Reply to reviewers – PhD dissertation

Reviewer: Prof. Dr. Peter Thorvald, University of Skövde, Sweden
Title: Human Cognitive Load and Awareness Monitoring Using AI and Biosignals in Assembly Operations
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1. General assessment

"*This dissertation addresses the monitoring of cognitive load and awareness in assembly-related work using physiological signals and data-driven models, and places this within a broader conceptual framework, Extended HAAS, intended for human-centred and adaptive production systems. The topic is relevant and timely, and the dissertation combines conceptual work with several experimental studies covering dual-tasking, task switching, instruction design, and multitasking in human-robot collaboration.*

Overall, the dissertation presents a coherent line of work and demonstrates solid competence in experimental design, signal processing, and applied modelling. The work is technically demanding and positioned in an interdisciplinary field that is both scientifically relevant and practically important. One of its main strengths is that it does not rely on a single study or a single type of measure, but instead combines physiological, behavioural, subjective, and performance-related perspectives across a series of related experiments. The dissertation also shows a generally careful treatment of methodological limitations, particularly regarding the use of HRV in short and event-based recordings."

Response:

Dear Professor Peter Thorvald,

Thank you very much for your careful and constructive review, and for your continued support in helping me refine this dissertation from the home defense stage to the final defense. I truly appreciate the time and attention you gave to reading the work so thoroughly.

Your comments were very valuable for me, especially in helping me think more clearly about the conceptual framing of the dissertation, the interpretation of the different constructs, and the practical positioning of the Extended HAAS framework. I am also grateful for your balanced evaluation of both the strengths and the limitations of the work, which is very helpful for me at this final stage.

Thank you again for your support, your thoughtful feedback, and your contribution to improving this dissertation.

2. Limitations

"*At the same time, the dissertation has a number of limitations that should be clearly acknowledged in the final assessment.*"

2.1. Conceptual limitations

"*The most important weakness is conceptual. The thesis uses cognitive load as a central concept, but the distinction between cognitive load, mental workload, mental effort, mental demand, arousal, and attention is not sufficiently clear throughout the text. The terminology shifts over the course of the dissertation, and it is not always evident whether these constructs are treated as distinct, overlapping, or interchangeable. This does not invalidate the empirical work, but it weakens the theoretical precision of the overall argument and makes some interpretations broader than they should be.*"

Response:

Thank you for this important conceptual remark. I agree that the distinction between cognitive load, mental workload, mental effort, mental demand, arousal, and attention could have been stated more explicitly and more consistently across the dissertation. My intention was not to treat these constructs as fully interchangeable, but rather to use cognitive load as the central umbrella concept of the dissertation, while treating attention, arousal, and related terms as connected but more task-specific constructs or observable correlates depending on the study context. For example, in the dual-task studies, reaction time was used more specifically as a proxy for attentional demand and situational awareness, while some physiological responses were interpreted more cautiously as load-related or arousal-related correlates rather than as direct measures of cognitive load itself. I fully acknowledge that this conceptual layering could have been expressed with greater precision throughout the dissertation. I will address this point explicitly in the defense by clearly separating these constructs and by stating more carefully how each is used in the interpretation of the different studies.

"*Another limitation concerns the Extended HAAS framework itself. The framework is ambitious and interesting, but the dissertation remains somewhat unclear regarding who the actual end user of the system is and how it would be used in practice. It is not entirely clear whether the intended user is the operator, a system designer, a production engineer, a supervisor, or an automated adaptive system. Likewise, the real-time ambitions of the framework are stronger than the demonstrated implementation. The dissertation argues convincingly for the importance of real-time assessment, but it does not fully show how such a system could integrate and interpret multiple data streams quickly and robustly enough for practical industrial use.*"

Response:

Thank you for this important observation. I agree that the intended end user and the practical mode of use of the Extended HAAS framework could have been defined more explicitly. My intention was to present Extended HAAS primarily as a conceptual and architectural framework for human-centred cognitive-load management, rather than as a fully implemented end-user application. In that sense, the most immediate users would more likely be system designers, production- and process engineers, supervisors, or a higher-level adaptive decision-support system that uses these inputs to guide task design or adaptation. The operator is primarily the person whose state is being monitored and supported.

I also agree that the real-time aspect of the Extended HAAS is presented more as an intended direction of the framework than as a fully demonstrated implementation in this dissertation. The dissertation shows the methodological components and experimental building blocks that support such a future system, but it does not yet constitute a fully integrated, robust, real-time industrial deployment. I will clarify this point explicitly during the defense and present Extended HAAS more carefully as a framework and research direction rather than as a completed practical solution.

2.2.Validity

"*A related concern is the use and interpretation of subjective workload measures, especially NASA-TLX. NASA-TLX is primarily an instrument for overall task workload rather than a specific measure of cognitive load or mental workload in a narrow sense. In tasks that are predominantly mental or predominantly physical, aggregated NASA-TLX scores may distort the construct of interest rather than capture it cleanly. This is particularly important in a dissertation that claims to study cognitive load specifically.*"

Response:

Thank you for this important point. I agree that NASA-TLX is broader than a narrow measure of cognitive load, and that this should have been expressed more carefully in the dissertation. My intention was to use NASA-TLX mainly as a subjective indicator of overall perceived task workload, and not as a standalone measure of cognitive load in a strict conceptual sense. I also agree that, especially in tasks with both mental and physical components, the aggregated NASA-TLX score can blur the specific construct of interest if interpreted too directly as cognitive load. In the dissertation, I intended the subjective interpretation to be supported by the more specific subscales, and also by triangulation with ISA, short DSSQ, physiological features, and performance measures, rather than by NASA-TLX alone. Still, I acknowledge that the wording in some parts of the dissertation, especially where the aggregated NASA-TLX score is discussed more directly in relation to cognitive load, is broader than it should be. I will clarify this explicitly during the defense and refer to NASA-TLX more carefully as a measure of perceived overall workload rather than a narrow direct measure of cognitive load.

"*The ecological validity of the empirical studies is also limited. Several of the studies rely on small sample sizes and controlled laboratory conditions. This is acceptable to a point at the doctoral level, especially in exploratory and technically demanding work, but it does limit generalizability and weakens the practical claims regarding real industrial environments. The dissertation would have been stronger had it included at least one study in a more realistic shop-floor setting or offered a more explicit rationale for why this was not feasible within the scope of the work.*"

Response:

Thank you for this important remark. I agree that the ecological validity of the empirical studies is limited by the controlled laboratory settings and the relatively small sample sizes in some chapters, and that this reduces the direct generalizability of the findings to real industrial environments. My intention was to first establish the conceptual, methodological, and signal-processing foundations of the work under controlled conditions, where multimodal data collection and interpretation could be handled more reliably. A more realistic shop-floor study would have strengthened the dissertation further, but this was difficult to achieve within the scope of the PhD because of the complexity of synchronising physiological, behavioural, and performance data in less controlled industrial conditions. For this reason, the dissertation should be understood mainly as methodological and conceptual groundwork developed in manufacturing-like laboratory settings, rather than as a fully validated shop-floor implementation. I will make this point more explicit during the defense.

"*There are also some specific modelling choices that remain open to criticism. The task classification used in Extended HAAS, for example routine versus non-routine, cognitive versus physical, and individual versus social, is useful as a high-level simplification, but it risks presenting tasks as more discrete than they really are. Many industrial tasks contain mixed characteristics and shift along these dimensions over time. Similarly, while the choice of HRV and EDA is understandable and well motivated from a practical sensing perspective, the dissertation would have benefited from a more explicit justification of why these signals were prioritized over other potentially more sensitive indicators.*"

Response:

Thank you for this valuable point. I agree that both of these modelling choices could have been framed more explicitly. Regarding the task classification in the Extended HAAS, my intention was to use the routine/non-routine, cognitive/physical, and individual/social dimensions as a high-level structuring model for describing tasks within the framework, rather than to suggest that industrial tasks are fully discrete or fixed categories. I fully agree that many real tasks combine these characteristics and may shift along these dimensions over time. In that sense, the classification should be understood as a simplifying abstraction to support modelling and interoperability, not as a complete representation of task reality.

I also agree that the prioritisation of HRV and EDA could have been justified more explicitly in relation to other possible sensing modalities. My intention was to prioritise these signals mainly from a practical sensing perspective, because they provide complementary information on autonomic activity, can be collected with relatively feasible wearable setups, and fit the human-centred industrial scenarios addressed in the dissertation. At the same time, I do not claim that they are always the most sensitive indicators in every context. Rather, they were selected as a realistic and interpretable subset within a broader multimodal perspective, while other signals such as EEG, eye tracking, or EMG remain important alternatives for future extensions. I will clarify both of these points more explicitly during the defense.

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