# A. COVER PAGE

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|---|---|
| **Project Title:** Reliability Modeling of Shoulder Fatigue and Recovery for Warehouse Operators Performing Dynamic Tasks | |
| **Grant Number:** 5R21OH011749-02 | **Project/Grant Period:** 09/30/2020 - 09/29/2022 |
| **Reporting Period:** 09/30/2021 - 09/29/2022 | **Requested Budget Period:** 09/30/2021 - 09/29/2022 |
| **Report Term Frequency:** Final | **Date Submitted:** 12/21/2023 |
| **Program Director/Principal Investigator Information:**<br>LORA ANNE CAVUOTO , PHD MS MS BS<br><br>**Phone Number:** 7166454696<br>**Email:** loracavu@buffalo.edu | **Recipient Organization:**<br>STATE UNIVERSITY OF NEW YORK AT BUFFALO<br>STATE UNIVERSITY OF NEW YORK AT BUFFALO Sponsored Projects Services, 520 Lee Entrance<br>AMHERST, NY 142282567<br><br>**DUNS:** 038633251<br>**UEI:** LMCJKRFW5R81<br>**EIN:** 1146013200F6<br><br>**RECIPIENT ID:** |
| **Change of Contact PD/PI:** NA | |
| **Administrative Official:**<br>BRIAN LEW<br>UB Commons Suite 211<br>Buffalo, NY 14228<br><br>**Phone number:** 17166454401<br>**Email:** belew@buffalo.edu | **Signing Official:**<br>BRIAN LEW<br>UB Commons Suite 211<br>Buffalo, NY 14228<br><br>**Phone number:** 17166454401<br>**Email:** belew@buffalo.edu |
| **Human Subjects:** NA | **Vertebrate Animals:** NA |
| **hESC:** No | **Inventions/Patents:** No |

# B. ACCOMPLISHMENTS

## B.1 WHAT ARE THE MAJOR GOALS OF THE PROJECT?

The objectives of the current work are to (1) determine the effects of warehouse task conditions on shoulder fatigue, and (2) provide a novel model that accurately predicts fatigue development and recovery in the evolving warehouse industry by reflecting the new occupational task parameters affecting workers. It is hypothesized that fatigue and recovery can be modeled based on worker characteristics and the task conditions using reliability theory models. To test this hypothesis, we propose the following aims:

Aim 1: Model the fatigue development and recovery processes for functional upper extremity tasks (with different load and repetition requirements) for one fatigue-recovery cycle. Male and female workers from industry will perform simulated shoulder-intensive warehousing tasks that incorporate the range of physical demands of typical order picking, which will be followed by a recovery period. Multiple measures (including subjective ratings, kinematics, and task performance measures) will be collected and synthesized into a unified fatigue outcome. This fatigue outcome will then be modeled as a function of working conditions, characteristics of the worker, and time using degradation models. Hypothesis 1.1: Fatigue development will be task dependent; Hypothesis 1.2: Rate of recovery will be dependent on the starting fatigue level; Hypothesis 1.3: Fatigue and recovery can be modeled as degradation processes from reliability theory

Aim 2: Evaluate the influence of repeated fatigue and recovery cycles on the developed models. Each warehousing task will be performed for four repeated cycles of work and rest. The fatigue and recovery processes will be modeled as degradation/inverse degradation processes over multiple cycles. Here, we will examine if, as the number of cycles increases: (a) fatigue accumulation increases, indicating that the fatigue cycles are not independent and identically distributed, and (b) recovery has diminishing returns. Hypothesis 2: The rate of fatigue will increase and the rate of recovery will decrease over repeated cycles

Aim 3: Validate the developed models through field testing. The models from Aims 1 and 2 will be used to evaluate eight workers each for three order picking tasks in a warehouse. Assessment will be based on the degree of agreement between the model predictions and operators' subjective ratings. Depending on the agreement between the lab and field, the models can be either directly used (validated with statistical test), or tuned to the field by domain adaptation and missing data imputation if needed.

## B.1.a Have the major goals changed since the initial competing award or previous report?

No

## B.2 WHAT WAS ACCOMPLISHED UNDER THESE GOALS?

File Uploaded : Accomplishments.pdf

## B.3 COMPETITIVE REVISIONS/ADMINISTRATIVE SUPPLEMENTS

**For this reporting period, is there one or more Revision/Supplement associated with this award for which reporting is required?**

No

## B.4 WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?

File Uploaded : B4 - Training Opportunities - Final Report.pdf

**B.5 HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?**

NOTHING TO REPORT

**B.6 WHAT DO YOU PLAN TO DO DURING THE NEXT REPORTING PERIOD TO ACCOMPLISH THE GOALS?**

Not Applicable

## Accomplishments

### *Major Activities*

As planned, an in-lab experimental study was conducted to generate the dataset from which the models for Aims 1 and 2 were built. First, a simulated parts to person warehouse setup was built, including a warehouse shelving unit with return conveyors. With the shelving unit in place, pilot testing of the experimental conditions occurred to identify the combinations of picking pace and bottle weight. Bottles were selected based on comfortable handling. It was determined to use 2 bottle weights – 1.5 kg and 2.5 kg – and 3 picking paces – 5 bottles/min (bpm), 10 bpm, and 15 bpm. Due to lab safety requirements imposed by pandemic restrictions, a within subjects study design was selected, with all participants completing 4 sessions, one at each condition of: 1.5kg/15bpm, 2.5kg/5bpm, 2.5kg/10bpm, and 2.5kg/15bpm. Seventeen participants were recruited and 14 completed all four conditions. Each completed session included three 45-minute work periods separated by 15-minute rest periods. The work periods involved picking weighted bottles from shoulder height and packaging them at waist height. Participants reported their RPEs every 5 min and performed a maximum isometric shoulder flexion exertion every 9 min. They were also instrumented with a heart rate monitor and inertial measurement units on the wrist, upper arm, and trunk. The data generated was then used for modeling fatigue and recovery to address the specific objectives. Reliability modeling incorporating the sensor data on participant kinematics continues to identify whether we can advance upon the achieved results described below.

### *Specific Objectives and Significant Results*

Aim 1: Model the fatigue development and recovery processes for functional upper extremity tasks for one fatigue-recovery cycle. Hypotheses: Fatigue development will be task dependent; Rate of recovery will be dependent on the starting fatigue level; Fatigue and recovery can be modeled as degradation processes from reliability theory.

Pearson product-moment correlation was used to evaluate the linear relationship between RPE and relative strength for each subject and work period. For the first 45-min period, there were no significantly different correlations between RPE and relative strength across conditions (average $r = -0.62$ (standard deviation = 0.38); $p = 0.57$). Most individual correlations were significant for the first work period (30 out of 56 correlations), particularly for the 1.5kg-15bpm condition (10 out of 14 participants). Across sessions, the average starting strength ranged from 64.1 to 67.4 N for the first work period and from 58.8 to 61 N for the second work period. Thus, participants returned to ~90% of their baseline strength following the rest period.

The lack of statistical differences in the correlations across conditions extends previous findings that focused on controlled isometric or isokinetic tasks. Thus, based on this experimental setup, the answer to the second research question is that the relationship between RPE and strength loss remained the same for the specific task conditions considered. However, from a practical perspective, it is important to note that the strength of the linear relationship was only moderate, and thus there may not be sufficient support for the suitability of using RPE in lieu of strength change measurement for such dynamic order picking tasks. While linear relationships between perceived exertion/fatigue and fatigue accumulation have been reported in the literature for varying sustained and intermittent static tasks, the relationship may vary depending on the nature of the task, supporting the need for investigation into a wider range of task parameters.

Based on this finding, we evaluated additional statistical approaches for understanding fatigue development during these dynamic tasks. A functional analysis of variance (FANOVA) was executed as the principal analytical approach, considering the functional nature of the two fatigue indicators measured over the work period. FANOVA outcomes affirm that both task factors, load, and pace, significantly influence both fatigue indicators. Remarkably, FANOVA's efficacy in identifying the significance of these factors surpassed that of repeated-measures ANOVA and two-way ANOVA in all but one instance. The FANOVA approach proved its effectiveness in detecting the impact of task factors on fatigue indicators, yielding superior results compared to conventional benchmark methods. To address participant heterogeneity, functional clustering and gender-based clustering were introduced into the FANOVA framework, both effectively mitigating this challenge. Notably, gender clustering demonstrated comparable outcomes to functional clustering, presenting a pragmatic alternative for practitioners in field experiments.

Aim 2: Evaluate the influence of repeated fatigue and recovery cycles on the developed models. Hypothesis: The rate of fatigue will increase and the rate of recovery will decrease over repeated cycles.

From the correlation analysis, there was a significant decrease in average correlation for the second work period ($r = -0.39$ (0.53)). The weakest average correlations were observed for the 2.5 kg-5 bpm and 1.5 kg-15 bpm conditions. These results suggest that individual subjective responses consistently increase while relative strength declines when starting from a non-fatigued state. However, correlations were weaker when re-engaging in work following incomplete recovery. The results showed that the initial RPE at the start of the second work period of ~1.5 was higher than the RPE of ~ 0.1 at the start of the first period. Hence, the participants' RPE did not reset to baseline for the second time period. Similarly, the participants' MVIC strength did not reset following the rest period. Thus, starting fatigue levels should be accounted for when considering the expected relationship between RPE and relative strength.

The time course of ratings of perceived exertion were then fitted with a recurrence model. The initial work cycle was described using an exponential function with a fully rested initial energy. Terms were defined for the decay rate, the energy boost gained from rest, and the expected time to full fatigue. The results showed the high potential of this model in fitting the data. Repeated measures analysis of variance showed significant differences in parameters across the periods. From these findings it was identified that fatigue accumulated over the three periods and that the time to fatigue was shorter for the faster work rates, but that the rate of fatigue development did not differ by condition or period.

***Key Outcomes***

To date, six manuscripts have been published based on this project. One paper is under revision following review, and two are under preparation. Nine presentations have been made to disseminate the work, with three additional conference abstracts submitted with planned presentations during 2024. The audiences for these presentations include industry representatives, ergonomists, industrial engineers, and human factors researchers.

**Opportunities for Training and Professional Development**

Four PhD students and four undergraduate students worked with the PI and Co-Is on the project. These students have worked one-on-one with the faculty and as a group on the experimental study setup, data collection, and analysis. They have participated in regular group meetings and attended conferences related to industrial engineering, ergonomics, and safety.

**Saeb Ragani Lamooki:** PhD graduate
Saeb led the preliminary analysis, pilot experimental testing, and data collection under the mentorship of Dr. Cavuoto. He is a co-author on 4 peer-reviewed journal publications that were supported by the project. He also co-authored an abstract for the International Ergonomics Association Conference that took place in 2021.

**Sahand Hajifar:** PhD graduate
Sahand worked under the mentorship of Dr. Sun on the background for the implementation of the reliability analysis models. He also worked under the mentorship of Dr. Cavuoto. He is a co-author on 4 peer-reviewed journal publications that were supported by the project and an abstract presented at the International Ergonomics Association conference in Summer 2021. He was awarded a Pilot Project Research Training (PPRT) Grant from the NY/NJ ERC to support an extension of this work and for professional development. He presented his work at the INFORMS and IISE Annual Meetings, and participated in the IISE Doctoral Colloquium.

**Zahra Vahedi:** PhD student
Zahra has been mentored by Dr. Cavuoto during the project. She initially focused on the data collection, and then worked on understanding the implications of the findings. She took a graduate-level course on Human Factors Laboratory Methods to support her development of the skillset for wearable sensor data collection and analysis. She has co-authored 2 papers. In Fall 2023, she attended the Human Factors and Ergonomics Society Annual Meeting.

**Setareh Kazemi Kheiri:** PhD student
Setareh has been mentored closely by Dr. Sun on the analysis of the experimental data, learning new statistical methods that are relevant to the complex data for this project. She has also received one-on-one mentoring from Drs. Cavuoto and Megahed with regards to ergonomics fundamentals and R programming. She has recently received a PPRT grant from the NY/NJ ERC to expand the project to focus on privacy-preservation in the use of wearable sensor data. She has presented her research work at the INFORMS Annual Meeting.

**Martin Bustamante:** BS graduate
As part of his senior capstone course, Martin worked under the mentorship of Dr. Cavuoto and Dr. Megahed. He completed training in R programming and data analytics. This was applied to preliminary data analysis for the experimental study. He is now employed at Amazon as a workplace health and safety specialist.

**Sonjii Parris:** BS graduate
For an undergraduate research course, Sonjii worked under the mentorship of Dr. Cavuoto on the development and testing of the experimental conditions. She also participated in the project during the summer as part of the Louis Stokes Alliances for Minority Participation.

**Linh Tran:** BS graduate
Linh recently graduated from Miami University. She received mentoring from Dr. Megahed including topics related to advanced statistical methods and R programming.

**Yusuf Ozdemir:** BS student
Yusuf worked on an independent study under the mentorship of Dr. Megahed with support from Dr. Cavuoto. Over the course of the project, he completed an analysis of the sensor data for predicting fatigue level. He learned machine learning methods and sensor feature analysis. He is now working on a manuscript for the work.

# C. PRODUCTS

## C.1 PUBLICATIONS

**Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, monograph) during the reporting period resulting directly from this award?**

Yes

**Publications Reported for this Reporting Period**

| Public Access Compliance | Citation |
|---|---|
| N/A: Not NIH Funded | Hajifar S, Lamooki SR, Cavuoto LA, Megahed FM, Sun H. Investigation of Heterogeneity Sources for Occupational Task Recognition via Transfer Learning. Sensors (Basel, Switzerland). 2021 October 8;21(19). PubMed PMID: 34641001; PubMed Central PMCID: PMC8512259; DOI: 10.3390/s21196677. |
| N/A: Not NIH Funded | Ragani Lamooki S, Hajifar S, Hannan J, Sun H, Megahed F, Cavuoto L. Classifying tasks performed by electrical line workers using a wrist-worn sensor: A data analytic approach. PloS one. 2022;17(12):e0261765. PubMed PMID: 36490294; PubMed Central PMCID: PMC9733853; DOI: 10.1371/journal.pone.0261765. |
| N/A: Not NIH Funded | Lamooki SR, Hajifar S, Kang J, Sun H, Megahed FM, Cavuoto LA. A data analytic end-to-end framework for the automated quantification of ergonomic risk factors across multiple tasks using a single wearable sensor. Applied ergonomics. 2022 July;102:103732. PubMed PMID: 35287084; DOI: 10.1016/j.apergo.2022.103732. |
| N/A: Not NIH Funded | Schall MC Jr, Chen H, Cavuoto L. Wearable inertial sensors for objective kinematic assessments: A brief overview. Journal of occupational and environmental hygiene. 2022 September;19(9):501-508. PubMed PMID: 35853137; DOI: 10.1080/15459624.2022.2100407. |
| N/A: Not NIH Funded | Kazemi Kheiri S, Vahedi Z, Sun H, Megahed FM, Cavuoto LA. Human reliability modeling in occupatinoal environments toward and safe and productive operator 4.0. International Journal of Industrial Ergonomics. 2023;97:103479. DOI:. |
| N/A: Not NIH Funded | Vahedi Z, Kazemi Kheiri S, Hajifar S, Ragani Lamooki S, Sun H, Megahed FM, Cavuoto LA. The relationship between ratings of perceived exertion (RPE) and relative strength for a fatiguing dynamic upper extremity task: A consideration of multiple cycles and conditions. Journal of occupational and environmental hygiene. 2023 March;20(3-4):136-142. PubMed PMID: 36799881; DOI: 10.1080/15459624.2023.2180512. |

## C.2 WEBSITE(S) OR OTHER INTERNET SITE(S)

NOTHING TO REPORT

## C.3 TECHNOLOGIES OR TECHNIQUES

NOTHING TO REPORT

## C.4 INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

**Have inventions, patent applications and/or licenses resulted from the award during the reporting period?** No

**If yes, has this information been previously provided to the PHS or to the official responsible for patent matters at the grantee organization?** No

## C.5 OTHER PRODUCTS AND RESOURCE SHARING

| Category | Explanation |
|---|---|
| Data or Databases | https://github.com/Setareh-Kazemi/Setareh-Kazemi.github.io/tree/main/functional_anova |
| Data or Databases | https://github.com/Setareh-Kazemi/Setareh-Kazemi.github.io/tree/main/functional_regression |
| Research Material | “The Intersection of Ergonomics with Wearable Sensors and Data-Driven Decision Making”, Fleet Safety Leadership Council, August 2022 |
| Research Material | “Roundtable: Implementing Wearables”, IISE Applied Ergonomics Conference, March 2022 |
| Research Material | INFORMS Annual Conference, “Explaining the Variability in the Profiles of Ratings of Perceived Exertion for a Dynamic Upper Extremity Task: A Functional Regression Approach”, Oct. 2023, Phoenix, AZ |
| Research Material | INFORMS Annual Conference, “Analysis of Upper-body Fatigue during Warehouse Worker Material Handling”, Oct. 2022, Indianapolis, IN |
| Research Material | IISE Annual Conference, “Analysis of Occupational Worker Fatigue and Risk”, May 2022, Seattle, WA |
| Research Material | Armstrong, D. P., Moore, C. A., Cavuoto, L. A., Gallagher, S., Lee, S., Sonne, M. W., & Fischer, S. L. (2021, June). Advancing Towards Automated Ergonomic Assessment: A Panel of Perspectives. In Congress of the International Ergonomics Association (pp. 585-591). Springer, Cham. |
| Research Material | “Operator 4.0 and the Intersection of Human Factors and Ergonomics with Sensing and Data-Driven Decision Making”, Department of Industrial and Systems Engineering, Wayne State University, March 2021 |
| Research Material | “Work-to-Zero: Introduction to Fatigue in the Workplace & Detection Technology to Save Lives”, National Safety Council, May 2021 |
| Research Material | “Strategies for Identifying and Monitoring Fatigue in the Workplace”, Puget Sound Human Factors and Ergonomics Society Summit, October 2021 |

# D. PARTICIPANTS

## D.1 WHAT INDIVIDUALS HAVE WORKED ON THE PROJECT?

| Commons ID | S/K | Name | Degree(s) | Role | Cal | Aca | Sum | Foreign Org | Country | SS |
|---|---|---|---|---|---|---|---|---|---|---|
| LCAVUOTO | Y | Cavuoto, Lora Anne | BS,MS,MS,PHD | PD/PI | 0.0 | 0.3 | 0.3 | | | NA |
| HONGYUESUN | N | Sun, Hongyue | PhD | Co-Investigator | 0.0 | 0.3 | 0.0 | | | NA |
| | N | Hajifar, Sahand | | Graduate Student (research assistant) | 2.7 | 0.0 | 0.0 | | | NA |
| | N | Kazemi Kheiri, Setareh | MS | Graduate Student (research assistant) | 1.4 | 0.0 | 0.0 | | | NA |
| | N | Houle, Joshua Kennedy | | Undergraduate Student | 0.2 | 0.0 | 0.0 | | | NA |
| | N | Vahedi, Zahra | MS | Graduate Student (research assistant) | 2.0 | 0.0 | 0.0 | | | NA |

**Glossary of acronyms:**
S/K - Senior/Key
Cal - Person Months (Calendar)
Aca - Person Months (Academic)
Sum - Person Months (Summer)

Foreign Org - Foreign Organization Affiliation
SS - Supplement Support
RS - Reentry Supplement
DS - Diversity Supplement
OT - Other
NA - Not Applicable

## D.2 PERSONNEL UPDATES

### D.2.a Level of Effort

Not Applicable

### D.2.b New Senior/Key Personnel

Not Applicable

### D.2.c Changes in Other Support

Not Applicable

### D.2.d New Other Significant Contributors

Not Applicable

### D.2.e Multi-PI (MPI) Leadership Plan

Not Applicable

# E. IMPACT

**E.1 WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES?**

Not Applicable

**E.2 WHAT IS THE IMPACT ON PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES THAT FORM INFRASTRUCTURE?**

NOTHING TO REPORT

**E.3 WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER?**

Not Applicable

**E.4 WHAT DOLLAR AMOUNT OF THE AWARD'S BUDGET IS BEING SPENT IN FOREIGN COUNTRY(IES)?**

NOTHING TO REPORT

# G. SPECIAL REPORTING REQUIREMENTS SPECIAL REPORTING REQUIREMENTS

## G.1 SPECIAL NOTICE OF AWARD TERMS AND FUNDING OPPORTUNITIES ANNOUNCEMENT REPORTING REQUIREMENTS

NOTHING TO REPORT

## G.2 RESPONSIBLE CONDUCT OF RESEARCH

Not Applicable

## G.3 MENTOR'S REPORT OR SPONSOR COMMENTS

Not Applicable

## G.4 HUMAN SUBJECTS

### G.4.a Does the project involve human subjects?

Not Applicable

### G.4.b Inclusion Enrollment Data

File(s) uploaded:
CumulativeInclusionEnrollmentReportFinal.pdf

### G.4.c ClinicalTrials.gov

**Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?**

## G.5 HUMAN SUBJECTS EDUCATION REQUIREMENT

NOT APPLICABLE

## G.6 HUMAN EMBRYONIC STEM CELLS (HESCS)

**Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?**

No

## G.7 VERTEBRATE ANIMALS

Not Applicable

## G.8 PROJECT/PERFORMANCE SITES

Not Applicable

## G.9 FOREIGN COMPONENT

No foreign component

## G.10 ESTIMATED UNOBLIGATED BALANCE

Not Applicable

## G.11 PROGRAM INCOME

Not Applicable

## G.12 F&A COSTS

Not Applicable

# Cumulative Inclusion Enrollment Report

**This report format should NOT be used for collecting data from study participants.**

**Study Title:** Reliability Modeling of Shoulder Fatigue and Recovery for Warehouse Operators Performing Dynamic Tasks

**Comments:**

| Racial Categories | Ethnic Categories | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | Not Hispanic or Latino | | | Hispanic or Latino | | | Unknown/Not Reported Ethnicity | | | |
| | Female | Male | Unknown/ Not Reported | Female | Male | Unknown/ Not Reported | Female | Male | Unknown/ Not Reported | |
| American Indian/ Alaska Native | | | | | | | | | | 0 |
| Asian | | | | | | | | | | 0 |
| Native Hawaiian or Other Pacific Islander | | | | | | | | | | 0 |
| Black or African American | | | | | | | | | | 0 |
| White | | | | | | | | | | 0 |
| More Than One Race | | | | | | | | | | 0 |
| Unknown or Not Reported | 8 | 9 | | | | | | | | 17 |
| **Total** | **8** | **9** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **17** |

# I. OUTCOMES

**I.1 What were the outcomes of the award?**

Many occupational environments require labor intensive activities, which could result in fatigue and injuries and cause decreased work performance. Recently, the breakthroughs of Industry 4.0 have allowed for monitoring worker conditions through the use of wearable sensors. A systematic literature review conducted as part of this project identified that previous models of worker fatigue lack the consideration of several important aspects of upper limb fatigue analysis, such as the full use of motion data in a time series manner, consideration of the heterogeneity of workers and measurement devices, and the difference between simulated and actual work environment.

In this project, we conducted a laboratory experiment and collected data from individuals performing simulated ordering picking, moving bottles from shoulder height to waist level, for three hours at four different pace and bottle weight combinations. During the three-hour task, participants completed three 45-minute work periods separated by 15-minute rest periods.

The main findings include:
- For the first 45-minute work period, the average correlations between perceived exertion and strength change were equivalent across conditions. This extends previous findings from controlled isometric or isokinetic tasks to this less controlled dynamic one.
- Participants returned to ~90% of their baseline strength following the first rest period. The starting perceived exertion level did not reset to baseline following rest. After this, correlations were weaker when re-engaging in the work task. Thus, starting fatigue levels should be accounted for when considering the expected relationship between perceived exertion and strength change.
- A functional approach was effective in detecting the impact of task factors, pace and load, on fatigue indicators. We also explored the use of the functional relationships of kinematic features and fatigue outcomes for more accurate fatigue identification. These methods support our understanding of the time course of fatigue development and recovery for the upper extremity.
- The use of wearable sensors was investigated for automating ergonomic risk assessment. We showed that, with a motion sensor worn on the wrist, we could achieve >90% accuracy for task identification, ~7% error rate for estimating task duration, and ~7% error for counting task repetitions. This supports the utility of the framework for estimating important risk factors, particularly when accompanied with knowledge of task loads.