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Wristband-type wearable health devices to measure construction workers' physical demands

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ABSTRACT

Recent advancements in wearable health devices equipped with biosensor systems (e.g., heart rate (HR) sensor) have provided an ample opportunity to continuously measure and understand workers' physical demands from construction work. Specifically, a relative measurement of physical demands, which is a percentage of HR reserve (%HRR), is convenient and useful by normalizing individual differences of HR. Since affordable HR monitoring using wearable devices (particularly, a comfortable wristband-type device: wristband hereafter) becomes available, %HRR-based physical demand measurement, which can be continuously calculated without interfering with workers' ongoing work, provides an enormous potential to protect workers' safety and health and to sustain expected productivity. This research investigates the usefulness of affordable %HRR-based physical demand measurement using a wristband from a case study of 19 workers in construction sites. The aim of the analysis is to examine the potential of this continuous measurement in capturing any significant physical demand variations, by investigating in-depth information on factors affecting physical demands (e.g., work tasks, individual and environmental factors). The results show that workers' physical demands are highly variable according to their working patterns (i.e., direct work, and indirect work including tool/equipment/material handling, traveling, and preparatory work), combined influences of work tasks, as well as individual and environmental factors (e.g., age and heat stress). These results demonstrate the need for continuous physical measurement during workers' ongoing work so that any significant high physical demands, which need to be avoided if possible, can be captured. The findings of this paper show that the continuous measurement of physical demands using a wristband provides rich information to understand, manage, and design physically demanding construction work (e.g., flexible work-rest cycle and managing demanding indirect work) by balancing workloads throughout a day and/or reducing unnecessary physical demands beyond direct work. By anticipating potential health and safety problems from excessive physical demands, as well as productivity loss before they occur, this research will have an ameliorative impact across the construction industry.

1. Introduction

Due to the labor-intensive nature of construction work, many construction workers face excessive demands beyond their physical capabilities [1,31,41]. The consequences of workers' frequently high physical demands include chronic fatigue, a high number of injuries and illnesses, stagnant on-site productivity, work-related musculoskeletal disorder, and early retirement among others [2,27,62]. In this sense, managing physical demands within an acceptable limit by measuring them is critical in labor-intensive construction to sustain expected productivity without sacrificing workers' safety and health [2,38,47].

Recent advancements in wearable health devices provide an ample opportunity to measure workers' physical demands by virtue of embedded biosensors (e.g., heart rate sensor and skin temperature sensor) [5,28,44]. Specifically, a light-weight and comfortable form of wristband-type wearable health devices (e.g., wristband hereinafter, such as a smart watch and a fitness tracker), which are also affordable, possess a great potential for physical demand measurement at the worksite without interfering with their ongoing work. Among diverse physiological signals from the wristband, heart rate (HR) has been widely used in physical demand measurement because HR is proven as a reliable indicator from the perspective of cardiovascular loads [9]. Specifically, the percentage of HR reserve (%HRR), which is a relative measurement of physical demands by normalizing original absolute HR considering

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individual difference [4,32,61], has been reliably and widely used for diverse dynamic muscular work [12,22,26,52,63]. This method assumes resting HR (i.e., minimum HR during resting) as a level with no physical intensity and demand, and calculates a percentage of the difference between working and resting HRs among HR reserves (i.e., HR reserve indicates the difference between maximum HR and resting HR) [4,26,49]. Although individuals originally have different levels of HR due to internal body status (e.g., hypertensive diseases that increase blood pressure and resting HR and chronic mental stress) [3], this relative measurement (%HRR) can only focus on relative changes of HR originated from physical activities to infer physical demands by offsetting each individual's different HR level [22,26,61]. On the other hand, many other mental factors, such as emotions (e.g., fear), can also affect HR [3,64]. However, the effect of physical demands on HR changes is more dominant in the long term than others' effects while mental factors acutely change HR: therefore, while mental factors are generally estimated in the short term based on the variation of beat-to-beat interval which is less than one seconds [16,64], relatively long-term measurement (e.g., half-hourly, hourly, or daily basis) of HR and conversion into %HRR can be more useful for investigating physical demands [4,26,49].

As such, %HRR has been applied to construction to investigate overall physical demands among workers with different task types [30], and analyze the effects of physical demands on productivity [17]. Although these studies have demonstrated the usefulness of %HRR in an occupational (particularly construction) work, they still lack an in-depth understanding of how and why physical demands vary over time. Because high physical demands should not last for a long time due to risk to a worker's health (e.g., risky if 40%HRR is sustained over 30–60 min, 60%HRR over 30 min, and/or 30%HRR over eight hours: [10,42,61]), it is very important to continuously measure workers' physical demands every 30–60 min. This continuous measurement ensures that significant physical demands which may result from irregular workloads, varying work conditions, and an individual's daily physical conditions can be monitored and alerted. This continuous measurement is particularly meaningful in construction, where diverse types of tasks are performed under various work conditions (e.g., indoor vs. outdoor and hot vs. cold).

In this regard, a wristband can be very useful because it provides continuous HR while causing no discomfort to workers, especially when compared to other HR monitoring devices (e.g., an uncomfortable and tight chest strap with a HR sensor that previous studies [17,22,30] on understanding physical demands using %HRR in construction have used). Therefore, the authors conducted a case study to examine the potential of the wristband in capturing any significant variation of construction workers' physical demands over time. Specifically, by studying factors affecting physical demands, the authors investigate whether %HRR-based physical demand variations measured by a wristband are feasible and useful. The scope of this analysis includes physical demand variations among different individuals (e.g., different age), tasks, working patterns (i.e., percentages of work activities including direct work, and indirect work such as tool/equipment/material handling, traveling, and preparatory work), or other environmental conditions (e.g., outdoor vs. indoor).

2. Research background

2.1. Need to measure physical demand as a worker response

Worker activities with high physical demands may cause fatigue and exhaustion. For example, 37.9% of the U.S. workforce experiences serious fatigue that may result in devastating consequences related to workers' safety, health, and productivity [48]. The outcomes of physical fatigue have been widely recognized in the construction industry, which include decreased productivity and motivation, inattentiveness, poor judgment and quality work, low job satisfaction, and high accidents and injuries [2]. Further, it can have a more severe effect on the construction industry due to an increased proportion of an aging workforce [14,51].

Physical demands refer to each individual's physical responses to given workloads. Previous research efforts on measuring physical demands have focused on assessing workloads by measuring workers' work elements, such as postures (e.g., back bent and twisting), activity types (e.g., walking, lifting, and carrying), weight and forces, as well as activity duration and frequency [58,23,59]. Because physical performance is greatly influenced by diverse factors such as individual factors (e.g., age, training, and nutrition) or environmental factors (e.g., temperature, humidity, and noise) [9,34,39], reliable physical demand measurement should consider not only workloads but also all these factors [9,58]. However, due to many individual and environmental factors affecting physical demands, it is very difficult to take into account all of them. Different effects of workloads on workers' physical capacity exist among workers performing similar tasks in the same work conditions, or among workers performing same tasks at different workplaces [17,39]. Åstrand et al. [9] have also confirmed that "a workload that is fairly easy for one worker can be quite exhausting for another." If physical demands are measured based on factors affecting physical demands (specifically, work elements) and if this measurement cannot include all the factors, some factors that are particularly important to a certain worker (e.g., high temperature to a worker who is more sensitive to heat stress than others) can be omitted. This can lead to improper interventions (e.g., motivating the worker who is more sensitive to heat stress than others to work faster under hot weather), which can result in his/her safety and/or health issues as well as productivity loss.

In this regard, physical demand measurement based on workers' physiological response (e.g., HR-based measurement: [17,30]) can be an alternative means to understand the impact of all the factors in worker's physical demands because all these influences on the human body are represented in physiological signals: for example, HR used in this research is affected by not only workloads but also all the individual and environmental factors listed above [3,40]. Therefore, given the difficulty to constantly identify all important factors affecting physical demands at the worksite, %HRR-based physical demand measurement in construction can be relevant and useful to understand how each worker physically responds to given work tasks with irregular workloads and varying work conditions over time.

2.2. Measuring physical demands using a wristband

As described earlier, a wristband that monitors workers' physiological status, particularly HR, provides an ample opportunity of continuous %HRR-based physical demand measurement as a human body response at the worksite. Despite this potential, the application of this measurement into construction can be challenging due to the following issues: first, HR monitoring accuracy of a wristband; and second, the accuracy of %HRR method in representing construction workers' physical demands.

First, while accurate HR can be obtained from an electrocardiogram (ECG) sensor which directly measures electrical signals from heart's activity near the chest (e.g., chest strap) [29,66], HR in a wristband is measured based on a photoplethysmography (PPG) sensor, which detects blood flow rates as controlled by a heart's pumping action by capturing the light intensity reflected from skin based on a LED and a photo detector [8,20,35,54]. Because HR from PPG is indirectly estimated by blood volumes through the wrist and PPG signals can be contaminated by noises during a user's intense movements, accurate HR calculation from the PPG sensor in the wristband during intensive physical activities has been challenging [20,54]. However, recent studies have improved the accuracy of PPG-based HR from a wristband by applying signal processing techniques (e.g., denoising through a signal decomposition into noise- and noise-free-components) [35,54,65,66].