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Personalized method for self-management of trunk postural ergonomic hazards in construction rebar ironwork

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ABSTRACT

Construction rebar workers face postural ergonomic hazards that can lead to work-related Lower Back Disorders (LBDs), primarily due to their prolonged awkward working postures required by the job. In a previous study, Wearable Inertial Measurement Units (WIMUs)-based Personal Protective Equipment (PPE) was developed to alert workers when their trunk inclination holding time exceeded acceptable thresholds as defined in ISO standard 11226:2000. However, subsequent field testing identified PPE was ineffective for some workers because the adopted ISO thresholds were not personalized and did not consider differences in individual's response to postural ergonomic hazards. To address this problem, this paper introduces a worker-centric method to assist in the self-management of work-related ergonomic hazards, based on data-driven personalized healthcare intervention. Firstly, personalized information is gathered by providing each rebar ironworker a WIMU-based personalized mobile health (mHealth) system to capture their trunk inclination angle and holding time data. Then, the captured individual trunk inclination holding times are analyzed by a Gaussian-like probability density function, where abnormal holding time thresholds can be generated and updated in response to incoming trunk inclination records of an individual during work time. These abnormal holding time thresholds are then adapted to be used as personalized trunk inclination holding time recommendations for an individual worker to self-manage their working postures, based on their own trunk inclination records. The proposed worker-centric method to assist in the self-management of ergonomic postural hazards leading to LBDs was field tested on a construction site over a three-month duration. The results of the paired *t*-tests indicate that posture scores evaluated by the Ovako Working Posture Analysis System (OWAS) significantly decrease when the personalized recommendation is applied, while increase again when the personalized recommendation is removed. Based on data-driven personalized healthcare intervention, the results demonstrate the significant potential of the proposed worker-centric self-management method for rebar workers in preventing and controlling postural ergonomic hazards during construction rebar ironwork.

1. Introduction

Work-related Lower Back Disorders (LBDs) are common occupational injuries, especially in the often labor-intensive and physically demanding construction industry [1,2]. Rebar ironwork (also known as concrete reinforcement work), typically involves unloading, placing and tying reinforcing steel bars (rebar) into a formwork system before the formwork is filled with concrete [3]. A survey by Forde et al. [4] reported that more than half of rebar workers (56%) in the United States suffer from lower back injury. Manually tying rebar at ground level requires deep trunk bending and non-neutral trunk postures such as stooping, squatting or kneeling for nearly half of working hours [5]. Such awkward postures can significantly increase the risk of lower back injury [6,7]. Thus, compared with workers in other construction trades, rebar workers are exposed to greater postural ergonomic hazards that can lead to LBDs [8].

Previous postural ergonomic analysis methods [9–14] assess postural ergonomic hazards by analyzing posture angles and holding times of different body parts based on ergonomic rules, such as the Ovako Working Posture Analysis System (OWAS) [66]. The OWAS classifies the posture combinations of back, arms, and legs, and relative proportions of certain postures during work time into four action categories based on the risk assessment of musculoskeletal disorders. In the OWAS, the action categories range from 1, no action is required, to 4,

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corrective measures are required immediately. If the proportion of a certain posture during the observation period is larger than the frequency threshold defined by the OWAS, the action category changes from lower to higher, which indicates the increasing urgency of corrective action. However, previous ergonomic analysis methods require site observations and questionnaires by safety personnel to collect posture data, which can be inaccurate due to subjective bias [15].

To achieve automated and precise ergonomic analysis in construction, we have previously developed a wearable Inertial Measurement Units (WIMUs)-based Personal Protective Equipment (PPE) to capture real-time trunk posture, and to warn workers regarding non-ergonomic trunk inclination and holding time [16]. The warning thresholds were derived from the ISO 11226:2000 [17], as a global standard that specifies the acceptable ergonomic thresholds of working postures without any (or minimal) external force exertion, while taking into account body angles and holding time aspects. Our WIMU-based PPE can assist the self-management of postural ergonomic hazards among workers in the construction industry, where a smartphone application attached to the PPE sends out alarm for the wearer to adjust their trunk posture if the captured holding time of trunk inclination angles is larger than the thresholds defined in ISO 11226:2000.

However, during the field test of the PPE system on a construction site, new problems were recognized during an open-ended interview with the recruited rebar ironworkers. When we asked them whether the PPE system interfere their normal operations during the field test, most of the workers reported that the trunk inclination angle threshold (60°) is too strict for them to normally perform because most rebar tying works on the ground level requires heavily back bent postures whose inclination angles are larger than 60°. As a result, the frequently activated alarms regarding trunk inclination angle would interfere their normal operation. For the same question, some workers also reported the trunk inclination holding time alarm was strict. On the contrary, some others reported the trunk inclination holding time alarm was still not activated when they feel muscle soreness in lower back when being asked the question whether the PPE system helped you in reduce feelings of lower back pain. In summary of the interview, we found that the trunk inclination angle threshold (60°) is not practical for construction rebar ironwork, thus should be cancelled. We also found that the trunk inclination holding time thresholds specified in ISO 11226:2000 can be high for some individuals, resulting in the impaired effectiveness of the ergonomic intervention. Conversely, the thresholds were found to be too low for some individuals, negatively impacted on the worker's performance and leading to potential productivity loss. This is because the acceptable thresholds defined in ISO 11226:2000 are general in nature and only reflect an average level of acceptability of working postures. As such, the average level of acceptability may not be suitable for all workers due to individual differences in physical capability, knowledge, working experience, and skill [18,19]. Further, this problem may also be generalized because the workers we interviewed during the field test of our WIMU-based PPE were randomly sampled. The motivation of this paper arose from the need to address this problem from the field test. Therefore, the primary objective of this paper is to develop a data-driven personalized worker-centric trunk posture system to assist workers in the self-management of work-related postural ergonomic hazards in construction rebar ironwork.

Different from traditional healthcare, where healthcare providers play dominant roles, personalized healthcare advocates patient power, engagement and control over their health, in which healthcare providers provide professional recommendations based on individual needs. In this study, we propose a method to learn personalized trunk posture distribution, and provide personalized trunk inclination holding time recommendations, based on individual posture data. The personalized recommendations derive from individual historical probabilistic distribution of trunk posture holding time, based on probability density estimation. A three-month field test of the proposed WIMU-based PPE with the personalized recommendation module was conducted, including: one month of trunk posture data pooling using the WIMU-based PPE, one month of worker self-management of postural ergonomic hazards leading to LBDs (according to their personalized recommendations), and one-month self-management without personalized recommendations. During the field test, we translated each worker's trunk posture data (inclination angel and holding time) into OWAS scores in each work day and examined any significant changes among three field test periods by paired *t*-tests.

Our research addresses two important knowledge gaps. Firstly, we address the problem that many ergonomic rules for posture assessment are not suitable to all individuals' needs by introducing a data-driven personalized healthcare and worker-centric self-management approach to rebar ironwork in the construction industry. Secondly, we propose a new method to learn personalized trunk posture distribution and provide personalized trunk inclination holding time recommendations based on individual posture data. The effects of the proposed personalized healthcare interventions were empirically tested and validated on a construction site.

2. Background

2.1. Ergonomic posture analysis of rebar ironwork

Construction rebar ironwork is typically involves placing steel rods into concrete formwork and tying the rods together using a spool of wire and pliers (or a steel hook) before the formwork is filled with concrete. Rebar ironwork requires deep back bending and non-neutral trunk postures such as stooping, squatting and kneeling for nearly half of working hours (usually more than 2 h per workday) [5]. The prolonged resultant forces stretches or torques at the skeletal muscle tissue of lower back that can cause muscle fatigue, pain and even permanent injury and disorders [20]. As a group of painful disorders, relating to muscles, tendons, nerves, cartilage, and joints, LBDs among construction workers mainly originate from compression, shear, tensile stress, and muscle force repeatedly acting on load bearing tissues [21]. Specifically, much of this loading in the construction rebar ironwork originates from repetitive back movements in prolonged awkward working postures. For example, a stooping posture in rebar tying can significantly reduce the electromyographic activity of lumbar muscles, with a reduction of 60–80% compared to one-legged kneeling and squatting postures [7]. The reduced electromyographic activity of muscles may shift the loading to ligaments and joint capsules of load bearing structures, which is known as a significant risk factor of work-related LBDs. As a result, rebar workers are severely exposed to work-related trunk postural ergonomic hazards, which is a known risk factor leading to LBDs [7,22–24].

Postural ergonomic hazards in rebar ironwork is determined by both command of workload and individual's response to that command [25]. The major command of workload in rebar ironwork is job site arrangement [26,27], such as the height of the rods with respect to rebar workers. The individual's postural response is what posture or holding time a worker adopts under a certain command of workload [28].

Job site arrangement is an important ergonomic consideration for reducing postural ergonomic hazards in rebar ironwork. However, job site arrangement is usually based on the design of structures, and can change as the project progresses, leaving little room for personalized redesign, considering human factors in practice. This is further challenged by the differences in human body size that may not meet standard ergonomic design of a construction job site. For example, design in the height of a rebar tying workbench could be comfortable for a worker of average height, while may be ergonomically hazardous for taller or shorter workers over a prolonged working period. For example, taller workers may need to further bend their trunk and neck to effectively use the workbench, while shorter workers may need to lift their hands or arms higher.

In consideration of the above limitations in improving job site