30, 17.9% for those in their 30s, 25.1% for those in their 40s, 32.6% for those in their 50s, and 15.4% for those in their 60s or older. The number of patients with disease was 95,814 (22.4%). The number of patients with suspected hypertension and diabetes was 59,102 (13.8%). That is, it seemed that subjects of this study used for the calculation of MAWT were different from actual construction workers. Moreover, Wu and Wang[14] used a bicycle to determine the RHR and MAWT curve, which might not reflect the relationship between RHR and MAWT for construction workers. Thus, additional physiological studies are necessary to understand this relationship better.

Several studies have reported different formulas for estimating maximum HR, and the commonly used [220 − (Age)] formula lacks scientific rigor.[19] In our study, we used [208 − 0.7 × (Age)][20] following previous studies on construction workers[13,21] but there are studies[33] using [206 − 0.7 × (Age)],[36] too. Moreover, the formula we used has a better fit for the Korean population [37] than the [220 − (Age)] formula.

When calculating the RHR, it is necessary to determine the resting HR. In our study, we measured ResHR daily before work. Since we could not control the workplace for enough resting, some measurements of ResHR during the workday were higher than the actual minimum HR. In these cases, we used the 1st centile value of the HR measured during work as the minimum HR. A similar approach was taken by a previous study[33] while other previous studies used a single measurement[13] or an estimation formula.[18,38,39] However, since the HR is lower at night than during the day,[40] and we only measured HRs during the day, there is a possibility that the minimum HR was overestimated, leading to an overestimation of MAWT.

It is important to note that the change in ResHR itself can act as a cardiovascular risk factor. For example, in patients with heart failure, lowering the HR has been shown to prevent cardiovascular events.[41] On the other hand, too low ResHR can act as a risk factor for atrial fibrillation.[42] In our study, we only focused on the calculation of RHR and used the minimum HR measured during work as ResHR. This approach has limitations since ResHR itself has an effect on cardiovascular risk. Therefore, it is necessary to establish a model that can simultaneously track changes in both RHR and ResHR to evaluate the risk of cardiovascular events.

We utilized the Polar M430 model as a measurement tool to accurately record HRs per second. There are several validation studies that support its reliability for measurements.[43,44] However, as the device lacks a communication function and data analysis can only be done when stored on a device and connected to a PC, the EOI cut-off point proposed in this study cannot be implemented using this device. Recently, HR studies using Fitbit have reported the same level of validation as the Polar model.[45] As HR data can be transmitted to the server in real-time via Bluetooth-connected LTE devices, it is possible to apply the management plan proposed in this study using EOI with Fitbit or other devices that support real-time telecommunication.

Our research results indicate that HR monitoring can be used for health care management at construction sites. The management plan can be implemented in both short-term and long-term approaches. In the short-term, measures can be taken to prevent acute diseases by monitoring rapid HR drops. In the long-term, we suggest continuous evaluation of work suitability through rigorous RHR evaluations, periodic health checkups to detect abnormalities, and improvement of workers' cardiovascular functions through aerobic exercise, smoking cessation, and weight control.

Compared to previous classical methods that rely on yearly health checkups, our approach has the advantage of real-time monitoring to control workload and enable intervention by field managers at the appropriate time. In particular, it can increase work efficiency and ensure worker safety by identifying appropriate rest times during hot seasons. Overall, our management plan offers a useful approach to promoting health and safety at construction sites.

CONCLUSIONS

In conclusion, the EOI showed promising results as a predictive tool to assess overwork in real-time using HR monitoring and calculation through MAWT. The EOI value cut-off in our study ranged from 15.4% to 29.3%, which could be used by field managers to monitor physical workload and prevent overwork. However, since HR is influenced by various factors, including weather condition, smoking, coffee intake, stress, and anxiety,[46] further research is needed to assess physical workload accurately and determine cut-off values across industries.

Nevertheless, the proposed scheme based on RHR and MAWT provides a feasible approach to monitor physical workload and prevent overwork, contributing to the well-being and safety of workers.

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SUPPLEMENTARY MATERIALS

Supplementary Table 1

Overwork index and heart rates of study population divided by overwork with assessment using first measurements of heart rate

Click here to view

Supplementary Table 2

Overwork index and heart rates of study population divided by overwork with assessment using all the measurements allowing duplication

Click here to view

Supplementary Fig. 1

ROC curve in a model predicting overwork with assessment using last measurements of heart rate. Area under curve is 0.82.

Click here to view

Supplementary Fig. 2

Distribution of excess overwork index by overwork class (Y = overwork, N = non-overwork) using last measurements of heart rate. Vertical lines are the optimal cut-off for The Closest to (0,1) Criteria.

Click here to view

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