Catastrophe Models for Cognitive Workload and Fatigue: Project Log 2012-2020

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This paper was prepared for the benefit of visitors to this e-Publications site and my incoming lab students. It is very similar to the project log that is posted on *Research Gate*, varying only in typescript format and a few minor edits intended to prevent an ugly-looking document. It starts with a brief explanation of how the project was started, and continues with installments related to each of the cognitive processes that we studied over the years. There were some interesting digressions from the primary focus on the cusp catastrophe models that appeared along the way as well. The project is still very active.

EARLY HISTORY

The roots of the project trace back to early 1980s when I was simultaneously exploring applications of catastrophe theory to work behaviors and developing statistical methods for testing the validity of models with real data. I was working for a major steel manufacturer at the time, and we had a project underway studying predictors of performance in physically demanding jobs. Physical workload and fatigue came to the foreground, and resulted in two articles [1, 2].

The similarity between the dynamics of physical and cognitive fatigue were already known as long ago as 1914. Further developments proceeded slowly through the mid-1930, and went into a moratorium for decades before and after [2]. Philip Ackerman revitalized the fatigue topic in *Cognitive Fatigue* [3]. Henry Thompson revisited the catastrophe model for workload [1] in *The Stress Effect: Why Smart Leaders Make Dumb Decisions* [4]. David Pincus and Anna Metton adopted the workload model as an explanation for psychosocial resilience, with clinical applications in mind [5].

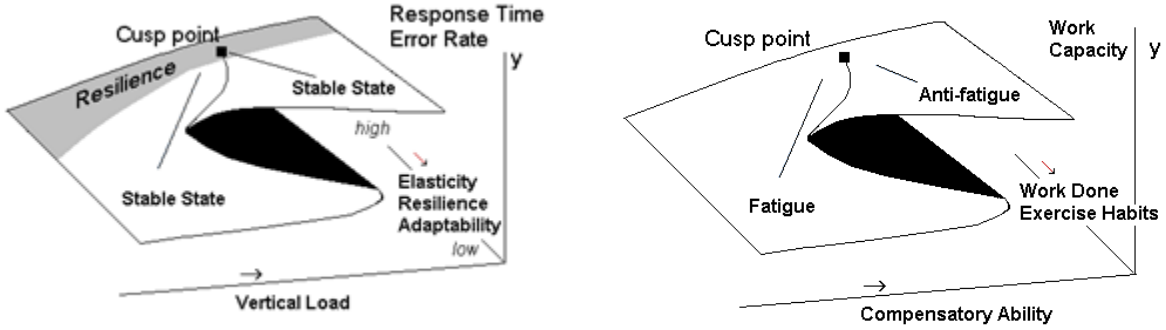

Fig. 1. Cusp catastrophe models for cognitive workload (left) and fatigue (right).

I started the lab project in the fall of 2009 when I noticed that workload and fatigue dynamics were often intertwined in many human factors (ergonomics) research studies, and concluded that two types of dynamics needed to be separated in the same experimental context. The central goal of the study plan was to investigate the twin cusp dynamics in a broad range of cognitive tasks – each one probably having its

own special properties – to establish generalizability and explore psychological variables that contribute to the two control parameters in each model. There were several spin-off ideas that came to the foreground as well, notably task switching and individual differences in response to CWLF. The work eventually expanded into team-level workload and fatigue. The general models appear in Fig. 1 above. The developments from the lab are presented next in chronological order of the experiments.

[1] Guastello, S. J. (1985). Euler buckling in a wheelbarrow obstacle course: A catastrophe with complex lag. *Behavioral Science, 30*, 204-212.

[2] Guastello, S. J., & McGee, D.W. (1987). Mathematical modeling of fatigue in physically demanding jobs. *Journal of Mathematical Psychology, 31*, 248-269.

[3] Ackerman, P. L. (Ed.). (2011). *Cognitive fatigue*. Washington, DC: American Psychological Association.

[4] Thompson, H. L. (2010). *The stress effect: Why smart leaders make dumb decisions—and what to do about it*. San Francisco, CA: Jossey-Bass.

[5] Pincus, D., & Metton, A., 2010. Nonlinear dynamics in biopsychosocial resilience. *Nonlinear Dynamics, Psychology, and Life Sciences, 14*, 353–380.

2012: EPISODIC AND PICTORIAL MEMORY

Guastello, S. J., Boeh, H., Shumaker, C., & Schimmels, M. (2012). Catastrophe models for cognitive workload and fatigue. *Theoretical Issues in Ergonomics Science*, *13*(5), 586-602. DOI**:**10.1080/1463922X.2011.552131

We reconceptualised several problems concerning the measurement of cognitive workload – fixed versus variable limits on channel capacity, work volume versus time pressure, adaptive strategies, resources demanded by tasks when performed simultaneously, and unclear distinctions between workload and fatigue effects – as two cusp catastrophe models: buckling stress resulting from acute workload, and fatigue resulting from extended engagement. Experimental participants completed a task that was intensive on non-verbal episodic memory and had an automatically speeded component. For buckling stress, the epoch of maximum (speeded) performance was the asymmetry parameter; however, anxiety did not contribute to bifurcation as expected. For fatigue, the bifurcation factor was the total work accomplished, and arithmetic, a compensatory ability, was the asymmetry parameter; R^2 for the cusp models outperformed the linear comparison models in both cases. A research programme is outlined that revolves around the two models with different types of task and resource configurations.

Guastello, S. J., Boeh, H., Schimmels, M., Gorin, H., Huschen S., Davis, E., Peters, N. E., Fabisch, M., & Poston, K. (2012). Cusp catastrophe models for cognitive workload and fatigue in a verbally-cued pictorial memory task. *Human Factors*, *54*, 811-825. DOI: 10.1177/0018720812442537.

Objective: The aim of this study was to evaluate two cusp catastrophe models for cognitive workload and fatigue. They share similar cubic polynomial structures but derive from different underlying processes and contain variables that contribute to flexibility with respect to load and the ability to compensate for fatigue. **Background:** Cognitive workload and fatigue both have a negative impact on performance and have been difficult to separate. Extended time on task can produce fatigue, but it can also produce a positive effect from learning or automaticity. **Method:** In this two-part experiment, 129 undergraduates performed tasks involving spelling, arithmetic, memory, and visual search. **Results:** The fatigue cusp for the central memory task was supported with the quantity of work performed and performance on an episodic memory task

acting as the control parameters. There was a strong linear effect, however. The load manipulations for the central task were competition with another participant for rewards, incentive conditions, and time pressure. Results supported the workload cusp in which trait anxiety and the incentive manipulation acted as the control parameters. **Conclusion:** The cusps are generally better than linear models for analyzing workload and fatigue phenomena; practice effects can override fatigue. Future research should investigate multitasking and task sequencing issues, physical-cognitive task combinations, and a broader range of variables that contribute to flexibility with respect to load or compensate for fatigue. **Applications:** The new experimental medium and analytic strategy can be generalized to virtually any real-world cognitively demanding tasks. The particular results are generalizable to tasks involving visual search.

2013: MULTITASKING

This experiment took us to perceptual-motor tasks and multi-tasking. From there we dug further into individual differences in multi-tasking performance and the dynamics of task switching. There are four articles in this sequence.

Guastello, S. J., Boeh, H., Gorin, H., Huschen, S., Peters, N. E., Fabisch, M., & Poston, K. (2013). Cusp catastrophe models for cognitive workload and fatigue: A comparison of seven task types. *Nonlinear Dynamics, Psychology, and Life Sciences, 17,* 23-47.

The study introduces a nonlinear paradigm that addresses several unresolved problems concerning cognitive workload and fatigue: (a) how to separate the effects of workload versus fatigue, (b) whether the upper boundaries of cognitive channel capacity are fixed or variable, and how multitasking produces a bottleneck phenomenon, (c) that prolonged time on task can produce performance decrements but also produce improvements in task performance associated with practice and automaticity, and that (d) task switching can alleviate fatigue but could be mentally costly. This study describes two cusp catastrophe models that have become useful for separating the workload and fatigue performance phenomena and explores the role of task switching and multitasking in both performance phenomena. In the experiment, 105 undergraduates completed seven computer-based tasks seven times under one of four experimental conditions: tasks fully alternated, tasks aggregated with the multitask module performed first, aggregated with the multitask module performed last, and where the participants chose the task order themselves. Results supported both the cusp models such that fatigue effects were stronger for tasks with higher memory or attentional demand, and were often counteracted by practice effects; spelling ability acted as a compensation variable in most cases, and the intervening amount of work done acted as the bifurcation variable. For cognitive workload, catastrophic shifts in performance were noted between the single tasks and the multitask, with relative difficulty of the single task acting as the load (asymmetry) variable and the flexible task ordering condition as the bifurcation variable.

Guastello, S. J., Gorin, H., Huschen, S. Peters, N. E., Fabisch, M., & Poston, K. (2012). New paradigm for task switching strategies while performing multiple tasks: Entropy and symbolic dynamics analysis of voluntary patterns. *Nonlinear Dynamics, Psychology, and Life Sciences, 16,* 471-497.

It has become well established in laboratory experiments that switching tasks, perhaps due to interruptions at work, incur costs in response time to complete the next task. Conditions are also known that exaggerate or lessen the switching costs. Although switching costs can contribute to fatigue, task switching can also be an adaptive response to fatigue. The present study introduces a new research paradigm for studying the emergence of voluntary task switching regimes, self-organizing processes therein, and the possibly conflicting roles of switching costs and minimum entropy. Fifty-four undergraduates performed 7 different computer-based cognitive tasks producing sets of 49 responses under instructional conditions requiring task quotas or no quotas. The sequences of task choices were analyzed using orbital decomposition to extract

pattern types and lengths, which were then classified and compared with regard to Shannon entropy, topological entropy, number of task switches involved, and overall performance. Results indicated that similar but different patterns were generated under the two instructional conditions, and better performance was associated with lower topological entropy. Both entropy metrics were associated with the amount of voluntary task switching. Future research should explore conditions affecting the trade-off between switching costs and entropy, levels of automaticity between task elements, and the role of voluntary switching regimes on fatigue. **Key Words:** topological entropy, Shannon entropy, orbital decomposition, task switching, fatigue, performance.

Guastello, S. J., Gorin, H., Huschen, S., Peters, N. E., Fabisch, M., Poston, K., & Weinberger, K. (2013). The minimum entropy principle and task performance. *Nonlinear Dynamics, Psychology, and Life Sciences, 17, 405-424.*

According to the minimum entropy principle, efficient cognitive performance is produced with a neurocognitive strategy that involves a minimum of degrees of freedom. Although high performance is often regarded as consistent performance as well, some variability in performance still remains which allows the person to adapt to changing goal conditions or fatigue. The present study investigated the connection between performance, entropy in performance, and four task-switching strategies. Fifty-one undergraduates performed 7 different computer-based cognitive tasks producing sets of 49 responses under instructional conditions requiring task quotas or no quotas. The temporal patterns of performance were analyzed using orbital decomposition to extract pattern types and lengths, which were then compared with regard to Shannon entropy, topological entropy, and overall performance. Task switching strategies from a previous study were available for the same participants as well. Results indicated that both topological entropy and Shannon entropy were negatively correlated with performance. Some task-switching strategies produced lower entropy in performance than others. Stepwise regression showed that the top three predictors of performance were Shannon entropy and arithmetic and spatial abilities. Additional implications for the prediction of work performance with cognitive ability measurements and the applicability of the minimum entropy principle to multidimensional performance criteria and team work are discussed. **Key Words:** topological entropy, Shannon entropy, orbital decomposition, task switching, fatigue, performance

Guastello, A. D., Guastello, S. J., & Guastello, D.D. (2014). Personality trait theory and multitasking performance: Implications for ergonomic design. *Theoretical Issues in Ergonomics Science, 15(5), 432-450.* DOI: 10.1080/1463922X.2012.762063.

Although system designers usually minimise the role of individual differences in operation, personality variables could explain differences in multitasking performance. A concomitant theoretical issue is whether primary or surface personality traits do a better job of predicting performance than the Five-Factor Model (FFM) or global traits. A sample of 174 undergraduates completed the Sixteen Personality Factor Questionnaire (16PF), which was followed by a performance task. A computer-based task that measured simultaneous performance on an arithmetic task and a mental rotation task was used to measure multitasking performance; scores measured the percent accuracy. Primary traits for low emotional sensitivity and high abstractedness, self-control, and general reasoning were all correlated with performance (R^2 = .11), but global or traits corresponding to the FFM were not, except in one sporadic task trial. There was also a strong gender effect on performance. Implications for the study of personality traits in ergonomics are discussed.

2014: VIGILANCE DUAL TASK, NIGHTTIME SCENARIO

Here we investigated the possible value of the two cusp catastrophe models for untangling and interpreting laboratory experiments on vigilance. Peter Hancock's article on vigilance (*American Psychologist*, 2013) was influential here as he uncovered several deficits in realism between vigilance experiments in a laboratory and real-world vigilance demands. We developed a security camera monitoring task using a virtual reality video feed, in which the participants rang a bell to indicate (to the researchers) that they spotted an intruder in an otherwise vacant office building. Participants worked in pairs and completes a jig-saw puzzle at the same time; the dual task was meant to be analogous to a real-world situation where security personnel perform other tasks while monitoring the cameras. In addition to manipulating workload with the experimental conditions, we added subjective measures of workload, e.g. the NASA TLX ratings scales.

There are four articles in this batch. The first one listed here is the central article on the CWLF cusp models. The second is a brief comment to Hancock indicating that some of the persistently curious results in the vigilance studies could be explained by the cusp models. The third investigated individual differences in workload ratings; the individual differences were the set of variables known at the time to explain the elasticity-rigidity factor in the workload-performance cusp. The fourth summarizes the status of theory and results, including two more CWLF projects that were in press at the time.

Guastello, S. J., Malon, M., Timm, P., Weinberger, K., Gorin, H., Fabisch, M., & Poston, K. (2014). Catastrophe models for cognitive workload and fatigue in a vigilance dual-task. *Human Factors*, 56(4), 737-751. DOI: 10.1177/0018720813508777

Objective: This study investigated two cusp catastrophe models for cognitive workload and fatigue for a vigilance dual task, the role of emotional intelligence and frustration in the performance dynamics, and the dynamics for individuals and teams of two participants. **Background:** The effects of workload, fatigue, practice, and time on a specific task can be separated with the two models and an appropriate experimental design. Group dynamics add further complications to the understanding of workload and fatigue effects for teams. **Method:** In this experiment, 141 undergraduates responded to target stimuli that appeared on a simulated security camera display at three rates of speed while completing a jigsaw puzzle. Participants worked alone or in pairs and completed additional measurements prior to or after the main tasks. **Results:** The workload cusp verified the expected effects of speed and frustration on change in performance. The fatigue cusp showed that positive and negative changes in performance were greater if more work on the secondary task was completed and whether the participants who started with the fast vigilance condition demonstrated less fatigue. **Conclusion:** The results supported the efficacy of the cusp models and suggested, furthermore, that training modules that varied speed of presentation could buffer the effects of fatigue. **Application:** The cusp models can be used to analyze virtually any cognitively demanding task set. The particular results generalize to vigilance tasks, although a wider range of conditions within vigilance tasks needs to be investigated further.

Guastello, S. J. (2014). Vigilance phenomena, cognitive workload and fatigue. *American Psychologist*, *69*, 85-87. DOI: 10.1037/a0034941.

Guastello, S. J., Shircel, A., Malon, M., & Timm, P. (2015). Individual differences in the experience of cognitive workload. *Theoretical Issues in Ergonomics Science*, 16(1), 20-52. doi: 10.1080/1463922X.2013.869371

This study investigated the roles of four psychosocial variables – anxiety, conscientiousness, emotional intelligence, and Protestant work ethic – on subjective ratings of cognitive workload as measured by the

Task Load Index (TLX) and the further connections between the four variables and TLX ratings of task performance. The four variables represented aspects of an underlying construct of elasticity versus rigidity in response to workload. Participants were 141 undergraduates who performed a vigilance task under different speeded conditions while working on a jigsaw puzzle for 90 minutes. Regression analysis showed that anxiety and emotional intelligence were the two variables most proximally related to TLX ratings. TLX ratings contributed to the prediction of performance on the puzzle, but not the vigilance task. Severity error bias was evident in some of the ratings. Although working in pairs improved performance, it also resulted in higher ratings of temporal demand and perceived performance pressure.

Guastello, S. J. (2014). Catastrophe models for cognitive workload and fatigue: Memory functions, multitasking, vigilance, financial decisions and risk. *Proceedings of the Human Factors and Ergonomics Society*, 58, 908-912. doi: 10.177/1541931214581190

The cusp catastrophe models for cognitive workload and fatigue and their supporting research program evolved in response to numerous difficulties encountered in previous research. The two cusp models separate the two processes, which have the same temporal dynamic structure but different contributing variables, using an integrated experimental design that tests them both in the same situation. This presentation describes the structural models, experimental tasks, and principles of elasticity-rigidity, compensatory ability, minimum entropy, and the performance-variability paradox. Results from the series of six studies are summarized and discussed.

2015: N-BACK TASK

An N-back task requires the participants to remember a series of stimuli and respond as to whether the stimulus most recent viewed was the same as the stimulus appearing immediately prior (1-back), two steps prior (2-back), three steps prior (3-back), etc. N-back tasks are well-known in cognitive studies for putting a high level of demand on working memory.

We have two articles in this installment. The first one below evaluated the CWLF cusp models. We were expanding our roster of elasticity-rigidity variables for the workload model. The second is a spin-off study on attentional blink.

Guastello, S. J., Reiter, K., Malon, M., Timm, P., Shircel, A., & Shaline, J. (2015). Catastrophe models for cognitive workload and fatigue in N-back tasks. *Nonlinear Dynamics, Psychology, and Life Sciences, 19*, 173-200.

Abstract: N-back tasks place a heavy load on working memory, and thus make good candidates for studying cognitive workload and fatigue (CWLF). This study extended previous work on CWLF which separated the two phenomena with two cusp catastrophe models. Participants were 113 undergraduates who completed 2-back and 3-back tasks with both auditory and visual stimuli simultaneously. Task data were complemented by several measures hypothesized to be related to cognitive elasticity and compensatory abilities and the NASA TLX ratings of subjective workload. The adjusted R^2 was .980 for the workload model, which indicated a highly accurate prediction with six bifurcation (elasticity versus rigidity) effects: algebra flexibility, TLX performance, effort, and frustration; and psychosocial measures of inflexibility and monitoring. There were also two cognitive load effects (asymmetry): 2 vs. 3-back and TLX temporal demands. The adjusted R^2 was .454 for the fatigue model, which contained two bifurcation variables indicating the amount of work done, and algebra flexibility as the compensatory ability variable. Both cusp models were stronger than the next best linear alternative model. The study makes an important step forward by uncovering an apparently complete model for workload, finding the role of subjective workload in the context of performance dynamics, and finding CWLF dynamics in yet another type of memory-intensive task. The results were also consistent with the developing notion that performance deficits induced by

workload and deficits induced by fatigue result from the impact of the task on the workspace and executive functions of working memory respectively.

Guastello, S. J., Reiter, K., Malon, M., & Shircel, A. (2015). When auditory and visual signal processing conflict: Cross-modal interference in extended work periods. *Theoretical Issues in Ergonomics Science*, 16(3), 232-254. doi: 10.1080/1463922X.2014.1003989

Auditory and visual stimuli presented at intervals of about 300 m sec often produce miss errors in one or the other channel, which result from a bottleneck in a neural circuit associated with executive memory. The present study examined the possibility that cross-modal interference could carry over to performance units that transpire over 3 min or longer. An N-back task performed by 113 undergraduates with simultaneous auditory and visual stimuli was organised into 1-min blocks of 20 trials in 2-back and 3-back conditions. Results showed that impairment of visual processing was more frequent than impairment of auditory processing under conditions of fatigue. A substantial number of person blocks showed no such interference, however. Bottlenecks during early stages of processing may have more extensive effects on later processing than previously recognised. Further research should consider perceptual cycling in longer term tasks involving complex stimuli.

2016: FINANCIAL DECISION MAKING

The series of CWLF studies thus far all focused on the effects of CWLF on performance. The financial decision study investigated a new dependent measure – risk taking – along with optimization performance. We also explored field (in)dependence as another new bifurcation variable for elasticity-rigidity. The project resulted in a short book and a separate article on the performance variability that is usually associated with fatigue. The minimum entropy principle soon evolved into the optimum variability principle. *Nonlinear Dynamics, Psychology, and Life Sciences* published a special issue on optimum variability in all sorts of living systems in October, 2015.

Guastello, S. J. (Ed.). (2016). *Cognitive workload and fatigue in financial decision making*. Tokyo: Springer.

This project assessed the cusp catastrophe models for cognitive workload and fatigue as outlined in previous installments. Participants were 299 undergraduates who completed a series of psychological tests and measurements, which were followed by a financial decision making task that escalated in workload. The task required the participants to work in one of three speed conditions. Results supported both cusp models for both optimizing and risk taking criteria as evidenced by a superior degree of fit compared to the alternative linear models. For workload, conscientiousness and self-control as were the elasticity-rigidity (bifurcation) factors in optimizing, and field dependence and work ethic were elasticity variables in risk tasking; speed and decision complexity were the asymmetry variables. For fatigue, work completed and work speed were the bifurcation factors, as hypothesized, for both optimizing and risk taking; field independence was the asymmetry variable for both dependent measures, and performance on an anagram test was another compensatory ability that inhibited risk taking.

Guastello, S. J., Reiter, K., Shircel, A., Timm, P., Malon, M., & Fabisch, M. (2014). The performance-variability paradox, financial decision making, and the curious case of negative Hurst exponents. *Nonlinear Dynamics, Psychology, and Life Sciences, 18,* 297-328.

Abstract: This study examined the relationship between performance variability and actual performance of financial decision makers who were working under experimental conditions of increasing workload and fatigue. The rescaled range statistic, also known as the Hurst exponent (H) was used as an index of variability. Although H is defined as having a range between 0 and 1, 45% of the 172 time series generated

by undergraduates were negative. Participants in the study chose the optimum investment out of sets of 3 to 5 options that were presented a series of 350 displays. The sets of options varied in both the complexity of the options and number of options under simultaneous consideration. One experimental condition required participants to make their choices within 15 sec, and the other condition required them to choose within 7.5 sec. Results showed that (a) negative *H* was possible and not a result of psychometric error; (b) negative *H* was associated with negative autocorrelations in a time series. (c) *H* was the best predictor of performance of the variables studied; (d) three other significant predictors were scores on an anagrams test and ratings of physical demands and performance demands; (e) persistence as evidenced by the autocorrelations was associated with ratings of greater time pressure. It was concluded, furthermore, that persistence and overall performance were correlated, that "healthy" variability only exists within a limited range, and other individual differences related to ability and resistance to stress or fatigue are also involved in the prediction of performance.

2016 VIGILANCE DUAL TASK – DAYTIME SCENARIO

We developed a new version of the virtual reality security camera monitoring task using a video feed, in which the participants rang a bell to indicate (to the researchers) that they spotted an intruder that was presented to them at the beginning of the experimental session. The daytime scenario was more difficult than the night time scenario because the intruder was moving through rooms occupied by other virtual people. Once again the participants worked in pairs and completed a jig-saw puzzle at the same time; the dual task was meant to be analogous to a real-world situation where security personnel perform other tasks while monitoring the cameras.

Another nuance in this study was that approximately half of the two-person teams were wearing GSR sensors. The GSR data were analyzed in a streaming format, rather than an event-based format, for further investigations of synchrony in working dyads. The sync studies that eventually evolved are described in a separate project log on Research Gate, SYNCHRONY, WORKLOAD, AND GROUP DYNAMICS.

Guastello, S. J., Reiter, K., & Malon, M. (2016). Cognitive workload and fatigue in a vigilance dual task: Miss errors, false alarms, and the impact of wearing biometric sensors while working. *Nonlinear Dynamics, Psychology, and Life Sciences*, *20*, 509-535.

Abstract: The effects of workload, fatigue, and practice on the performance of cognitive tasks are often intertwined. Previous research has shown that these influences can be separated with the two cusp catastrophe models. This study expanded an earlier investigation of the two models for workload and fatigue in a vigilance task to include a wider range of bifurcation variables that could affect the elasticity versus rigidity of the operator in response to workload and added performance variability resulting from fatigue. The study also responded to a concern in the literature that performance on cognitive tasks can be complicated by adaptive responses to artificial task situations and thus distort underlying cognitive events. Therefore, we also explored whether wearing biometric sensors, frequently used in workload studies, can affect performance dynamics. Participants were 279 undergraduates who responded to target stimuli that appeared on a simulated security camera display at three rates of speed while completing a secondary task. Participants worked alone, in pairs, or in pairs wearing GSR sensors. Results supported the efficacy of the two models and isolated the impact of wearing sensors on the fatigue process. The strongest control variables across both the workload and fatigue models were field independence, anxiety, indecisiveness, inflexibility, secondary task completion, working in pairs, and wearing the sensors. The contributing effect of wearing sensors could possibly extend to other types of wearable technologies.

2017-19 EMERGENCY RESPONSE SIMULATION

"The Creature That Are Sheboygan" is a board game that was modified for a group task. Three to eight emergency responders worked as a team to subdue a Godzilla-type monster who was in the process of destroying a city. In some experimental conditions there were two monsters who also worked as a team. The nuances in this project, besides the emergency response idea itself, included team-level workload and fatigue, additional ratings of workload associated with working in a team, the use of streaming GSR data to measure sync in teams larger than dyads, and leadership emergence.

There are five CWLF studies in this cluster. The first assessed the responsiveness of Helton et al.'s rating scales for team workload, which was first published at the time the experiment was started. The second contribution investigated individual differences in ratings of both individual and team workload; the range of elasticity-rigidity variables had expanded substantially since the time of the first study of individual differences in workload ratings. The third article was the evaluation of two cusp models for team level performance.

The fourth article explored the role of workload and team synchronization. The fifth article headed in yet another direction – the nonlinear dynamics of leadership emergence, which is something else I have been investigating in spurts since 1998. Does workload deter people from taking a leadership role? Indeed it does!

Guastello, S. J., & Marra, D. E. (2018). External validity and factor structure of individual and group workload ratings. *Theoretical issues in Ergonomics Science*, *19*(2), 229-253. doi:10.1080/1463922X.2017.1356395

Work teams experience workload from the group dynamics in addition to the usual sources of individual workload. This study had three objectives: to assess the responsiveness of new rating scales for group workload (GWL), investigate their component structure, and determine if changes in workload occur as the team matures. Participants (360 individuals, 44 groups) engaged in an emergency response (ER) simulation in the form of a board game; team size, game difficulty (one versus two opponents), and time constraints were varied. ER teams rated workload after each of two sessions using the NASA Task Load Index (TLX) and GWL. GWL was most responsive to larger task demands and reflected changes in coordination demand over time. Components reflected mixtures of TLX and GWL scales and suggested that self-organising processes were operating.

Guastello, S. J., Marra, D. E., Correro, A. N. II, Michels, M., & Schimmel, H. (2017). Elasticity and rigidity constructs and ratings of subjective workload for individuals and groups. In L. Longo & M. C. Leva (Eds.), *Human mental workload: Models and applications* (pp. 51-76). Cham, Switzerland: Springer

Abstract. Differences in workload inherent in a task have indirect and nonlinear relationships to performance differences because of coping strategies that people can deploy. Thus subjective ratings of workload have become commonplace for evaluating task workload. It has become apparent, however, that those ratings are affected by individual differences in personality and cognitive traits that correspond to a general theme of elasticity versus rigidity. Additionally, workload can originate from both the task and group dynamics when team work is involved. This study explored the relationship among 11 such constructs related to anxiety, coping, and fluid intelligence and ratings of individual and group workload. Participants were 360 undergraduates organized into 44 groups of different sizes who engaged in an emergency response (ER) simulation against one or two opponents. Regression analyses indicated that task conditions accounted for 7–10% of variance in individual workload ratings, and elasticity accounted for another 1–2% of the variance. Task conditions accounted for 2–4% of the variance in group-level workload

ratings, and elasticity accounted for another 2–4%. Results support the continued investigation of elasticity-rigidity in the understanding of workload arising from the task and group dynamics.

Guastello, S. J., Correro, A. N. II, & Marra, D. E. (2019). Cusp catastrophe models for cognitive workload and fatigue in teams. *Applied Ergonomics, 79*, 152-168. doi: 10.1016/j.apergo.2018.08.019

The use of two cusp catastrophe models has been effective for untangling the effects of cognitive workload, fatigue, and other complications on the performance of individuals. This study is the first to use the two models to separate workload and fatigue effects on team performance. In an experiment involving an emergency response simulation, 360 undergraduates were organized into 44 teams. Workload was varied by team size, number of opponents, and time pressure. The cusp models for workload and fatigue were more accurate for describing trends in team performance criteria compared to linear alternatives. Individual differences in elasticity-rigidity were less important than subjective workload and experimental conditions as control variables. Fluid intelligence within the team was an important compensatory ability in the fatigue model. Results further supported the nonlinear paradigm for the assessment of cognitive workload and fatigue and demonstrated its effectiveness for understanding team phenomena.

Guastello, S. J., Correro, A. N. II, Marra, D. E., & Peressini, A. F. (2019). Physiological synchronization and subjective workload in a competitive emergency response task. *Nonlinear Dynamics, Psychology, and Life Sciences, 23,* 347-376.

Abstract: Human dyads and larger teams tend to acquire synchronized movements and autonomic arousal levels while working together or simply socializing. The synchronization of arousal patterns is of theoretical interest for group dynamics because they may add predictive value to the dynamics of group cohesion and team performance. This study examined the four-way relationship among experimental conditions: team size, task difficulty, time pressure (between-subjects) and subsequent experimental sessions (within-subjects). Previously, we have shown these conditions affect subjective ratings of workload that come from individual and group-level sources, synchronization of arousal, and team performance. In an experiment involving an emergency response (ER) simulation, 360 undergraduates, who were wearing electrodermal sensors, were organized into 44 teams of various sizes. Workload was experimentally varied by team size (three, four, seven or eight members), number of opponents (one or two), and time pressure; the latter was introduced sooner or later across two experimental sessions. Results showed that the experimental conditions affected synchronization levels, either at the beginning of a session or in the middle; synchronization and experimental conditions were not directly related to team performance. Subjective group workload ratings of the coordination demand of the task correlated with synchronization at the beginning of a session while team satisfaction was correlated with greater synchrony at the end of a session. The competitive nature of the ER task, as compared to strictly cooperative tasks, could be responsible for the complexity of these empirical relationships.

Guastello, S. J., Correro, A. N. II, & Marra, D. E. (2018). Do emergent leaders experience greater workload? The swallowtail catastrophe model and changes in leadership in an emergency response simulation. *Group Dynamics: Theory, Research, and Practice, 22*(4), 200-222. doi: 10.1037/gdn0000091

Although positions of greater responsibility imply greater workloads and consequences for actions, the experience of emergent leaders might be different. People who gravitate toward leadership roles might have a better understanding and skill set for the task requirements, and thus report lower workload. However, they might also report greater workload because they recognize demands that others do not foresee. Either way, the demands could impact a person's willingness to play a leadership role. This study examined workload effects within the framework of the swallowtail catastrophe model for leadership emergence. The experiment involved an emergency response simulation in two sessions; 348 undergraduates were organized into 44 teams of various sizes. Workload was experimentally varied by team size, number of

attackers, and time pressure. Subjective experience was measured by standardized ratings of individual and group-level sources of workload. In the empirical models, team discussions contributed to the asymmetry parameter, group size contributed to the bifurcation parameter, and team performance corresponded to the bias parameter. Changes in leadership between sessions were explained by the same dynamics, but here, individual ratings of performance demands and frustration also contributed to the bias parameter; moreover, ratings of coordination demands—a type of group-level workload—contributed to the asymmetry parameter. Participants who were not leaders in the first session but assumed leadership roles later were less frustrated by the task, perceived the performance demands as greater, and perceived the coordination demands to be less compared to others.

2020: FORECASTING ABILITY AND THE PREDICTION OF CHAOS

We examined humans' ability to anticipate and respond to chaotic events, as opposed to numerical forecasting. Often there is no time to fiddle with data collections, simulations, and scenarios; one must figure out what's happening in the moment, and make a response. There are three articles in this set. The first investigated the heuristics that one might use. The second investigated individual differences in personality and cognitive propensities that lead into accurate forecasts. The third is a now-classic CWLF study with the two cusp catastrophe models.

Guastello, S. J., Futch, W., Mirabito, L., Green, D., Marsicek, L. & Witty, B. (in press). Heuristics associated with forecasting chaotic events: A rare cognitive ability. *Theoretical Issues in Ergonomics Science*. Online first, 2019 doi: 10.1080/1463922X.2020.1818001

ABSTRACT: Chaos is a mathematical phenomenon in which seemingly random events are actually predictable by simple deterministic equations. Chaos has been identified in numerous situations requiring humans' situation awareness, sense-making, and control. The management of chaos could be a rare skill, however, and the heuristics for doing so are not well understood. These hiatuses thus motivated a new theoretical issue in ergonomics science concerning the distribution of this ability across different chaotic attractors and some of the heuristics that might be used to forecast events. Untrained undergraduates (N = 147) forecasted number series from four chaotic attractors of varying levels of computational complexity. Performance was measured as the correlation between forecasted numbers and real numbers. Participants' performance varied by type of attractor and whether the forecasts were made for one to four steps into the future. The less capable participants used moving averages strategies, whereas the best forecasters matched the real numbers more closely.

Guastello, S. J., Futch, W., Mirabito, L., Green, D., Marsicek, L. & Witty, B. (in press). Forecasting chaotic events and the prediction of a rare cognitive ability. *Personality and Individual Differences*. Online First, https://doi.org/10.1016/j.paid.2020.110430

ABSTRACT: People often live and work in chaotic environments, and thus need to forecast and control what will happen next. The management of chaos is an apparently rare skill, and it would be valuable to identify and develop this skill in the workforce. Untrained undergraduates (N = 147) forecasted number series from four chaotic attractors of varying levels of complexity. They contributed measurements of 16PF personality traits, general intelligence, field independence, and divergent thinking. The results indicated that field independence and personality traits associated with the creative personality profile were the most frequent correlates of performance on forecasting one to four steps into the future. It should be possible to adapt the experimental results to personnel selection and placement decisions that require the search for talent for forecasting.

Guastello, S. J., Futch, W., & Mirabito, L. (2020). Cognitive workload and fatigue dynamics in a chaotic forecasting task. *Nonlinear Dynamics, Psychology, and Life Sciences, 24*, 179-213.

Abstract: Many real-world tasks require people to forecast chaotic events in order to take adaptive action. This ability is considered rare, and less understood than other cognitive processes. The present study examined how the performance dynamics in a chaotic forecasting task would be affected by stressors such as cognitive workload and fatigue using two cusp catastrophe models. Participants were 147 undergraduates who were shown graphs and brief chaotic number series for which they needed to forecast the next four values. Performance data were complemented by variables known to represent cognitive elasticity versus rigidity, compensatory abilities for fatigue, and NASA TLX ratings of subjective workload. R^2 for the workload cusp was .56, which compared favorably to the next best linear alternative model (.12); it contained six bifurcation variables and three measures of workload (asymmetry). R^2 for the fatigue cusp was .54, which also compared favorably to the next best linear alternative (.07); it contained one bifurcation variable and two compensatory abilities. The role of field independence as an elasticity variable in the workload model and as a compensatory ability in fatigue was particularly noteworthy. Several elasticity-rigidity variables have now been identified over a series of studies. They appear to be operating in unison to produce a bifurcation effect, and different variables become salient depending on the task. Future research should consider how the ability to forecast chaos and its susceptibility to workload and fatigue carry over to dynamical decisions made while managing a complex system.