Evaluation of the Doctoral Dissertation entitled

Human Cognitive Load and Awareness Monitoring Using AI and Biosignals in Assembly Operations

by Abdulrahman Khalid Eesee Al-sabaawi

Choice of topic, timeliness, and general evaluation of the dissertation

This dissertation addresses a significant challenge in human-centric manufacturing: how to monitor and manage human cognitive load and situational awareness in real time using multimodal biosignals (HRV and EDA) and AI-driven analytics. This topic is both novel and forward-looking, and is in line with current international research trends in Industry 4.0/5.0 and human–machine cooperation. Beyond its relevance to engineering and ergonomics, the topic has clear societal significance as cognitive overload can lead to operator error, accidents, inefficiency and reduced well-being. The proposed Extended Human Asset Administration Shell (Extended HAAS) is a new conceptual and practical contribution to the ongoing development of human digital twins and adaptive production systems. Overall, the topic is timely, innovative, interdisciplinary and of substantial applied value.

From a system engineering perspective, the work successfully integrates task characteristics, environmental context, and human physiological signals into a unified assistance architecture. Drawing on my background as a cognitive scientist — specifically, an experimental cognitive researcher, as will be apparent from my questions below — I find the focus on cognitive load, awareness and workload dynamics to be firmly rooted in established theoretical frameworks while also extending them to an applied, engineering-driven context. The topic is well chosen for a doctoral dissertation and clearly reflects current and future directions in human-centered AI and smart manufacturing.

The literature review is comprehensive and up to date. It is also well structured and covers a wide range of domains, including cognitive load theory, human information processing, physiological workload measurement (EDA/HRV), attention, multitasking and situational awareness, job rotation and task sequencing, digital twins and Asset Administration Shell structures, human–robot collaboration, instruction design, and extraneous cognitive load. The review clearly includes all major scientific antecedents and contextualizes them well. It also sets up the research questions convincingly. The candidate demonstrates strong critical thinking by highlighting gaps in the literature, such as the limited attempt-level physiological analysis and the absence of real-time situational awareness measures, which the dissertation directly addresses.

The candidate does more than summarize prior work; they compare conflicting findings, identify methodological limitations and thoughtfully analyse conceptual inconsistencies (e.g. subjective vs. objective workload measures). The literature is not only reviewed, but also actively used to justify methodological choices and inform the design of the experimental program. This meets the criterion fully.

Each research question and hypothesis is explicitly linked to existing scientific results, such as cognitive load theory, attentional resource models and recent literature on physiological sensing. The objectives are correctly defined using prior work as a springboard, including the aim to track attempt-level cognitive load dynamics.

The dissertation employs modern, state-of-the-art methods, including high-quality wearable sensing, advanced preprocessing, individualized baselines and normalization, event-based windowing, and linear models for unbalanced repeated-measures analysis. Signal processing is carried out rigorously, with due consideration given to the limitations of short-window HRV metrics and motion artefacts, as well as the complementary role of subjective measures. Maturity is demonstrated through the handling of noisy physiological data and the justification of exclusion criteria. The methodology is careful, transparent and reproducible. The chosen tools are fully suitable for the formulated research questions. Data processing and analytics are carried out with great care.

The conclusions are modest and nuanced, and are fully supported by the results. For example, physiological signals reliably track rest–task differences; attempt-level adaptation is mainly visible in EDA and kinematics; instruction format affects workload and precision differently; situational awareness can be partially inferred from tonic EDA and context; and real-time deployment faces practical sensing and generalization challenges. The author avoids overclaiming and clearly states the boundaries of inference.

The dissertation systematically compares its findings with prior literature on topics such as VLF suppression, SCR frequency, instructional design research and dual-task HRV patterns. It demonstrates both converging evidence and novel observations. This criterion is thus thoroughly fulfilled.

Achievements of the candidate

In addition to the dissertation itself, the scientific productivity of the candidate deserves explicit recognition. According to Google Scholar, the candidate has authored or co-authored 13 scientific publications, which have accumulated 66 citations, resulting in an h-index of 5. This publication record is an outstanding achievement for an early-career researcher and provides strong independent evidence of the candidate's ability to conduct high-quality, internationally visible research. The dissertation clearly builds upon and integrates this body of work in a coherent and mature manner.

Theses accepted as new

This dissertation introduces an extended human asset administration shell (HAAS) that integrates worker characteristics, environmental descriptors and multimodal physiological signals (heart rate variability (HRV), electrodermal activity (EDA) and acceleration) to estimate required and evaluated cognitive load. This framework enables adaptive task allocation and represents a new conceptual contribution to the field of human digital twins.

Using multimodal sensing and linear mixed models, the author demonstrates that specific physiological features (especially those based on EDA) and kinematic features reliably track within-session, attempt-level learning and adaptation during assembly tasks — an analytical granularity rarely achieved in previous research.

The research shows that visual instructions reduce workload and increase repetition rate, but decrease precision. In contrast, code-based instructions impose a higher cognitive load, but yield superior assembly accuracy. This establishes a nuanced trade-off between efficiency and quality, thereby expanding the existing literature on instruction design.

In a dual-task study, the author demonstrates that tonic EDA and dominant-hand movement patterns correlate with changes in reaction time during a Go/No-Go test embedded in a manual task. This offers a new event-based approach to investigating situational awareness in manufacturing.

The dissertation reveals that adding a parallel cognitive task to HRC increases attentional demand and subtly degrades performance. Operators are found to adopt task-prioritization strategies spontaneously. These findings provide new design recommendations for HRC task allocation.

Questions for the defense

You clearly define what can and cannot be inferred from HRV, EDA, and kinematic signals. You also explicitly state that these are indirect indicators of changes in load-related states rather than direct measures of attention, effort, or awareness. Looking to the future, what kind of empirical validation strategy would be necessary to progress from reliable load tracking to stronger construct validity for higher-level cognitive states, such as situational awareness or monitoring capacity?

You emphasize that the proposed models are context-dependent and are trained within clearly defined task structures. If the goal were to deploy this system across heterogeneous industrial tasks with different temporal dynamics and attentional profiles, which area of research would you prioritize to enable cross-task generalization without compromising sensitivity?

Finally, from a future research perspective, how would you investigate the long-term cognitive and behavioral consequences of continuous adaptation based on estimated cognitive load, particularly regarding the risks of overreliance, reduced self-regulation, and altered learning trajectories?

Final remarks

The dissertation is well organized, logical and readable, with clear progression between chapters. The tables, figures and appendices are extensive, informative and presented professionally. The writing style is polished and coherent. All tables and figures are clear, accurate and unambiguous, and fulfil the formal criteria. The references are numerous, up to date and correctly formatted throughout the document. The dissertation meets the professional standards of formatting, typography and structure. The candidate satisfies the doctoral school's publication requirements based on the official rules attached to the evaluation document.

Based on a thorough evaluation against all official criteria, I conclude that the dissertation is scientifically sound and methodologically rigorous. It is also multidisciplinary and innovative, and presents new, original and valuable scientific results. I fully recommend that the dissertation be accepted for public defense, considering it to be a strong basis for awarding the PhD degree.

Recommendation: I recommend approval.

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