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Efficacy of Bluetooth-Operated Heart Rate Monitors for Use in Construction

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Abstract

In the construction industry, workers are exposed to many hazards that pose risks to their health. Bluetooth-connected devices host the potential to reduce health risks to workers by tracking heart rate (HR), particularly upon implementation into an Internet of Things (IoT) framework. An IoT system is one in which multiple devices are connected to transmit information to each other in real-time. A literature and industry review were conducted to determine which devices would be most applicable to monitor HR in an IoT system to accurately portray real-time worker conditions. Experimentally, the most applicable devices found were then put under field tests imitating traditional work conditions. The performance and accuracy of the devices under these conditions were then evaluated from the data collected. The study has been designed to determine whether chest, finger, and wrist devices could be used to accurately track HR. The devices used included the Viatom Wellue O2Ring finger monitor, Polar Ignite GPS Fitness Watch wrist monitor, and the Polar H10 chest monitor. All three devices connected to the IoT system and transmitted data within a specific timeframe correctly. Covariance and standard deviation, measured in the finger monitor and the fitness watch participant trials, were above the normal thresholds, indicating non-negligible differences around the mean. Hence, this indicated disparities in the accuracy of these devices. Likewise, the results were found to be too inaccurate for widespread commercial deployment for tracking mid-to- high HR levels while performing heavy labor. Overall, the use of Bluetooth-connected devices to track workers' HR and other vitals has potential in improving safety in hazardous environments. However, future technological development must occur before implementing predictive safety systems into real-time monitoring to effectively monitor laborers performing strenuous tasks in harsh environments.

Keywords: *Internet-of-Things (IoT), Bluetooth, Heart Rate, Heart Monitor, Construction Industry*

Introduction

An international study found that the construction site ranked as one of the most dangerous workplaces where workers are at risk of dying from accidents (Mehata et al., 2019). Casualties on sites can include accidents from handling machinery to non-machinery related accidents, such as falls from dehydration, overexertion, and/or lack of necessary breaks. Around 5,317 different types of fatal incidents occur on the construction site, showing how dangerous the site is (Lee et al., 2021). Likewise, heat exhaustion due to fatigue can result in long-term medical conditions that can affect the worker off site.

Due to the dangerous nature of the construction environment, certain safety measures are in place, but not consistently applied to all sites (Costin et al., 2019). One of these measures includes providing guardrails on areas where individuals are at high risk of falls. However, these solutions do not account for the ever-changing environment of construction that requires active monitoring of both the construction worker's surroundings and their health. Gyroscopes, video cameras, and more help construction sites to prevent accidents that can occur due to moving building parts or falls from tall heights (Costin et al., 2019).

Heart Rate (HR) monitors track the vital signs of construction workers on site to ensure they are taking appropriate water and nourishment breaks during their shift. HR also provides useful information on trauma, as a sudden increase or decrease can indicate the worker has faced physical trauma. As such, this paper focuses on monitoring and assessing construction workers' health on a real time basis by tracking HR. HR has been chosen due to its importance in predicting the risk of injury or other medical concerns, as well as how widespread HR monitoring devices are in various fields, such as exercise training.

The purpose of this research is to compare the accuracy of three different HR monitoring devices placed on the chest, wrist, and finger. These devices are all Bluetooth-connected and linked via smartphone to a broader Internet of Things (IoT) system. An IoT system is a network of devices connected to each other via internet protocol (IP) to share information between devices in real time. For instance, in the study performed, the heart rate monitors directly transmitted heart rate readings to a smart phone to show the heart rate. The data collected from these devices is then wirelessly transmitted over the internet from the phone to a centralized system that stores and displays this data in near real time. The chosen framework could be used in a construction setting to overcome technical restraints that prevent real-time tracking of workers' heart rate.

A study with three participants undergoing two trials each, with all three devices attached to each person, was performed. The participants performed three tasks: walking, jogging, and running, with breaks in between each activity. The chest monitor was chosen as the baseline due to a study by Wang et al., (2017) that showed 99% accuracy of the Polar chest monitor when compared to the Electrocardiogram (ECG). The data was compiled into graphs, tracing the HR of the participant as the activities were performed and evaluated, provided covariance between the chest HR monitor and either the finger or wrist monitor. The standard deviation compares the same HR monitors' deviation from the mean. The significance of this study is to show how the finger and wrist monitors differ when compared to the chest monitor and analyze whether they can be used effectively in a construction environment.

One reviewed study proposed a system to continuously track heart rate and body temperature of workers without invading the skin so workers can take appropriate breaks (Sergi et al., 2021). Similarly, another study focused on continuous heart rate monitoring for the decreasing rate of atrial fibrillation that can occur due to overexertion (Bathilde et al., 2018). Yet another study focused on the interoperability of multiple sensors that not only tracks physiological data, but also the surrounding environment, so the construction worker can avoid accidents due to things like falling construction beams (Awolusi et al., 2019).

Another study investigated a solution to allow practitioners to see which types of technologies, such as wearable sensors, are the most effective at preventing work-site accidents (Yao et al., 2020). Furthermore, Kim et al. (2020) used commercially available smart bands containing three sensors to monitor vital parameters, sending data to servers on a long-range network, which could then be accessed by a smart device. The data assessed individual workers' risk of heat-stress related issues from high-temperature working environments. A related study included smart helmets detecting falls through an embedded accelerometer and gyroscope (Jayasree & Kumari, 2020). Most similarly however, research by Wang et al. (2017) compared the accuracy of chest and heart monitors among 50 healthy adult participants wore standard electrocardiographic limb leads and a Polar H7 chest strap monitor secured tightly to ensure skin contact. Four wrist-worn monitors were assessed, and the paper concluded the Polar H7 monitor as the most accurate in tracking HR during physical activity compared to the wrist monitors.

Methods

Purpose, Aims, Scope and Objectives

The purpose of this research is to evaluate the feasibility and effectiveness of commercially available health monitors for deployment in construction safety applications utilizing an IoT-based framework. Compared to internal data storage, an IoT system enables decentralized data storage, near-real-time tracking, and dynamic response in the event of a safety incident. Previous research investigated the IoT system architecture and concluded that systems can be built to predict future threats to safety in a construction environment by processing incidents and near misses through devices connected via Internet Protocol (IP) (Costin et al., 2019). For example, by taking the heart rate of construction workers, the IoT system can be programmed to recognize consistently high heart rates as a cause for the construction worker to take a break. Since that paper focused on the system architecture, this paper only focuses on the devices that integrate with the system.

The following research questions were investigated:

1. Do the devices collect data accurately and reliably?
2. Are the results as expected?

The scope of this work is limited to the physiological condition of cardiovascular or HR monitoring. Thus, only technologies relating to heart monitoring is evaluated. Key features in the division of these include: 1) commercial availability, 2) ergonomic comfortability and usability while performing tasks, 3) efficient data monitoring and sharing, and 4) durability for the construction environment. These devices should not obstruct, impede, or delay the worker using them. The first objective of this research was to establish existing literature on devices used to monitor various physiological parameters, including HR, and potential integration into an IoT framework. The objective of the field test experiment was to compare the accuracy of the chosen devices placed across the chest, wrist, and finger to collect data while the participants were performing a certain activity. The hypothesis: due to the proximity to the heart, the chest monitor would most accurately track HR during the activities performed by the participants.

Study Design and Materials

This study has been approved by the University of Florida Internal Review Board (IRB), study #IRB202200411. Testing was conducted outside at Rinker Hall, at the University of Florida. A secure path was established for participants to safely perform the tests. The three devices chosen for this experiment were Viatom Wellue O2Ring Wearable Oxygen Monitor (ring monitor), Polar H10 HR Sensor with Chest Strap (chest monitor), and Polar Ignite GPS

Fitness Watch (wrist monitor). The O2Ring Wearable Oxygen Monitor was chosen because the ring monitor tracks SpO2, which has future uses in construction environments. The chest monitor was chosen because of the close distance to the heart when worn, and the Fitness Watch was chosen because watches are the most common method to track heart rate, measured in beats per minute (bpm). The field test experiments aimed to compare the chest, wrist, and finger HR monitors, and identify if a alternatives could be used in place of a highly accurate chest-strap monitor to track HR under the stress of physical activity that simulated working in a construction environment.

In this study, only three participants were recruited, and each wore all three devices on the chest, wrist, and finger. Walking, jogging, and running were chosen to see if increased intensity of activity affected HR monitoring. These activities were chosen because they strictly measured the performance of heart rate monitors by intensity, in that the results could directly differentiate between low, medium, and high intensity activities by intuitive comparison. Construction activities were not chosen because they could not be scaled by intensity as easily. Furthermore, workers themselves are influenced both by the environment and the activity contributing to their heart rate, rather than just the activity alone. Thus, these three specific activities provide a consistent framework that allowed for testing the accuracy of the selected devices in monitoring HR.

The study design includes 6 periods: 3 activities at 3 minutes per activity, and 1.5 minute rest periods in between. Beforehand, using the Occupational Health and Safety Administration (OHSA) guidelines, the maximum activity duration was calculated to be 3 minutes, and the minimal resting time calculated to ensure participant safety was concluded to be 1.5 minutes. Afterwards, the data of the chest and wrist monitors were averaged every 4 seconds for standardization with the ring, which only takes data every 4 seconds, thereby creating equal numbers of observation. This ensured standardized accuracy of the devices in relation to the baseline heart rate. Again, the covariances and standard deviations found for these devices are based on differences from the baseline heart rate monitor.

Before beginning, initial resting HR was collected as a baseline for duration of 1.5 minutes. The first activity allowed the participants to take light walks for 3 minutes. The second and third activities had the participants jogging and then sprinting, respectively, for a timed duration of 3 minutes apiece. In between each activity, the participants were given a rest period to allow their HR to slow. In total, the participants were given four rest periods, each 1.5 minutes long.

Procedure

The participant puts on the wearables according to the specified manufacturer procedures and ensures that they are secure and comfortably fit. The wearable monitors are connected to the data collection device, with the connection being verified. 10 seconds allow for all the devices to reach similar resting HR. Resting Period 1 records the participant's resting HR, allowing them to sit for 1.5 minutes. Once the resting period is over, Activity 1 begins. Activity 1 records the participant's HR for a walk around Perry Yard at Rinker Hall for 3 minutes. Once the activity is over, the timer is stopped, and Resting Period 2 begins. The devices should be re-checked for connectivity and a new timer started for Activity 2. Activity 2 records the participant's HR for a jog around the same Perry Yard at Rinker Hall for 3 minutes. Once the activity is over, the timer is stopped, and Resting Period 3 begins. The devices are checked again for connectivity and a new timer is started for Activity 3. Activity 3 records the participant's HR for a fast run around Perry Yard for 3 minutes. Once the activity is over, the timer is stopped, and Resting Period 4 begins. The device connectivity is verified again before beginning a new trial.

The data collected is analyzed using absolute precision and other statistical methods. The total number of observations: 3 participants with 3 activities each at 3 minutes plus 4 rests at 1.5 is 45 minutes, or 2700 seconds. With a data record interval of 4 seconds, the total number of observations is 675.

Data analysis

Data collected while participants were performing their activities was exported from the internal data logs of the devices and imported into Microsoft Excel to perform Z-statistical analysis. A Z-value of 1.96 was used to ensure 95% confidence, due to the large sample size: 675 observations. The raw data became organized into tables to show HR, covariance, and standard deviation from the devices. Covariance and standard deviation were measured across all three devices to give insight into their accuracy and ability to track HR when the participant is under physical stress. A positive covariance indicated that both devices recorded the HR as increasing or decreasing correspondingly, but the actual recorded HR could vary. A negative covariance indicated that, as the baseline device recorded an increase/decrease in HR, the compared device would read the opposite. Standard deviation found how far apart or close together the devices readings were from the average. These statistical measures provided more insight into the accuracy of the chosen devices tested.

Results

Overview of Results

The acquired information dictates whether the finger and watch monitors could replace the chest HR monitor in a construction setting to track HR of workers. The combined results summarize the covariance and standard deviation data across the six trials, with each participant doing two trials. The smart watch and the smart ring were compared to the chest monitor, which, again, was used as the baseline. Trial 1 for participants 1 and 2 did not have one of the devices recording heart rate information due to connectivity issues. In Trial 1 for Participant 1 this is the chest monitor, which was not appropriately connected before the trials began. For Participant 2, the smart ring was not appropriately connected. However, this was due to human error, rather than error within the devices themselves. The associated covariance and standard deviation values for these trials have been considered and shown accordingly in the summary tables.

Combined Results

Results were combined to get the total averages, covariance, and standard deviations. Table 1 and 2 display the covariance summary for each trial. The covariance is in units of beats per minute squared ($bpm^{2)}$ and measures the degree to which the alternative monitors differ from the chest-strap heart rate monitor. Table 3 displays the deviation summary for each trial. The standard deviation is in beats per minute (bpm) and shows how much the data differs from the mean. Table 4 summarizes the covariance and deviations by activity, whilst Table 5 summarizes the results by equipment. Table 6 assesses the total experiment covariance and deviation.

Regarding device covariance compared to the chest monitor, both the ring and the watch show several trends that affirm the inadequacy of alternative Bluetooth-operated heart rate monitors. In Table 1, the rightmost column indicating the absolute sum of the row of trials, the covariance for jogging (178.3 bpm^2), is much greater than that for walking (33.35 bpm^2) showing the disparity between the utilized devices as heart rate increases. This conclusion is further affirmed by comparing the running trials to jogging, and by comparing resting periods to active periods. This further proves that as activity intensity increases, and therefore heart rate increases, there are larger values of covariance indicating greater differences from the standard. These trends are not just apparent in consideration of the sums of magnitudes, but also relatively consistent within the individual trials.

Table 1. Ring Trial Covariance Summary

Activity	Ring Trial 1 Part. 1 ((Beats/min)^2)	Ring Trial 2 Part. 1 ((Beats/min)^2)	Ring Trial 1 Part. 2 ((Beats/min)^2)	Ring Trial 2 Part. 2 ((Beats/min)^2)	Ring Trial 2 Part. 3 ((Beats/min)^2)	Ring Trial 2 Part. 3 ((Beats/min)^2)	Ring Trial Covariance Total ((Beats/min)^2)
Resting H.R.	-2.16	-2.9	NR	-0.95	5.75	20	31.76
Walk	18.6	1.75	NR	-2.34	-1.02	-9.64	33.35
Rest	0	-1.05	NR	-1.68	-2.27	-5.43	10.43
Jog	42.9	87.3	NR	-4.1	24	20	178.3
Rest	4.13	-5.63	NR	-7.81	3.57	4.4	25.54
Run	-104	-52.6	NR	33.6	-3.41	-24	217.6
Rest	-36	-1.44	NR	6.13	-2.55	-5.85	51.97

Table 2 also shows this similar trend with the watch, as there is an absolute covariance sum of 37.088 bpm^2 in the resting heart rate that increases to 86.446 bpm^2 in the walking segment and then goes further up in jogging and running with an absolute covariance sum of 306 bpm^2 and 511.3 bpm^2, respectively.

Table 2. Watch Trial Covariance Summary

Activity	Watch Trial 1 ((Beats/min)^2)	Watch Trial 2 ((Beats/min)^2)	Watch Trial 1 Part.2 ((Beats/min)^2)	Watch Trial 2 Part. 2 ((Beats/min)^2)	Watch Trial 1 Part. 3 ((Beats/min)^2)	Watch Trial 2 Part. 3 ((Beats/min)^2)	Watch Trial Covariance Total (Beats/(min)^2)
Resting H.R.	NR	0.375	-0.333	1.4	-30.8	4.18	37.088
Walk	NR	52.2	3.28	0.556	26	-4.41	86.446
Rest	NR	0.683	-1.33	4.18	3.13	-0.367	9.69
Jog	NR	206	47.5	10.3	40.4	2.3	306.5
Rest	NR	3.93	10.6	-9.46	-1.73	-1.93	27.65
Run	NR	252	199	12	34.9	13.4	511.3
Rest	NR	13.1	20.4	3.25	-0.08	-2.24	39.07

Table 3 displays a similar trend to Table 1 and 2, albeit more consistently. The sum of each row in Table 3 shows that each portion of the trial, from walking to running, and the rests in-between, maintained progressively larger deviations from the norm. For instance, the sum of the first, topmost row, resting period (59.75 bpm) is considerably less than the next resting period below (84.96 bpm), which is even less than the next (164.82 bpm), and is finally even smaller than the last (227.50 bpm). Similarly, the jogging period (102.64 bpm) hosted a greater sum of deviations than the walking period (77.67 bpm), but less than the running period (176.30 bpm). This shows the intensity of the exercise corresponds to a greater deviation from the standard heart rate, indicating more inaccurate heart rate measures as the intensity of the activity increases.

Table 3. Trial Deviation Summary

	Participant 1 Trial 1 (Beats/min)	Participant 1 Trial 2 (Beats/min)	Participant 2 Trial 1 (Beats/min)	Participant 2 Trial 2 (Beats/min)	Participant 3 Trial 1 (Beats/min)	Participant 3 Trial 2 (Beats/min)	Standard Deviation Total (Beats/min)
Resting H.R.	3.9	3.88	3.1	7.74	6.23	34.9	59.75
Walk	5.16	11	4.74	14.1	8.17	34.5	77.67
Rest	6.26	13.6	2.82	7.18	15.8	39.3	84.96
Jog	9.46	15.9	7.58	13.7	17.2	38.8	102.6
Rest	13.1	24.7	5.62	38.8	29.4	53.2	164,82
Run	16.3	21.3	15	42.2	25.9	55.6	176.3
Rest	31.9	29.2	10.7	49.1	40.9	65.7	227.5

In Table 4, the first point to notice is the great deviation from the norm in all activities, for both compared devices. Likewise, Table 4 visualizes the trend of increasing deviation as the trials progress. The covariance, for both the watch and ring, shows the dissimilarity between the aggregated data and data from the chest monitor.

Table 4: Device Deviation and Covariance per Activity

	Ring STD (Beats/min)	Ring covar ((Beats/min)^2)	Watch STD (Beats/min)	Watch covar ((Beats/min)^2)
Resting H.R.	14.89	169.81	19.82	-29.33
Walk	17.84	203.76	21.65	-1.17
Rest	18.02	104.77	25.57	-97.76
Jog	16.97	34.55	27.86	115.6
Rest	25.83	-34.43	41.16	4.96
Run	20.97	-59.55	44.96	114.31
Rest	31.82	-78.91	48.89	-194.82

In Table 5, the great range of covariance further suggests the unreliability of data comparing the two devices.

Table 5: Device Deviation and Covariance Summary

	mean	median	range
Ring covar ((Beats/min)^2)	48.57	34.55	282.68
Ring st.dev (Beats/min)	20.9	18.02	16.94
Watch covar ((Beats/min)^2)	-12.6	-1.17	310.42
Watch st.dev (Beats/min)	32.84	27.86	29.07

Finally, as Table 6 confirms, the average standard deviation (21.28 bpm) is too great to be considered feasibly acceptable by Z-tests, which deemed 1.96 standard deviation acceptable for 95% confidence in device accuracy given the 675 data points generated per device. Also, median covariance appears insignificant because the covariances were relatively and equally erratic in both the positive and negative trend. This study proved accuracy of HR monitoring devices can vary depending on body placement, with greatest accuracy coming from the chest.

Table 6. Total HR Monitor Performance Field Test Covariance and Deviation

	mean	median	mode	range
covar ((Beats/min)^2)	12.97	1.04	20	356
st.dev (Beats/min)	21.28	15.4	38.8	62.88

Discussion

Implications of Covariance and Standard Deviations

The HR Monitor Performance Field Test compared the smart watch, smart ring, and chest monitor based on performance in a setting where participants were walking, jogging, and running. The resultant standard deviations for the smart watch and smart ring were too high to be considered negligible, indicating that they would not appropriately assess HR when deployed in a construction setting compared to the chest monitor.

Deployment in the Construction Site

Assessing and monitoring construction workers' health in a real-time context is extremely important in preventing safety incidents and health issues. For example, workers with hypertension exposed to high temperatures are at risk of myocardial infarction and heat stroke (Acharya et al., 2018). Utilizing HR monitor devices that track body temperatures, heart rate and blood pressure can reduce the number of costly injuries to the workers and risk to employers.

Additionally, these devices can aid in identifying abnormalities and ensure proper treatment is received. Monitoring systems can be affected by external factors, such as sweat or unorthodox movement due to regular construction activities, causing error in measurements. Hence, error correction processes are important when implementing these devices in the future. Due to the physical nature of monitoring physiological conditions, our field test trial focused on efficacy of the wearable IoT devices only, and no further human-aspect. Human users were used to collect technological data and were not subjected to severe physiological conditions.

Conclusion

Devices monitor parameters such as HR, blood pressure, and EKG that can be worn on various parts of the body. However, not all the devices are feasible for a construction site. Construction environments require devices to be durable, long-lasting, and comfortable, without impeding the worker's ability to perform their job functions. Notable features of the utilized IoT system include near-real-time monitoring, battery power, and IP-based data collection.

The field test is used to determine the accuracy of a smart watch and a smart ring, as compared to a chest monitor. Implications are that IoT-enabled HR monitors may one day provide invaluable health data previously not available for workers in hazardous settings. However, based on the findings from the field test, the chest monitor alone shows HR data accurately. The smart watch and smart ring had covariance and standard deviations that were too high to be considered accurate to be deployed currently in a dynamic construction environment. In conclusion, further development of these products must be made before they can be deployed in such settings.

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References

Acharya, P., Boggess, B., & Zhang, K. (2018). Assessing heat stress and health among construction workers in a changing climate: A review. *International Journal Of Environmental Research And Public Health*, 15(2). 247. https://doi.org/10.3390/ijerph15020247.

Awolusi, I., Nnaji, C., Marks, E., & Hallowell, M. (2019). *Enhancing Construction Safety Monitoring through the Application of Internet of Things and Wearable Sensing Devices: A Review*. 530–538. https://doi.org/10.1061/9780784482438.067

Bathilde, J. B., Then, Y. L., Chameera, R., Tay, F. S., & Zaidel, D. N. A. (2018). Continuous heart rate monitoring system as an IoT edge device. *2018 IEEE Sensors Applications Symposium (SAS)*, 1–6. https://doi.org/10.1109/SAS.2018.8336777

Costin, A., Wehle, A., & Adibfar, A. (2019). Leading indicators—A conceptual IoT-based framework to produce active leading indicators for construction safety. *Safety*, *5*(4), 86.

Jayasree, V., & Kumari, M. N. (2020, July). IOT based smart helmet for construction workers. In 2020 7th International Conference on Smart Structures and Systems (ICSSS) (pp. 1-5). IEEE.

Kim, J. H., Jo, B. W., Jo, J. H., & Kim, D. K. (2020). Development of an IoT-based construction worker physiological data monitoring platform at high temperatures. *Sensors,* 20(19), 5682.

Lee, M., Jeong, J., Jeong, J., & Lee, J. (2021). Exploring Fatalities and Injuries in Construction by Considering Thermal Comfort Using Uncertainty and Relative Importance Analysis. *International Journal of Environmental Research and Public Health*, *18*(11), 5573. https://doi.org/10.3390/ijerph18115573

Mehata, K. M., Shankar, S. K., Karthikeyan, N., Nandhinee, K., & Hedwig, P. R. (2019). IoT Based Safety and Health Monitoring for Construction Workers. *2019 1st International Conference on Innovations in Information and Communication Technology (ICIICT)*, 1–7. https://doi.org/10.1109/ICIICT1.2019.8741478

Sergi, I., Catarinucci, L., Montanaro, T., Colella, R., Shumba, A. T., Del Ferraro, S., Lenzuni, P., & Patrono, L. (2021). An IoT-aware smart system to detect thermal comfort in industrial environments. *2021 6th International Conference on Smart and Sustainable Technologies (SpliTech)*, 1–6. https://doi.org/10.23919/SpliTech52315.2021.9566378

Wang, R., Blackburn, G., Desai, M., Phelan, D., Gillinov, L., Houghtaling, P., & Gillinov, M. (2017). Accuracy of wrist-worn heart rate monitors. *Jama cardiology*, 2(1), 104-106.

Yeo, C. J., Yu, J. H., & Kang, Y. (2020). Quantifying the Effectiveness of IoT Technologies for Accident Prevention. *Journal of Management in Engineering*, *36*(5), 04020054. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000825