This month, we highlight two articles from *IISE Transactions on Healthcare Systems Engineering* (Volume 15, No. 2). In the first paper, researchers sought to solve issues of cognitive fatigue in demanding environments to improve safety and productivity. They conducted an experiment in which participants were monitored for cardiac activity, performance and fatigue perception levels while engaged in a cognitively tiring activity. The data allowed machine learning algorithms to build forecasting models to predict performance and perceived fatigue. The study represents a step toward identifying the predictors of cognitive fatigue by using wearables. The second article features a research team introducing a methodology to detect lethal disease combinations in patient populations by analyzing large-scale electronic health records from more than 10 million patients. It revealed how certain disease combinations create significantly higher mortality risks, alerting physicians for high-risk conditions and allowing public health officials to target prevention strategies. The use of analytical tools applied to electronic health records can enable real-time risk assessment for patient comorbidities.

Theodora Chaspari

Rohith Karthikeyan

Ranjana Mehta

David Nartey

How wearables and machine learning could advance cognitive fatigue forecasting

In a rapidly accelerating world, there is a constant demand for mental resources, which may lead to cognitive fatigue due to sustained mental effort. Cognitive fatigue poses a threat to safety, productivity, and decision-making. In high-risk and cognitively demanding environments, the ability to anticipate the onset of fatigue could be crucial to prevent injuries and optimize performance.

This opportunity led fatigue researchers from the NeuroErgonomics Lab at the University of Wisconsin-Madison and Texas A&M University, and a computer scientist from the University of Colorado Boulder, to seek possible solutions to this phenomenon.

Current and former students from the NeuroErgonomics Lab, David Nartey and Rohith Karthikeyan, and Ranjana Mehta, lab director and the Grainger Institute for Engineering Professor at UW-Madison, investigated whether cardiac signals, specifically heart rate variability, could be used to forecast fatigue. In collaboration with Theodora Chaspari, an associate professor in Computer Science and Institute of Cognitive Science at UC Boulder, the team investigated the difference in accuracy between personalized and generalized machine learning models, and that between performance and fatigue perception-labeled models.

An experiment was conducted where participants completed a cognitively fatiguing task while their cardiac activity, performance and fatigue perception levels were monitored. Using interpretable machine learning algorithms, forecasting models were generated for both performance and perceived fatigue over 10 and 20 minutes. The findings showed that performance-labeled models were more accurate than fatigue perception labels, and personalized models also outperformed generalized ones.

These findings aligned with the neurovisceral integration model, which links cardiac activity to the prefrontal cortex during a working memory task via the vagus nerve, and the difference in fatigue manifestation among different individuals.

Feature importance analysis demonstrated that heart rate variability measures such as sample entropy, ratio of Standard Deviation-Poincaré, coefficient of variation of peak-to-peak intervals and low frequency were among the strongest predictors of cognitive fatigue-induced performance decline. These features highlight the need for most wearables to measure these features accurately to aid in forecasting cognitive fatigue accurately.

This study represents a step toward real-time cognitive forecasting systems that can identify predictors of cognitive fatigue using wearables to proactively alert users before the onset of fatigue-induced performance degradation.

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Uncovering deadly disease clusters through health data analytics

Numerous studies have demonstrated that when patients suffer multiple diseases simultaneously, i.e., comorbidities, their risk of death can increase dramatically. The work in "Identifying Most Lethal Cliques in Disease Comorbidity Graphs," was led by doctoral student Parisa Vaghfi Mohebbi and advisor Baski Balasundaram from the School of Industrial Engineering and Management at Oklahoma State University, and collaborators Yajun Lu. Ph.D., Jacksonville State University; Zhuqi Miao, Ph.D., SUNY New Paltz; Pankush Kalgotra, Ph.D., Auburn University; and Ramesh Sharda, Ph.D., Oklahoma State University. It introduces a methodology to detect lethal disease combinations in patient populations by analyzing large-scale electronic health records.

Our mathematical optimization framework models co-occurrences of diseases prevalent in a patient population recorded in electronic health records as a comorbidity graph. It uses mixed-integer programming and specialized clique enumeration algorithms to systematically identify disease clusters corresponding to high mortality rates in the patient population. We analyzed de-identified electronic health records from over 10 million patients made available to us by the Center for Health Systems Innovation at Oklahoma State University to reveal how certain disease combinations create significantly higher mortality risks than their individual effects would suggest.

The potential clinical applications of this framework are particularly valuable. Physicians could receive alerts when patients present with validated high-risk comorbidities and be proactive in providing care. Hospital systems might use these insights to prioritize care coordination efforts to reduce the likelihood of a patient being afflicted by a high mortality rate cluster of diseases.

Our approach also provides insights that public health officials can use to design targeted prevention strategies. While doctors would be aware of problematic comorbidities from experience, our approach enables systematic analysis of large-scale medical data for identifying such dangerous comorbidities, confirming known risks and potentially uncovering less obvious ones that deserve clinical attention.

As electronic health records become more comprehensive, such analytical tools will enable real-time risk assessment, helping clinicians identify which patients need immediate intervention and which disease interactions deserve prioritized clinical research attention.

From left, Zhuqi Miao, Baski Balasundaram, Parisa Vaghfi Mohebbi, Yajun Lu.

Pankush Kalgotra, left, and Ramesh Sharda.

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IISE Transactions (link.iise.org/iisetransactions) is IISE's flagship research journal and is published monthly. It aims to foster exchange among researchers and practitioners in the industrial engineering community by publishing papers that are grounded in science and mathematics and motivated by engineering applications.

IISE Transactions on Healthcare Systems Engineering (link.iise.org/iisetransactions_healthcare) is a quarterly, refereed journal that publishes papers about the application of industrial engineering tools and techniques to healthcare systems.