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Mica R. Endsley. From *Here to Autonomy: Lessons Learned From Human–Automation Research*. pp. 5-27.

As autonomous and semiautonomous systems are developed for automotive, aviation, cyber, robotics and other applications, the ability of human operators to effectively oversee and interact with them when needed poses a significant challenge. An *automation conundrum* exists in which as more autonomy is added to a system, and its reliability and robustness increase, the lower the situation awareness of human operators and the less likely that they will be able to take over manual control when needed. The human–autonomy systems oversight model integrates several decades of relevant autonomy research on operator situation awareness, out-of-the-loop performance problems, monitoring, and trust, which are all major challenges underlying the automation conundrum. Key design interventions for improving human performance in interacting with autonomous systems are integrated in the model, including human–automation interface features and central automation interaction paradigms comprising levels of automation, adaptive automation, and granularity of control approaches. Recommendations for the design of human–autonomy interfaces are presented and directions for future research discussed.

SPECIAL ISSUE IN REMEMBRANCE OF PROFESSOR RAJA PARASURAMAN: Guest Editors: Peter A. Hancock, Carryl L. Baldwin, Joel S. Warm, and James L. Szalma

Peter A. Hancock, Carryl L. Baldwin, Joel S. Warm, James L. Szalma. *Between Two Worlds: Discourse on the Vigilant and Sustained Contributions of Raja Parasuraman*. pp. 28–34.

Objective: To provide an evaluative overview of the life and contributions of Raja Parasuraman. **Background:** From his earliest contributions in clarifying and explaining the problematic area of vigilance to his most recent interdisciplinary advances in understanding how genotype relates to behavior in complex technical environments, Raja Parasuraman was a giant of human factors and ergonomics. Our present exposition articulates and recounts his many contributions to our science and to science in general beyond the confines of our own discipline. **Method:** We use the history of scientific contributions, biographical analysis, and reported personal experience to accomplish our

overall assessment of the man and his work. **Results:** We conclude that Parasuraman's contributions were unique, substantive, and seminal, and will continue to influence our science for many years to come. **Application:** This work will serve as a record for those to come who look to make significant contributions to the goals, aims, and aspirations that we set ourselves in human factors and ergonomics in seeking to improve the human condition.

Peter A. Hancock. *On the Nature of Vigilance*. pp. 35–43.

Objective: I explore the origins, theoretical underpinnings, applications, and importance of vigilance in a world ever more dominated by semiautomated, automated, and autonomous machines. **Background:** The empirical genesis of vigilance is taken as a case study in the etiology of the application of the behavioral sciences to the human culture of technology. The subsequent taxonomic ordering and theoretical clarification of its causal antecedents are set in the overall context of contemporary human–machine systems research. **Method:** The methods exercised in this work are historical analysis and informational synthesis in combination with projected theoretical implications and impact. **Results:** The profile of evolution of the concept of vigilance is clarified and cast in the light of critical events, such as the promulgation of the vigilance taxonomy, its linkage to attentional resource theory, and the recognition that the attendant performance decrement is as indicative of iatrogenic sources as it is a shortfall or limitation of the observer's processing capacity. **Conclusion:** Vigilance is alive and growing in importance. Understanding sustained attention will become ever more critical in the humanization of automation-dominated systems. **Application:** The application of vigilance is widespread and potentially ubiquitous for semiautomated, automated, and autonomous system interaction.

Gerald Matthews, Joel S. Warm, Andrew P. Smith. *Task Engagement and Attentional Resources: Multivariate Models for Individual Differences and Stress Factors in Vigilance*. pp. 44–61.

Objective: Two studies tested multivariate models of relationships between subjective task engagement and vigilance. The second study included a stress factor (cold infection). Modeling tested relationships between latent factors for task engagement and vigilance, and the role of engagement in mediating effects of cold infection. **Background:** Raja Parasuraman's research on vigilance identified several key issues, including the roles of task factors, arousal processes, and individual differences, within the framework of resource theory. Task engagement is positively correlated with performance on various attentional tasks and may serve as a marker for resource availability. **Method:** In the first study, 229 participants performed simultaneous and successive vigilance tasks. In the second study, 204 participants performed a vigilance task and a variable-foreperiod simple reaction-time task on two separate days. On the second day, 96 participants performed while infected with a naturally occurring common cold. Task engagement was assessed in both studies. **Results:** In both studies, vigilance decrement in hit rate was observed, and task performance led to loss of task engagement. Cold infection also depressed both vigilance and engagement. Fitting structural equation models indicated that simultaneous and successive tasks should be represented by separate latent factors (Study 1), and task engagement fully mediated the impact of cold infection on vigilance but not reaction time (Study 2). **Conclusions:** Modeling individual differences in task engagement elucidates the role of resources in vigilance and underscores the relevance of Parasuraman's vision of the field. **Application:** Assessment of task engagement may support diagnostic monitoring of operators performing tasks requiring vigilance.

Matthew E. Funke, Joel S. Warm, Gerald Matthews, Gregory J. Funke, Peter Y. Chiu, Tyler H. Shaw, Eric T. Greenlee. *The Neuroergonomics of*

***Vigilance: Effects of Spatial Uncertainty on Cerebral Blood Flow Velocity and Oculomotor Fatigue*. pp. 62–75.**

Objective: The aim of this study was to examine the effects of uncertainty about where in the field of view critical signals for detection appear during a vigilance task (spatial uncertainty) on cerebral blood flow velocity (CBFV) and oculomotor fatigue. **Background:** Neuroergonomics is a dimension of human factors founded by Raja Parasuraman that studies brain functions underlying performance at work. Neuroergonomic studies have shown that observers in vigilance tasks lose information-processing resources over time and experience oculomotor fatigue as indexed by a temporal decline in CBFV and elevation in eye closure as reflected in the PERCLOS metric. Because spatial uncertainty increases an observer's need for visual scanning relative to a spatial certainty condition, it was anticipated that spatial uncertainty would result in a greater temporal decline in CBFV and increased eye closure in a vigilance session. **Method:** Observers performed a simulated unmanned aerial vehicle (UAV) control task wherein collision flight paths were the events to be detected. UAV images could appear at random in any one of five locations on the controller's display (spatial uncertainty) or only in a fixed location (spatial certainty). **Results:** Signal detection was poorer in the spatial-uncertain relative to the certain condition, and predictions regarding CBFV and eye closure were confirmed. **Conclusion:** Vigilance tasks involving spatial uncertainty are more neurophysiologically taxing than those in which spatial uncertainty is not a factor. **Application:** The neuroergonomic approach helps in understanding the effects of psychophysical factors in vigilance and to signify when performance aiding is needed.

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Cynthia Laurie-Rose, Lori M. Curtindale, Meredith Frey. *Measuring Sustained Attention and Perceived Workload: A Test With Children*. pp. 76–90.

Objective: We examined the effects of spatial uncertainty, field dependence/independence (FD/I), and sex on vigilance performance and perceived workload in elementary school children. **Background:** Building on previous work in which children demonstrated their ability to evaluate workload, we tested whether spatial-uncertainty manipulations in a vigilance task would elicit in children the same deleterious effects on performance and workload as it does with adults. We also examined individual difference effects associated with FD/I and sex to determine their influence on both performance and workload. **Method:** In the low-uncertainty task, stimuli appeared in the center of the computer screen; in the high-uncertainty task, they appeared in one of the four quadrants of the screen. Neutral events consisted of uppercase letter strings. Critical signals consisted of a single lowercase letter among uppercase letters. Following each vigil, children completed a workload assessment via a modified version of the NASA Task Load Index. **Results:** Children showed lower perceptual sensitivity, greater response latency variability (RT^{SD}), and a higher response criterion in the uncertain display condition. Workload scores reflected these performance differences. Field-dependent children showed lower perceptual sensitivity and greater RT^{SD}than did field-independent children. The two groups exhibited differing workload profiles. Despite no objective performance differences, boys reported greater workload than girls. **Conclusion:** The scale demonstrated sensitivity and diagnosticity with regard to both the task variable and individual differences. **Application:** These findings contribute to the emerging field of "educational ergonomics" and indicate that appropriate assessment tools might identify children who are experiencing increased workload.

William S. Helton, Paul N. Russell. *Rest Is Still Best: The Role of the Qualitative and Quantitative Load of Interruptions on Vigilance*. pp. 91–100.

Objective: We examined the impact task interruptions of differing qualitative and quantitative load have on visuospatial vigilance sensitivity. **Background:** The vigilance decrement and attempts to develop countermeasures to the decrement is one of the most important human factors issues. There is an ongoing debate between those who interpret the increase in the rate of failures to detect signals over time as being due to objective task monotony or task underload and those who interpret this increased failure proneness as being predominately due to cognitive-resource depletion and task overload. **Method:** Participants were assigned at random to one of six interruptions: Participants were given a complete rest (rest); participants completed a 1-back verbal working-memory (WM) task, a 3-back verbal WM task, a 1-back spatial WM task, or a 3-back spatial WM task; or participants performed the primary vigilance task (continuous). **Results:** Postinterruption performance was best for rest and worst for continuous. A resource theory perspective led us to make two possible predictions of relative interruption effect orders of the six conditions out of 720 possible orderings. We found one of the two orders. **Conclusion:** Overall, the vigilance sensitivity decrement appears to be due to the recurring use of particular cognitive resources, and resource theorists should explore this more extensively in the future. **Application:** Countermeasures for the vigilance decrement should be based on clear cognitive-resource considerations. Rest is the best countermeasure. Intervening tasks should be chosen that minimize resource-demand overlap with the vigilance task.

Robert Earl Patterson. *Intuitive Cognition and Models of Human–Automation Interaction*. pp. 101–115.

Objective: The aim of this study was to provide an analysis of the implications of the dominance of intuitive cognition in human reasoning and decision making for conceptualizing models and taxonomies of human–automation interaction, focusing on the Parasuraman et al. model and taxonomy. **Background:** Knowledge about how humans reason and make decisions, which has been shown to be largely intuitive, has implications for the design of future human–machine systems. **Method:** One hundred twenty articles and books cited in other works as well as those obtained from an Internet search were reviewed. Works were deemed eligible if they were published within the past 50 years and common to a given literature. **Results:** Analysis shows that intuitive cognition dominates human reasoning and decision making in all situations examined. The implications of the dominance of intuitive cognition for the Parasuraman et al. model and taxonomy are discussed. A taxonomy of human–automation interaction that incorporates intuitive cognition is suggested. **Application:** Understanding the ways in which human reasoning and decision making is intuitive can provide insight for future models and taxonomies of human–automation interaction.

- **Keywords:** human–computer interaction, human reasoning, decision making, intuitive cognition

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Ewart J. de Visser, Samuel S. Monfort, Kimberly Goodyear, Li Lu, Martin O'Hara, Mary R. Lee, Raja Parasuraman, Frank Krueger. *A Little Anthropomorphism Goes a Long Way: Effects of Oxytocin on Trust, Compliance, and Team Performance With Automated Agents*. pp. 116–133.

Objective: We investigated the effects of exogenous oxytocin on trust, compliance, and team decision making with agents varying in anthropomorphism (computer, avatar, human) and reliability (100%, 50%). **Background:** Authors of recent work have explored psychological similarities in how people trust humanlike automation compared with how they trust other humans. Exogenous administration of oxytocin, a neuropeptide associated with trust among humans, offers a unique opportunity to probe the anthropomorphism continuum of automation to infer when agents are trusted like another human or merely a machine. **Method:** Eighty-four healthy male participants collaborated with automated agents varying in anthropomorphism that provided recommendations in a pattern recognition task. **Results:** Under placebo, participants exhibited less trust and compliance with automated aids as the anthropomorphism of those aids increased. Under oxytocin, participants interacted with aids on the extremes of the anthropomorphism continuum similarly to placebos but increased their trust, compliance, and performance with the avatar, an agent on the midpoint of the anthropomorphism continuum. **Conclusion:** This study provides the first evidence that administration of exogenous oxytocin affected trust, compliance, and team decision making with automated agents. These effects provide support for the premise that oxytocin increases affinity for social stimuli in automated aids. **Application:** Designing automation to mimic basic human characteristics is sufficient to elicit behavioral trust outcomes that are driven by neurological processes typically observed in human–human interactions. Designers of automated systems should consider the task, the individual, and the level of anthropomorphism to achieve the desired outcome.

Brett J. Borghetti, Joseph J. Giametta, Christina F. Rusnock. *Assessing Continuous Operator Workload With a Hybrid Scaffolded Neuroergonomic Modeling Approach*. pp. 134–146.

Objective: We aimed to predict operator workload from neurological data using statistical learning methods to fit neurological-to-state-assessment models. **Background:** Adaptive systems require real-time mental workload assessment to perform dynamic task allocations or operator augmentation as workload issues arise. Neuroergonomic measures have great potential for informing adaptive systems, and we combine these measures with models of task demand as well as information about critical events and performance to clarify the inherent ambiguity of interpretation. **Method:** We use machine learning algorithms on electroencephalogram (EEG) input to infer operator workload based upon Improved Performance Research Integration Tool workload model estimates. **Results:** Cross-participant models predict workload of other participants, statistically distinguishing between 62% of the workload changes. Machine learning models trained from Monte Carlo resampled workload profiles can be used in place of deterministic workload profiles for cross-participant modeling without incurring a significant decrease in machine learning model performance, suggesting that stochastic models can be used when limited training data are available. **Conclusion:** We employed a novel temporary scaffold of simulation-generated workload profile truth data during the model-fitting process. A continuous workload profile serves as the target to train our statistical machine learning models. Once trained, the workload profile scaffolding is removed and the trained model is used directly on neurophysiological data in future operator state assessments. **Application:** These modeling techniques demonstrate how to use neuroergonomic methods to develop operator state assessments, which can be employed in adaptive systems.

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Ryan McKendrick, Ranjana Mehta, Hasan Ayaz, Melissa Scheldrup, Raja Parasuraman. *Prefrontal Hemodynamics of Physical Activity and Environmental Complexity During Cognitive Work*. pp. 147–162.

Objective: The aim of this study was to assess performance and cognitive states during cognitive work in the presence of physical work and in natural settings. **Background:** Authors of previous studies have examined the interaction between cognitive and physical work, finding performance decrements in working memory. Neuroimaging has revealed increases and decreases in prefrontal oxygenated hemoglobin during the interaction of cognitive and physical work. The effect of environment on cognitive-physical dual tasking has not been previously considered. **Method:** Thirteen participants were monitored with wireless functional near-infrared spectroscopy (fNIRS) as they performed an auditory 1-back task while sitting, walking indoors, and walking outdoors. **Results:** Relative to sitting and walking indoors, auditory working memory performance declined when participants were walking outdoors. Sitting during the auditory 1-back task increased oxygenated hemoglobin and decreased deoxygenated hemoglobin in bilateral prefrontal cortex. Walking reduced the total hemoglobin available to bilateral prefrontal cortex. An increase in environmental complexity reduced oxygenated hemoglobin and increased deoxygenated hemoglobin in bilateral prefrontal cortex. **Conclusion:** Wireless fNIRS is capable of monitoring cognitive states in naturalistic environments. Selective attention and physical work compete with executive processing. During executive processing loading of selective attention and physical work results in deactivation of bilateral prefrontal cortex and degraded working memory performance, indicating that physical work and concomitant selective attention may supersede executive processing in the distribution of mental resources. **Application:** This research informs decision-making procedures in work where working memory, physical activity, and attention interact. Where working memory is paramount, precautions should be taken to eliminate competition from physical work and selective attention.