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Manufacturing Worker Perceptions of Wearing Ambulatory Inertial Sensors in the Workplace: An Exploratory Cluster Analysis

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Abstract: Wearable technologies such as ambulatory inertial sensors (AISs) are increasingly being used to track measures of well-being while at work and at home. While typically worn on the wrist, AISs secured to the upper arms and torso can provide objective information regarding occupational exposure to physical risk factors (e.g., non-neutral postures, high movement speeds) associated with the development of work-related musculoskeletal disorders. Wearing AISs on the upper arms and torso, however, may be uncomfortable, distracting, and/or burdensome to some workers. This preliminary analysis of a subset of data from a larger study characterized manufacturing worker (n=16) perceptions of discomfort, distraction, and burden associated with using AISs secured to both upper arms, the trunk, and the dominant wrist over 15 production days (240 total observations including 21 imputed values). Participants self-reported the amount of discomfort, distraction, and burden the sensors caused them using a 10cm visual analog scale (VAS) immediately following the completion of each work shift. Workers also rated the "stress" experienced and "force" exerted for work tasks they performed on a 10cm VAS. Full-shift time-weighted averages of the stress and force ratings were calculated using participant-reported daily task logs. Exploratory simple K-Mean clustering was used to explore potential patterns in the data based on the Euclidean distance criterion while considering other factors including Body Mass Index (BMI) and shift duration. Preliminary results indicated that participants did not find wearing the sensors to be uncomfortable, distracting, or burdensome. The group with higher reported levels of discomfort, distraction, and burden tended to report higher levels of job stress and force, as well as had a higher BMI, based on the cluster analysis. Thus, perceived job demands as well as some personal characteristics may be important to consider when implementing AISs at work.

Keywords: Wearable Technology, Inertial Sensors, Musculoskeletal Disorders, Physical Activity

1. Introduction

Manufacturing work is associated with a high risk of injury. The industry had the second highest number of cases and the fifth highest incident rate of nonfatal occupational injuries and illness of all United States industries in 2016 (U.S. Bureau of Labor Statistics, 2017). One of the most concerning issues is the high incidence of musculoskeletal disorders (MSDs). Work-related MSDs are painful and costly adverse health conditions that affect industrial workers. Over 600,000 work-related MSDs occur annually, accounting for approximately one-third of all lost workdays and all work-related injuries and illnesses in the United States from 2011 to 2015 (U.S. Bureau of Labor Statistics, 2016). Employers pay as much as $20 billion a year on direct costs associated with worker's compensation, and up to $100 billion on related indirect costs (OSHA, 2016). The National Occupational Research Agenda (NORA) for manufacturing indicates that research is needed "to quantify the effects of the mechanization of the work environment on risk exposure and on the development of work-related MSDs" (NIOSH, 2018).

Wearable technology systems such as ambulatory inertial sensors (AISs) have the potential to usher a new paradigm for measuring exposure to physical risk factors associated with MSDs into occupational health and safety practice. Despite their great potential, any discomfort, distraction, and burden associated with wearing the sensors may limit their utility and use (Bauer, 2016; Ertin, 2011; Knight, 2005; Rice, 2016). The authors are aware of no research, however, that has evaluated discomfort, distraction, and burden among manufacturing workers wearing AISs for extended time periods (e.g., multiple full-shift recordings). This paper describes a preliminary analysis of a subset of data from a larger study aiming to understand how AISs may be applied to improve manufacturing workplace safety surveillance and reduce workplace injuries and illnesses. Specifically, this sub-analysis aimed to (i) characterize perceived ratings of discomfort, distraction, and burden associated with using AISs for extended durations (i.e., multiple work shifts), and to (ii) explore relationships between worker perceptions with other potentially relevant variables such as perceptions of workplace stress, force exertion, and personal characteristics such as BMI and age.

2. Method

Sixteen workers of a global manufacturer of gasoline engines were recruited to participate in this study. Inclusion criteria included: 1) being 19 to 65 years of age; 2) reporting no history of a physician-diagnosed MSD in the low back, neck/ shoulder, or upper extremity; 3) reporting an absence of chronic low back, neck/shoulder, or upper extremity pain during the previous 14 days; and 4) reporting no history of a physician-diagnosed neurodegenerative disorder that may affect movement (e.g. Parkinson's Disease, multiple sclerosis, etc.). Subjects provided written informed consent. All study procedures were approved by the Auburn University Institutional Review Board.

Participants wore four ActiGraph GT9X Link AISs (ActiGraph, Pensacola, Florida, USA) wrapped in coban and secured via elastic straps over 15 production days while they completed their work. One device was secured to the sternum near the xyphoid process. One device was secured to the lateral aspect of each upper arm halfway between the lateral epicondyle and the acromion. Finally, one device was worn on the dominant wrist. Each participant was asked to record the number of hours he/she spent performing each of the tasks that were required by his/her job in a daily log. Workers rated the "stress" experienced and "force" exerted for each work task they performed on a 10 cm visual analog scale (VAS). Verbal anchors of "not at all stressful" or "no force" were attributed to a score of 0, while a score of 10 represented "very stressful" or "max force". At the end of the work shift, participants recorded the amount of discomfort, distraction, and burden the sensors caused them using a 10 cm VAS. Verbal anchors of "completely comfortable" or "no distraction" or "no burden" were attributed to a score of 0, while a score of 10 represented the devices being "as uncomfortable as possible", a "complete distraction", or "as burdensome as possible". A research assistant measured each rating using a ruler and full-shift time-weighted averages of the stress and force ratings were calculated based on the task-based logs. Missing values were imputed using the single imputation method.

An unsupervised learning K-means clustering approach (in Weka 3.8.0) was used to explore potential patterns in the data based on the Euclidean distance criterion (Berkhin, 2006; Palamara, 2011). The procedural steps used for clustering in this study included: establishing clusters and vectors being randomly chosen from the data set and forming temporary cluster centroids. Distances between the centroids and the vectors of the dataset were calculated and associations of each vector to its nearest centroid were assigned. After assigning all data sets, new cluster centroids were calculated based on Eq. (1):

$$c_i = \frac{1}{m_i} \sum_{j=1}^{m_i} x_{ji} \tag{1}$$

Where c_i is the centroid of cluster C_i; m_i is the number of x_j data gathered in cluster C_i. The process was iterated until no change for the centroids was present.

3. Preliminary Results

A total of 240 observations (including 21 imputed values) were considered. The average shift duration was 8.4 ± 0.6 hours. The average BMI was 32.6 ± 6.5 kg/m^2. In general, self-reported stress (1.8 ± 2.0) and force (1.8 ± 2.1) experienced at work was low. The mean discomfort rating (0.9 ± 1.3) each day exceeded that of distraction (0.8 ± 1.3), which exceeded burden (0.7 ± 1.0). However, all ratings were low. A slight decreasing trend was observed over the 15 days (Figure 1), suggesting that participants may have become more used to wearing the devices over time.

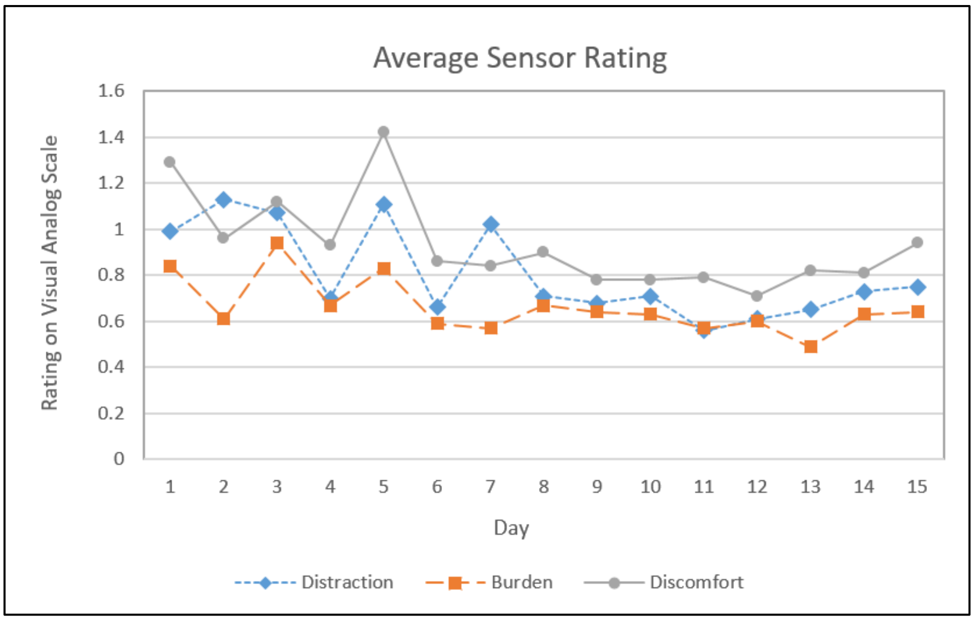

Figure 1. Average Sensor Rating Over 15 Days

A correlation table was generated to investigate the relationship between factors (Table 1). The results indicated that only work duration on each day was negatively correlated with discomfort and distraction. All other factors were positively correlated with discomfort, distraction, and burden. For instance, increasing BMI was correlated with discomfort. In addition, results indicate that discomfort, distraction and burden were all positively correlated with each other.

Table 1. Correlations among Factors

	Duration	Stress	Force	Distraction	Burden	Discomfort	BMI
Stress	-0.14 *						
Force	-0.15 *	0.93 *					
Distraction	-0.17 *	0.45 *	0.42 **				
Burden	-0.12	0.54 **	0.50 **	0.85 **			
Discomfort	-0.30 **	0.44 **	0.42 **	0.70 **	0.70 **		
BMI	-0.42 **	0.35 **	0.35 **	0.50 **	0.47 **	0.50 **	

* $p < 0.05$; ** $p < 0.001$

A separate cluster analyses was conducted for each sensor rating of discomfort, distraction, and burden, with two clusters generated for each analysis. In general, approximately 25% of the observations were clustered into a "high" discomfort, distraction, or burden rating group. The remaining observations were clustered into a "low" discomfort, distraction, or burden rating group. The high discomfort rating group tended to report more job stress and exerted force as well as a higher BMI in comparison to the low discomfort group (Table 2). A visualized example of the clustering is depicted in Figure 2 for discomfort and stress. The cluster results for distraction and burden showed similar trends. The high distraction or burden rating group reported higher levels of job stress and force as well as had a higher BMI.

Table 2. Cluster Results for Discomfort

	Duration		Stress		Force		BMI		Discomfort	
Cluster	High	Low	High	Low	High	Low	High	Low	High	Low
Mean	8.34	8.44	4.79	0.72	4.71	0.77	36.50	31.22	1.94	0.56
Median	8.25	8.39	4.40	0.50	4.25	0.60	38.39	30.65	1.35	0.20
Standard Deviation	0.63	0.62	1.43	0.70	1.82	0.68	8.28	5.01	1.66	0.89
Minimum	6.99	5.17	2.60	0.00	1.50	0.00	25.82	24.39	0.25	0.00
Maximum	9.46	9.42	8.00	3.90	8.80	4.50	49.91	49.91	7.80	4.05

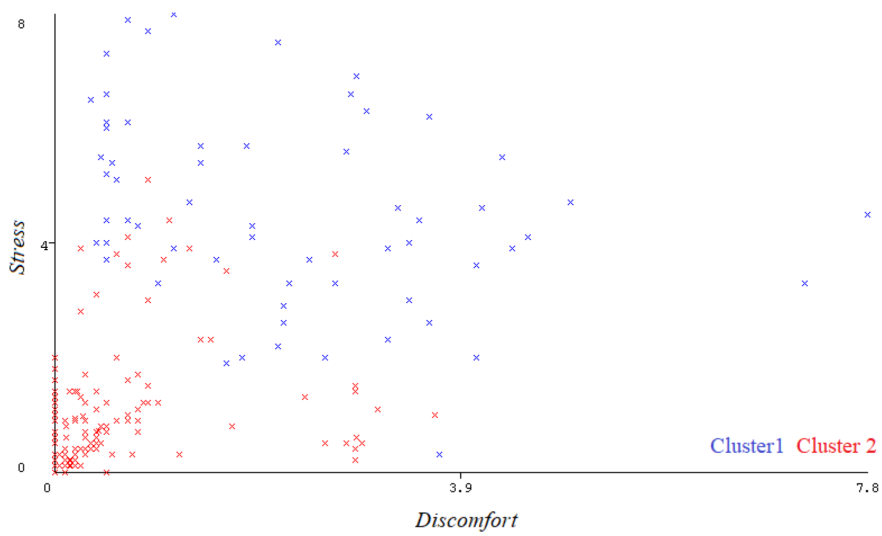

Figure 2. Clustering of Discomfort and Stress

4. Discussion

The results of this preliminary analysis suggest that manufacturing workers generally reported minimal ratings of discomfort, distraction, and burden when wearing sensors on their trunk, upper arms, and wrist across several weeks of full-shift work for occupational exposure assessment purposes. That is not to suggest that high levels of discomfort, distraction, and burden did not occur occasionally. Inconsistent sensor ratings from the same subject on different days might have been due to a reassigned job position or task content variability. Comments provided by the workers for high ratings included frustration from sensor straps loosening and slipping and irritating Velcro connections. Ratings of discomfort, distraction, and burden were positively correlated with each other. This result implies that if wearable sensors make a user feel uncomfortable, the user may be more likely to report the devices as distracting and burdensome. When considering application of wearable sensors in the working environment, the results of the cluster analysis suggest that factors such as discomfort, distraction, and burden should not be considered independently. It is important to understand the nature of users' job positions, task assignments and the characteristics among different workers.

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A limitation of this study was that the survey only asked for a general rating of discomfort, distraction, and burden for all four sensors worn on different body locations at the same time. Further research should request more detailed ratings regarding the sensor secured to the different body segments. Such an analysis may help researchers and practitioners decide which body location would be preferable for certain variables of interest. Another limitation is that only self-reported ratings of job stress and job force were considered. Posture data and other biometric variables collected using the sensor data will be included in future cluster analyses. Interesting questions such as whether subjects with higher percentages of times in extreme postures report greater discomfort, distraction, and burden will be possible with this additional data. Finally, it is possible that subjects with more positive opinions of wearable technologies were more likely to participate. Workers who may have had negative experiences using wearable technologies in the past, for example, may not have been interested in participating in this study given their previous experiences. Further research may investigate perceived ratings of wearable technologies among workers before using them in the workplace. Overall, further insights will be gained as additional data is collected and analyzed for the larger study.

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