Using wearable devices to explore the relationship among the work productivity, psychological state, and physical status of construction workers

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Abstract –

Due to the increasing growth of labor cost, academics and practitioners in this field have focused on finding ways to improve work productivity. Many previous studies have indicated that mental status has a deep influence on productivity. However, the relationship among work productivity, psychological state, and physical status has not been explored in the field of architecture, engineering, and construction (ACE).

As an initial exploration, this paper proposes a system to analyze how the psychological and physical status of construction workers influence their productivity. In this exploration, smart bands are adopted to measure the physical status of the bricklayers, STAI is used to collect the psychological data, and the time taken by construction workers to complete a unit of work (i.e., wall building) is recorded to reflect work productivity. Analysis on the correlations of the three dimensions (work productivity, psychological state, and physical status) was conducted. The initial experiment was conducted in Chongqing, China, from May 1st to May 3rd, 2018. The results show that bricklayers are in a relatively low level of anxiety, and that anxiety and heart rate levels are positively correlated with work productivity.

The wearable device-based system facilitates the real-time monitoring of construction workers' psychological and physical status. In turn, such information can help in planning their working schedules to enable them to work more efficiently.

Keywords –

Status monitor; Work productivity; Wearable devices

1 Introduction

Previous studies have suggested that mental health and psychological state are closely related to work productivity [1, 2]. Issah reported the association between mental health and emotional function with work productivity impairment, proving that the state of being nervous and depressed can result in lower work productivity [3]. Bubonya suggested that poor mental health can cause “emotional issues,” which may diminish the work productivity [4]. Bonnie studied the association between work productivity and depression, fatigue, and anxiety, and found that presenteeism is associated with increasing fatigue, depression, and anxiety [5]. Therefore, studying the relationship between mental state and work efficiency is necessary.

In the field of office work and manufacturing, researchers who tested the psychological state of workers recommended some solutions to achieve the goal of improving work productivity. Through an empirical study done in Australia, Bubonya proposed initiatives to reduce job stress and these offer the most potential to improve productivity [6]. Hillebrandt reported that psychological stress has a great impact on productivity. Setting some interventions can help increase job satisfaction, reduce adrenalin levels, and increase performance efficiency of workers in business [7]. Liff conducted a research in Northwest England and concluded that the productivity of women workers in the food factory industry can be affected by their mental status, which in turn, can reduce the overall work pressure and uplift work productivity [8]. All the studies above illustrate that, whether in the office or in the manufacturing industry, focusing on physical or mental states can avoid productivity inefficiency and lead to productivity improvement.

Due to the rapid growth of labor cost, increasing worker efficiency and reducing labor costs have become serious challenges in the architecture, engineering, and construction (AEC) field. Haas et al. presented for a prototype of a simple, low-cost, sensing solution for automatically monitoring undesirable movements and patterns of motion to help reduce Construction Work-related Musculoskeletal Disorders and help the workers work in a more efficient and safe way [9]. Gatti et al. propose that assessing physical strain in construction workforce is the first step for improving Safety and productivity management [10]. Lill use a simulation modelling to optimize the labour management strategies, and decrease the mismatch between required and available skilled labour and to discuss the consequences of ignoring the interests of craftsmen [11].

Unfortunately, few studies focus on how psychological and physical status influence work productivity. To fulfill this research gap, the current paper purpose a wearable device-based system to explore the relationship among work productivity, psychological state, and physical status.

The main problems and corresponding solutions in this paper are as stated below.

- For the measurement of psychological state, STAI questionnaire was used to reflect workers' mental status.
- For the measurement of physical status, the smart band was adopted to record workers' physical status.
- For the measurement of work productivity, the time spent by workers to complete a unit of work was measured.
- For the analyses of the three dimensions, regressive analysis was used to find the correlation

2 Research Method

This research proposes the use of a novel type of measurement (smart band) to monitor the physical data reflecting the mental status of the workers. Doing so can help us determine the relationship between mental status and work productivity. An initial experiment was done based on the logical framework of the experiment shown in Figure 1.

2.1 Psychological data collection

In this research, we collected psychological data, specifically data on state anxiety and trait anxiety. Trait anxiety is a relatively stable behavioral tendency of each individual, whereas state anxiety mainly indicates perceived risk or stimulation, producing brief emotional states, including individual tension, worry, anxiety, obsession, and euphoria of the autonomic nervous system.

Such data can be collected via a traditional but classic approach: by using the State-Trait Anxiety Inventory (STAI). First introduced in 1970 [12], this test has been proven to be effective in testing anxiety by many past studies, especially those in the medical field [13, 14]. This questionnaire is divided into two parts: one that tests trait anxiety and another that tests state anxiety. The test of trait anxiety mainly asks about how one person feels at the moment, whereas the test of state anxiety asks about how one feels in general. Each part has 20 items, and takes about 10 minutes to complete. These tests are answered on the basis of a scale with scores of 1 to 4 (1 - "not at all," 2 - "somewhat," 3 - "moderately so," and 4 - "very much so." It can reflex the emotion including tension, apprehension, and nervousness.

Table 1. Questionnaire of testing trait anxiety

Items	Options
I lack self-confidence	1 2 3 4
I am a steady person	1 2 3 4
……	

Table 2. Questionnaire of testing state anxiety

Items	Options
I lack self-confidence	1 2 3 4
I am a steady person	1 2 3 4
……	

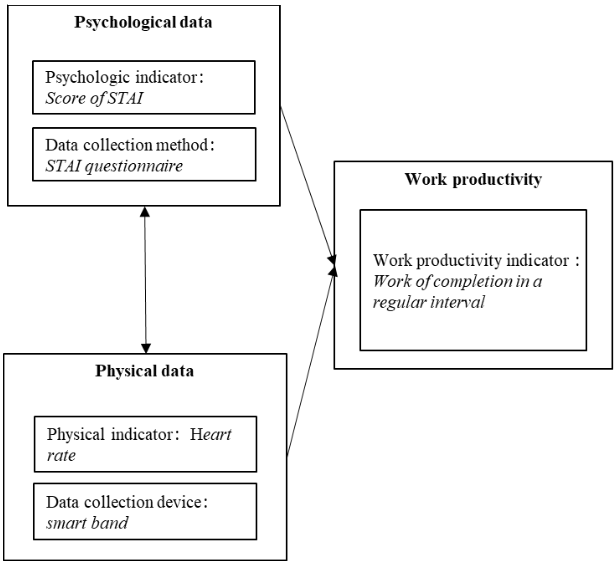

Figure 1. The logic framework of this study

2.2 Physical data collection

To collect the physical data, which can provide a real-time status of the jobsite workers, the physical indicators were selected. In the previous study, heart rate, ECG, electrodermal response, skin temperature, calorie, number of steps taken, and respiratory rhythm were used (Table 3). In this exploratory study, to make the study

Table 3. Questionnaire of testing state anxiety

Reference	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]
Heart rate	✓		✓	✓		✓	✓	✓	✓
EEG	✓	✓							
Skin temperature	✓	✓			✓		✓		
Electrodermal reaction		✓		✓			✓		
Calorie				✓					
Movement steps				✓				✓	
Breathing rhythm			✓						

feasible and credible, we used heart rate, which is the most frequently used indicator.

The smart band was used to measure the two indicators. It has the following three main advantages compared with traditional physical status measurements.

First, the smart band is wireless and easy to wear. Wearable devices usually appear in the form of a bracelet, vest, glasses, and helmet. It can be worn like regular clothing or an accessory to allow movement without restrictions. In contrast, traditional monitoring instruments generally require the subjects to stay in a fixed location. Also, the smart band can provide real-time. monitoring. With such sensors as the heart-rate monitor, barometer, and angular velocity trans embedded, it offers the opportunities to detect human activities in real time.

Another thing which cannot be ignored, that the smart band is a practical and non-expensive option. In fact, some construction workers recognize the benefits of using a smart band [24], such as wearing it while working.

2.3 Work productivity measurement

Investigating work efficiency or productivity is the main study objective of this research. As ours is an exploratory study, we can easily calculate work efficiency or productivity by recording the time spent by each worked in completing a unit of work (i.e., wall building). In future works, however, this indicator should also consider accuracy and the quality of the final product.

3 Experiment and data collection

3.1 Selection of the experiment site and subjects

This experiment was conducted at the Dazhulin project located in Chongqing, China, as shown in Figure 2. This project, undertaken by Chongqing Wantai Construction Co., Ltd., is a frame-shear wall structure with a construction height of 123 m.

Figure 2. The experiment site

The subjects consisted of three bricklayers working on the 22nd floor. Their task was to build the walls, and this required them to pick up bricks, apply the mortar, climb numerous stairs, and so on. This type of work is very common in the field of construction. In past studies, researchers have proven that workers performing this kind of work are suitable subjects for the monitoring of real-time data on their physical and psychological state. For example, Chen designed an experiment, which included climbing a ladder, selecting a screw and installing the screw to test the physical and psychological state of the workers [25]. This kind of work is similar to what the bricklayers in the current study do in terms of complexity.

3.2 Experiment process

The experiment was carried out in the following procedures:

First, the subjects were numbered and asked to fill out the T-test in the STAI questionnaire.

Then, to collect their physical data, the subjects were required to wear the smart band daily. They should put it on in the morning when they start to work and take it off after work. The heart rate was measured every 1 minute.

During a regular interval (once every 2.5 hours), they were asked have a rest and fill in the S-test in the STAI questionnaire. The quantity of wall structure they completed was then identified.

Their behaviours, including talking with co-workers, and changes in the external environment, such as the project manager's inspection, were also recorded.

(a) (b)

Figure 3. The testees is filling out the STAI questionnaire (a) and working while wearing the smart band (b)

3.3 Experimental data collection

Since it is an exploratory study, the experiment had just been conducted for 3 days in March, 2018. The physical data was collected by using Millet bracelet. As a result, 1 time/minute*60*10 minute/day/people*3 people*3 days = 5400 data sample of their heart rate were collected (table 4).
As for the psychological status (including S-test and T-test) and work productivity data，4 times / day / people ∗ 3 days ∗ 3 people = 36 data samples were collected.

Table 4. A part of the original data (worker B; day 1; 6:30-9:00）

Heart rate data: Mean=77.9; SD=14.99									
104	77	95	60	67	80	80	98	87	72
69	101	108	61	106	52	103	95	75	63
75	85	82	106	94	80	43	95	60	76
103	87	78	68	87	62	82	80	96	100
69	78	103	84	53	84	72	87	83	74
70	93	82	83	105	87	70	85	79	103
102	71	96	69	103	70	98	60	86	69
77	87	56	80	83	90	76	58	124	105
73	97	99	70	86	92	65	100	108	77
81	83	84	69	89	64	72	67	74	104
69	75	70	94	91	68	106	68	64	77
108	62	73	90	74	92	77	94	108	89
99	91	77	51	89	60	84	78	95	98
80	83	98	102	68	88	82	74	69	67
90	73	68	80	83	76	71	74	86	80
S-test score =22; work productivity=2.08m^3									

4 Data analysis and results

The experiment collected 5400 physical data and 36 sets of psychological and work productivity data. From these, several findings can be concluded.

All the subjects scored below 30 in T-test, indicating relatively low levels of anxiety and stress. The three subjects scored 22, 25, and 28, respectively. Compared with other occupations, for example, undergraduate student, the level of anxiety is significantly lower. Through the observation during the experiment, this result may have been due to the following reasons:

The most likely reason is.that the level of security at the construction site improves and the perceived risk is reduced, so construction worker feel more safe and the anxiety(stress) level decrease correspondingly.

The rise in wages may be the second reason for this phenomenon. The high wage make construction workers more satisfied with their lives.

The third reason this that the repeatability of the job makes them extremely confident in their ability to finish the work, thus reducing anxiety and annoyance

We can also observe that the score in the S-test (state anxiety index) is positively related with work productivity (Figure 4).

The findings indicate that workers work more efficiently when they feel relatively high levels of stress and anxiety. This is because the initial anxiety level of the bricklayers is very low given that the perceived stress is not enough. When the workers were supervised or criticized by the foreman, they felt more stressed and uncomfortable, which then increased their S-test scores

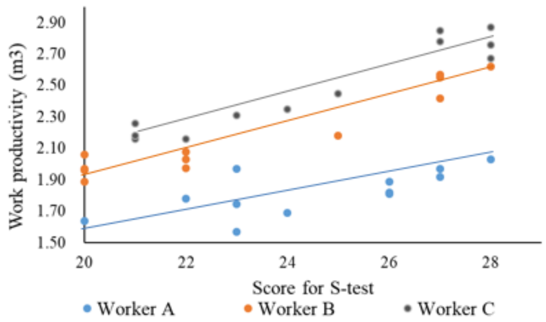

Figure 4. The correlation of work productivity and state anxiety index

and prompted them to work more efficiently. Another common situation is that workers talked to their workmates frequently, and such communication made them feel relaxed. As a result, their state anxiety index decreased, and their work productivity decreases correspondingly.

It can also be conclude that heart rate is positively correlated with state anxiety index and work efficiency

When bricklayers work efficiently, the peak values of their heart rates tend to be higher, and the standard deviation (SD) is also larger. A rapid heartbeat indicates the performance of efficient work (Figure 5).

The increase of heart rate during high work productivity can be explained from two perspectives. On the one hand, the amount of exercise increased, and on the other hand, relatively high degrees of mental stress and anxiety pushed them do better work.

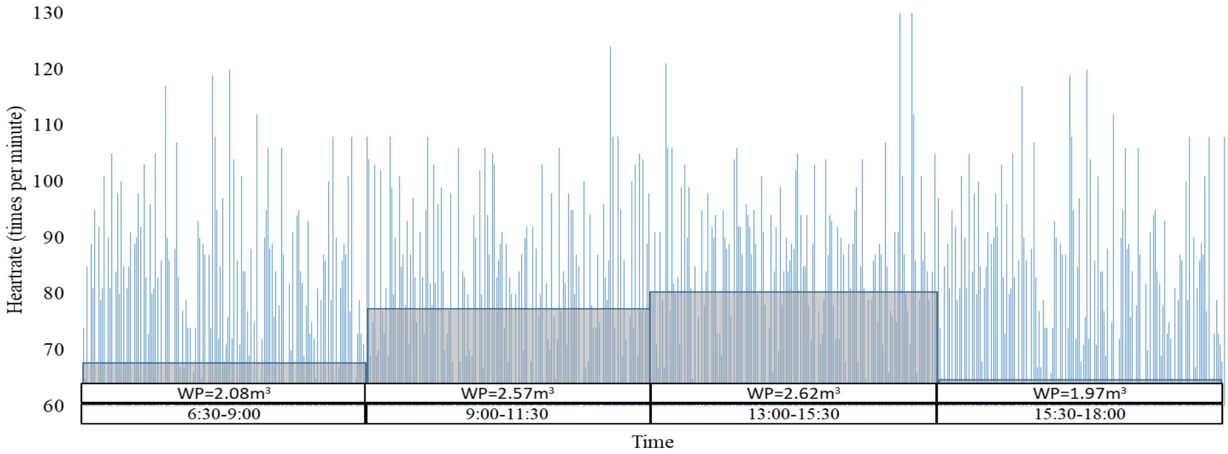

Figure 5. The relationship between work productivity and workers' real-time heart rate

5 Conclusion

This paper established a wearable-device based system that helped stakeholders understand the psychological and physical state of the construction workers in real time. Based on the experimental data, the following results can be concluded.

1. Bricklayers show a relatively low level of anxiety and stress.
2. State anxiety index is positively related with work productivity.
3. Heart rate was positively correlated with state anxiety index and work efficiency.

Though the real-time data, and the relationship among work productivity, psychological state, and physical status, the work productivity of construction workers can be predicted.

The significance of this research is that it provides an available approach to monitor construction workers' physical status and psychological state to predict their work productivity. A reasonable arrangement construction workers' working schedules can help improve their work efficiency.

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