Disaster Series: High Reliability Organizing for (HRO) Disasters – Disaster Ecology and the Color of Noise

Daved van Stralen, MD, FAAP, Sean D. McKay, Thomas A. Mercer, RAdm, USN

Abstract:

The frequencies of stochastic noise inherent to the environment can be described as colors. The various colors of noise refer to the disruptive potential of stochastic energy within the environment and its characteristics. The meaning of the type of noise lies in the unpredictability of events and the 'forcing functions' of energy. That is the strength of the environment to force a system or population to respond. For human activity, the color types correlate to problem characteristics such as leadership-line authority coupling, well-structured, ill-structured, and embedded problems. When the noise color changes, forcing functions and the types of problems also change, increasing characteristics necessary for adaptation or altering characteristics in unexpected ways through relaxed selection. The noise process applies equally to nursing homes, NICUs,and public safety and is independent of timescale or magnitude. We need not characterize normal environmental variation differently from catastrophes.

"The noise process applies equally to nursing homes, NICUs,and public safety and is independent of timescale or magnitude. We need not characterize normal environmental variation differently from catastrophes."

Introduction:

A disaster is an environmental disruption of the larger community that affects multiple community systems and government services. In medical care, a disaster is an environmental disruption of the healthcare system. This is not only from the location of the disaster but also through its effects as they radiate throughout the local healthcare system (1).

The environment has always intruded into healthcare in some form, often becoming a part of healthcare, such as public health. Aerospace medicine provides medical care when the patient is healthy, but the environment has the pathology, a valuable analogy for medical care during a disaster. The strength of the intrusion is increasingly entropic, something we have no control over. Energy dissipation can intrude slowly or abruptly, recede quickly, or have an extended resolution. We discuss the effects of these patterns and the response by NICUs in the Neonatology Today Disaster Series for abrupt disasters (2), approaching disasters (3), prolonged disasters (4), and epidemics [scheduled article]. We can protect healthcare systems by blocking or distancing ourselves from the environment or by increasing the capabilities of the system and individuals.

"We can protect healthcare systems by blocking or distancing ourselves from the environment or by increasing the capabilities of the system and individuals."

Preparations for a disaster often focus on logistics and some form of hierarchy. Embedded in this planning are linear thinking, scientific deduction, and classical logic, none of which were developed for the disaster environment (5). Deprecated is stress-induced impairment of cognitive processes and operational performance, a problem recognized by HROs (6, 7). Rather than describing disasters as singular events, we draw upon physics to demonstrate how disasters and routine exigencies emerge from environmental noise, differing only in scale (8). We can then use routine operations to respond, but with an increased level of response.

The dissipation of energy from the disaster injures people and impairs necessary system functions and human activities. The structure of these abrupt environmental fluctuations can be described as '1/*f*-noise' that follows a power-law distribution rather than the normal, or gaussian, distribution [**Table 1**]. The increased stochastic noise of a disaster becomes a forcing function causing change to organizations and people. Perhaps the true force of nature is entropy and the resulting stochastic processes.

Table 1. Pink Noise and Power Laws

Spectral density. 1/*f*-noise is a measure of power per frequency interval where *f* is frequency.
Power spectral density. It measures the signal's energy when it concentrates around a finite time interval.
Power laws. Describe relationships between two quantities where the change in one gives a proportional change in the other independent of the initial size.
1/f-noise and power laws. The graphed relation of power density versus frequency forms a power law (9).

Viewed in this manner, we can discuss a disaster as stochastic noise in a stochastically noisy system. This background noise comes from everyday stochastic processes that corrupt the actual-world application of scientific studies. Fluctuating entropy in our open environment amplifies this natural noise. We routinely operate with environmental stochastic noise, which fluctuates, at times exceeding our ability to respond readily.

> ***"The unpredictable time and force of entropic, stochastic noise cause a disaster to impair effective planning and logistic preparation. Because the behaviors and actions for a disaster are used for routine operations, we may better prepare by increasing our capabilities."***

The unpredictable time and force of entropic, stochastic noise cause a disaster to impair effective planning and logistic preparation. Because the behaviors and actions for a disaster are used for routine operations, we may better prepare by increasing our capabilities. "You do in a disaster what you do in everyday life," James P. Denney, EMS Captain, LAFD, and veteran of multiple disasters and multiple casualty incidents.

Healthcare operates in a relatively closed system separated from the open public domain. In the closed healthcare environment, participants adopt specific roles such as a physician, nurse, patient, and parent, and the information generated is privileged, that is, legally confidential. Some healthcare domains, such as intensive care units and operating theaters, are even more sequestered, severely restricting those who can enter, what clothing they can wear, and the procedures they must follow. These environments are more highly sequestered to manage expected severe, abrupt changes in the patient's medical condition.

This restriction does not mean the healthcare system is completely sequestered. Energy and resources from the external environment enter but are filtered and dampened, not fully controlled but limited in their effect on medical care. In this manner, the external environment becomes a dampened forcing function on medical care, mainly by changing the probabilities of variables, generating stochastic processes.

We can describe a disaster as an abrupt, severe 'forcing function' onto a system already buffeted by environmental stochastic processes. ("External forcing by environmental noise alters the qualitative nature of the dynamics" (10)) Stated in this simplistic way, one might presume healthcare systems need only to expand operations to extend medical care into the disaster environment while at the same time the outside environment temporarily intrudes into healthcare. This idea misses the difference between a normal environment consisting of multiple *independent* stochastic processes and an environment of intermittent *correlated* stochastic processes. Correlation amplifies stochastic processes. The first has some degree of predictability while the latter does not. The difference profoundly affects how systems adapt to each environment. 'Environmental stochasticity' reflects the unpredictability of the environment (11).

Within our environment, we experience and must differentiate between signals and noise. Noise is unwanted, apparently disorganized stimuli that do not carry information. Signals carry objective information from the environment. Cues are *unintentional* byproducts of activity, such as a chemical's heavy scent indicating its presence. Novices preparing to operate in dangerous contexts learn to discern the salience of a signal so they will not disregard subtle or nuanced yet vital information. The authors have had routine experience with novices or outsiders who mistake subtle, nuanced signals as noise.

An observer on a fire rescue ambulance asked one author (DvS) about an experience responding to a home with an agitated crowd outside. Why did the team respond to a person who fell and bring in resuscitation equipment for a cardiac arrest? The author asked whom the crowd was looking at as the rescue ambulance arrived. They looked toward the front door of the house, meaning a serious event had occurred to a neighbor inside. In a benign event, many of the crowd would be looking at each other. A hostile crowd would stare at the crew of two as they arrived.

> *The PICU of the same author worked closely with the regional poison center, reporting all ingestions admitted to the unit. Over months, the unit experienced an increase in admissions of toddlers with toxic ingestions of iron from prenatal vitamins. The poison center reported this to the national network and identified an early epidemic of toxic iron ingestions. This led to communications from the poison center with physicians regarding prescription practices of prenatal vitamins. Data' noise' to the PICU team was an early herald of a potentially deadly epidemic to the poison center.*

Entropic and stochastic energy inherent to the environment profoundly affects people and organizations within that environment. The light spectrum provides a helpful analogy for understanding stochastic environmental noise's effects as 'forcing functions,' which is the environment's strength to force a system or population to respond. Stochastic noise, viewed as various colors, has characteristics for statistical evaluation, predictability, problem types, and human response. The noise process is independent of timescale or magnitude. We need not characterize normal environmental variation differently from catastrophes (8).

> ***"The light spectrum provides a helpful analogy for understanding stochastic environmental noise's effects as 'forcing functions,' which is the environment's strength to force a system or population to respond. Stochastic noise, viewed as various colors, has characteristics for statistical evaluation, predictability, problem types, and human response."***

Stochastic Noise in the Environment:

The concept that noise in the environment is entropic and stochastic can help us understand the response by healthcare systems to various types of environmental noise, from the emergency of a cardiac arrest to widespread disruption from a regional disaster. These types of noise define spectrum with spectral densities lending to the colors white, brown, red, and pink [**Table 2**]. Blue and black noise are included in the spectrum but beyond discussion in this paper.

Table 2. Spectral densities of noise

White noise $1/f^0$
Brown noise $1/f^2$
Red noise $1/f^\alpha$
value of α between 0.5 and 1.5
Pink noise $1/f^1$

If we separate and remove signals (cycles with predictability that have meaning) from noise (the residual variability that causes unpredictability), we can distinguish patterns of environmental stochastic noise. This noise can fluctuate over time or through space as serial correlations of flux (autocorrelation), or noise can exist as dominant frequencies in a power spectrum (8, 12). In the analogy with visible light, these fluctuations are termed 'color' to describe the pattern of predominant frequencies in a certain range of fluctuation (10) [**Table 3**].

"Environmental noise with constant variance per unit frequency (an equal and independent representation of all frequencies without autocorrelation) is 'white noise.' Events in white noise environments are random, without temporal correlation, because no frequency dominates (8, 13)."

Environmental noise with constant variance per unit frequency (an equal and independent representation of all frequencies *without* autocorrelation) is 'white noise.' Events in white noise environments are random, without temporal correlation, because no frequency dominates (8, 13). The environmental pressure of white environments favors the generalization of a population with *evolutionary* changes over periods longer than the life of individuals (14). White noise gives tractability for the descriptions of the operating environment for healthcare that can incorporate constant variance. It is this variance that places unexpected demands on the organization. Opposite of the relative predictability of white noise is 'brown noise,' a measure of randomness named for Brownian motion.

Following the light analogy for variance frequency, stochastic processes with slow fluctuations or low frequencies (long periods) have a 'red' spectrum. Low-frequency events are rare and have a greater spectral density. They are said to have increased redness in the spectrum. These low frequency, rare events significantly influence the system more than more common, high-frequency events with less spectral density (8). Their influence comes from their spectral density.

This appears counterintuitive because our undergraduate science studies focus on the normal or gaussian distribution where the greatest probability density is in the center norm, rare events are in the tails. The emphasis on normal distributions creates the misconception that outliers, events far from the mean, are random and independent events that can be readily disregarded. HROs maintain vigilance for these outliers, considering such discrepancies as early heralds of failure or the initial presentation of disruptive processes (15). Rare events and outliers are treated differently between power distributions with increased redness of the spectrum (noise) and normal distributions. Red noise environments describe an outlier possibility, while normally distributed environments describe the *probability* of an outlier.

Red noise events, or residuals, are autocorrelated, meaning there is an increased chance the event can continue, producing above or below average conditions that cause environmental disruption (10, 16). Red noise explains the lasting correlation of effects from a single event (8, 11). The environmental pressure of noise in red environments favors the specialization of a population. *Ecological* change and responses occur within the lifetime of individuals (14). Special environments in healthcare, such as the ICU, Emergency Department, and operating theater, operate in a red noise spectrum environment.

Pink, 1/f, noise

'Pink' noise lies between the predictability of white noise (no correlation in time) and the randomness of brown noise (no correlation between increments). The variance of pink, or 1/*f*-noise, differs from other red-spectrum noises in that variance continues increasing regardless of the length of the measured time series. Pink noise power decays as the inverse of frequency, causing common and rare environmental events to gain equivalent weight in a pink environment (8). Midway between white and red noise, environmental pressure from pink noise equally favors a balance of generalization and specialization (14).

"Pink noise power decays as the inverse of frequency, causing common and rare environmental events to gain equivalent weight in a pink environment (8). Midway between white and red noise, environmental pressure from pink noise equally favors a balance of generalization and specialization (14)."

The stochastic noise fluctuations of white noise have equal power in every unit of bandwidth, while brown noise fluctuations demonstrate randomness. Astronomers studying quasars considered stochastic noise to be signals and found quasar signals fell exactly between white and brown noise, called' flicker noise' at a factor of 1/f (17). The name flicker noise came from John B. Johnson's initial measurements of the white noise spectrum. He measured an unexplained flicker at low frequencies halfway between white and brown noise (18).

Pink noise behavior (17) has been reported in:

- Quasar signals
- Deep undersea ocean current velocities at a depth of 3100m
- The radio audio output of Scott Joplin piano rags and news-and-talk programs

Pink noise characteristics (19) have been identified in:

- EEG alpha wave
- Heartbeat period time interval between the R peaks
- Body sway, when standing upright, the body sways later-

Table 3. Patterns and Characteristics of Noise

Color	**Analogy** Light spectrum	**Variance**	**Characteristics**
White	White light No frequencies dominate Flat spectrum Spectral density has equal amounts of all frequencies	Gaussian distribution - elements fully independent - no autocorrelation Mean converges over long periods - converges at low frequencies - diverges at high frequencies More data - narrows variance - forms Gaussian curve	Values of a random signal at two instants in time are entirely independent of each other
Brown	Brownian motion Spectrum generated by a signal in a random walk "Drunkard's" or "random" walk	Random distribution Over long periods: - no defined mean - value at a single point	Random The random variable drifts Brown processes are 'non-stationary.' A particle in Brownian motion: - *position* – brown noise process - *velocity* – white noise process
Red	Dominated by low-frequency or long-period cycles (hence, red) Optical spectra with surplus lower frequency light appear redder.	Power law distribution Not independent - mutual/reciprocal relations Variance increases with the length of the series - more data over more extended periods increase variance Autocorrelation of residuals Correlation events decline exponentially with separation in time	Time-domain – increased probability of long runs of above / below average effects Slow changes - low frequencies dominate - slow variations have greater 'strength' than rapid ones - (only 'revealed' in longer time series) If low frequencies have spectral density > high frequencies - *effect of low frequency (rare) events have more significant influence than high frequency (common) events*
Pink	Lies *exactly* midway between white noise and brown noise on a scale of redness "Flicker noise"	Power law distribution - no well-defined long term mean - no well-defined value at a single point Variance increases regardless of time series length - distinguishes pink noise from other reddened spectra More data continuously increases variance	Slower decline in correlation - correlation of fluctuations falls off as a power law

ally and back and forth

- Music, the spectral density of fluctuations in the loudness of (especially classic) music
- Pain-relieving stimuli, transcutaneous electrical nerve stimulation (TENS), the impulse repetition frequency generated by l/*f* fluctuations
- Traffic flow

> *"Each color noise creates a distinct operating environment. When unrecognized, adaptive traits are mistranslated for use by others or misapplied when one is unwittingly present in a changing environment."*

White, Red, Pink Noise:

Each color noise creates a distinct operating environment. When unrecognized, adaptive traits are mistranslated for use by others or misapplied when one is unwittingly present in a changing environment.

White Noise

The Gaussian distribution brings a normative value as error measure measurement in this information-dependent system. Error in the white noise environment comes from acting and is visible and correctable. The stability of the environment conceals 'error from not acting,' enabling such errors to become incorporated into organizational knowledge (20). Unfortunately, from the Gaussian distribution, we develop statistics for descriptions and probabilities for prediction. The Euclidean space has measurable hierarchies fitting the environment and forming the organization.

"I don't know": the Hedgehog, and the Fox

Hearing "I don't know" engendered confidence in the fire rescue ambulance and fire service. The phrase marked the initiation of an investigation. In medicine, hearing "I don't know" loses confidence in the person. The person *should* know. One of the authors (DvS) has personally experienced both reactions in each setting – the conflict between doubt and certitude.

We digress here because white noise environments are susceptible to certitude. Subordinates and novices often find security following an individual who demonstrates certitude, whereas veterans of live-or-die circumstances prefer doubt. This conflict is more profound than one's preferences.

"The fox knows many things, the hedgehog one great thing."

Archilochus, Greek poet

Studying the success rates of forecasters in politics, intelligence, and journalist commentary, Philip E. Tetlock (21) found the worst success rate from those with the greatest certitude and higher rates from those who entertained the most doubt. He turned to Isaiah Berlin's essay *The Hedgehog and the Fox* for the explanation.

Hedgehogs will extend their one theory to many domains with great confidence. When they are wrong, they focus on justifying their decision

The 'super forecasters,' Foxes know many things to a far lesser degree. They use a point-counterpoint style of thinking to sustain doubt and understand how opposing, and contradictory forces yield stability, a feature that confounds prediction. Superforecasters pursue and update information, revising conclusions as information becomes available.

Prediction and explanation are not tightly coupled. An explanation is possible without prediction. Prediction is possible without explanation.

Tightly coupled concepts support expert formation and mastery but at the risk of creating "hedgehog" experts who know one thing well that they apply to all situations (21). The linear structure allows matching resources to disturbances and solving problems much like a puzzle – find the pieces for their proper space (22). Problems match the well-structured problem amenable to algorithmic solutions described by Herbert Simon (23).

The stability of a white noise environment permits context-free concepts and problem solving, placing greater significance on classifications (24) and abstractions (25). System change occurs over generations in an evolutionary manner rather than context-dependent ecological processes. Leadership is less critical than executive, administrative, and managerial skills (26), where 'categorical work' creates classifications and rules to work by (24) [see below].

> *"The stability of a white noise environment permits context-free concepts and problem solving, placing greater significance on classifications (24) and abstractions (25). System change occurs over generations in an evolutionary manner rather than context-dependent ecological processes."*

Red Noise

The non-Gaussian distribution supports a more topological space influenced by relations rather than the metrics of points and distances. Rather than probabilities, possibilities, and the ease of an event influences predictions (27). Environmental' forcing functions' drive environmental influences into the organization, destabilizing the internal environment. Problems become contextual with pragmatic solutions. Changes occur within the experience of the individual. Contextualization in short periods makes a red noise environment ecological and amenable to pragmatism.

Loosely coupled, overlapping, and gapping concepts create a confusing environment where the problems are ill-defined (15). Simon (28) described how we naturally use heuristics to solve these ill-structured problems. Heuristics, however, create a bias (29) that can be corrected by error (30) and motor cognition (31) – 'error by acting' is visible and correctable (20). In a dynamic environment, the ill-structured problem is more of a mystery that we solve by finding clues (22).

Doubt as a problem-solving method, combined with rigorous evaluations of failure, breeds super forecasting 'foxes' who know a little about a lot, a strategy that further drives learning and develops a different type of mastery (21). Doubt, broad knowledge, and concern for consequences are practical common sense problem solving (32). Leadership is an integral part of the executive, administrative, and managerial skills (33), bringing together categorical work with 'articulation work,' the way things worked out in practice (24) [see below].

The long periods without change mimic a white noise environment. Individuals who enter a red-noise environment during such a period may believe they are operating in a stable environment, much like a shifting baseline (34) [see below]. The result is tolerance of 'hedgehog forecasting' but the greater value in 'fox super forecasting.'

Pink Noise

Environmental forcing functions are more severe and sudden in the pink noise environment, pushing the ill-structured problem into the environment as the environment is forced into the organization. Problem-solving differs with greater reliance on heuristics and early error identification (30). Characteristics such as certitude and rigid central authority cause less visible damage to the organization in white noise to become deadly in the pink noise environment, even during slack periods. As a 'leader-leader,' leadership integrates fully into the organization (35). The greatest difficulty in communicating across the gap between white and red noise environments is avoiding jargon and cliché (15). The *Neonatology Today Disaster Series* is one effort to translate pink noise organizational characteristics for those who work in the red and white noise environments.

"We sacrifice accuracy for conceptual tractability when separating the organization from the environment. The Gaussian distribution of white noise environments supports discrete concepts, hierarchical systems, and linear thinking independent of context or the environment."

The Meaning of Color:

We sacrifice accuracy for conceptual tractability when separating the organization from the environment. The Gaussian distribution of white noise environments supports discrete concepts, hierarchical systems, and linear thinking independent of context or the environment. The observer's frame of reference moves outside the flow of events and becomes fixed as Eulerian specificities (27). Authorities use this external reference frame to create models for the reddened environment. However, the reddening of the environment increases variance, dissolving Gaussian distributions and creating unpredictability (8).

We also cannot discuss the colors of noise without discussing the relation between internal changes of individuals, populations, and organizations against environmental forcing at different frequencies (13). The variance of red noise ensures that the energy in the environment will, at some interval, force the organization into a response. In ecology, these forces drive a population into extinction or adaptive change.

The resistance of human systems against such change creates two self-organizing systems – social and environmental. Social systems self-organize against stochastic noise. Self-organizing occurs within the environment from the interplay of social self-organizing and self-organizing from stochastic noise. Social self-organizing creates scale-free growth from small social units into society. Bringing structure to the reddened environment becomes less amenable to outside direction. "Many natural systems become structured by their internal processes: these are self-organizing systems, and the emergence of order within them is a complex phenomenon," E. Eugene Yates (36)

Unpredictability

White noise has a Gaussian distribution while colored noises deviate from the normal distribution, which can confound research results relying on a normal distribution (12). Reddened noise and pink noise (pink noise is specifically 1/*f*-noise) have a power-law distribution rather than a Gaussian distribution. Pink noise behaves in a fractal, power-law manner similar to snowflakes, coastlines, earthquake magnitudes, city size, Zipf's law (8), and explains the presentation of abrupt environmental disturbances.

Unpredictability, whether routine stochastic unpredictability or that of a disaster, demonstrates a striking difference between organizations operating with pink and red noise compared to white noise. High-Reliability Organizations (HRO) in the pink environment engage unpredictability through leadership, the purpose of safety, their use of error, and how they train novices. We must remember that High-Reliability Organizations (HRO) amalgamate safety into leadership and consider safety as integral to operations.

The amalgamation of leadership and safety ensures reliability through the development of the "leader-leader" rather than creating "leader-followers (26, 35). Organizational leadership in white noise environments follows the conventional line authority of executives, administrators, and managers. Authority derives from the organization's owners (or the head of one of the three branches of government for governmental organizations). Authority for decision-making as *line authority* derives from the need to control an organization's operations. *Functional authority* is employed to control local events, a type of authority more closely associated with high-reliability operations in pink noise (33, 37).

"Functional authority to control local events is significant for an HRO operating in the extreme stochastic randomness of pink noise. White noise organizations encounter stochastic randomness but with less frequency density than red noise organizations. With the greatest red frequency density, Pink noise organizations experience the most significant demands and disruptions."

Functional authority to control local events is significant for an HRO operating in the extreme stochastic randomness of pink noise. White noise organizations encounter stochastic randomness but with less frequency density than red noise organizations. With the greatest red frequency density, Pink noise organizations experience the most significant demands and disruptions.

In pink noise organizations, leadership and line authority are tightly coupled, creating a singular identity. 'Leadership-line authority' coupling can loosen in red noise organizations following extended periods without environmental forcing. The coupling becomes quite loose in white noise organizations, yet the leadership-line authority identity remains to muddle their distinct functions. This muddling compromises the necessary obedience to authority in pink noise environments and can motivate unaligned 'workarounds.'

"Extending an organization into pink noise environments utilizes different characteristics, dynamics, and social interactions than in a white noise environment (6, 31). Safety as an organizational response is the distance between stochastic environmental frequencies and the organization's stochastic operational frequencies. "

Extending an organization into pink noise environments utilizes different characteristics, dynamics, and social interactions than in a white noise environment (6, 31). Safety as an organizational response is the distance between stochastic *environmental* frequencies and the organization's stochastic *operational* frequencies. The operators' concerns are the density values of lower frequencies causing infrequent clustering that can presage systemic operational deficits or the stochastic downward fluctuations of operational performance. In either case, the forcing functions in a reddened environment may exceed stochastically lowered performance, or an abrupt stochastic peak in a pink noise environment may rapidly exceed the performance capabilities of the organization.

Separation of the stochastic flux of organizational processes from the stochastic fluctuations of a reddened environment gives tractability for management and planning but will lead to rare, costly failures. White noise administrators can operate much closer to their white noise environment by utilizing *proactive defenses*. When risks are predictable and controllable, proactive defenses have the greatest effectiveness. When risks are consistently high or defensive costs are low, fixed constitutive defenses become effective (38, 39). White noise environments are amenable to static defenses such as a centralized authority hierarchy having steep authority gradients and relying on algorithms, rules, and protocols. Following management science, principles for risk management are also prudent.

Increasingly unpredictable or uncontrollable risks in the reddened environment will vary by location or over time. *Reactive defenses* then become more effective and reliable. Inducible responses allow the selection of behaviors with variable expression, increasing behaviors for elevated risks and decreasing their expression as the risk abates (39). These organizations focus on capability and decision migration with increased information flow, the basic characteristics of HROs. Responsive, adaptive organizations will naturally develop into an HRO.

HROs incorporate safety as integral to operations through the mantra, "safety through operations and operations through safety" (26). Safe behaviors during operations create effectiveness and efficiency. Because threats, particularly at their initial presentation, are unpredictable, uncontrollable, and variable, any breach in safety is amplified as the incident consumes resources necessary for the operation. Safety as an individual response is part of leadership using the leader-leader model to extend safety into operations.

Error in a white environment derives from models and the Gaussian distribution. These errors are information-dependent and measure the distance from the desired mean or model (40). In the stochastic noise of the pink environment, error marks the boundary of knowledge and the border of capabilities (30). Error for the HRO becomes a safety border.

"Error in a white environment derives from models and the Gaussian distribution. These errors are information-dependent and measure the distance from the desired mean or model (40). In the stochastic noise of the pink environment, error marks the boundary of knowledge and the border of capabilities (30). Error for the HRO becomes a safety border."

A more predictable environment with white noise also reduces demands on less experienced personnel, with less supervision necessary compared to the variability of a reddened environment (13). Organizations operating in red environments, especially with pink noise, focus on training their novices with a particular focus on early fieldwork (6).

Forcing Functions

White and reddened environments have different onsets and strengths of environmental forcing functions that can affect organizational performance. White noise has longer forcing periods acting over more extended periods, somewhat equivalent to evolutionary processes. In systems dominated by lower frequencies, that is, increased redness, ecological processes predominate. In these situations, variation maintains equilibrium (13).

In a white environment, the organization may consider resilience as the goal for recovery. This resiliency makes sense because white environments are relatively stable, and the return to operations as before is likely a wiser use of resources. The organization may conclude that the environment has changed in a reddened environment. Prudence then dictates a change to increase capabilities. Persistence becomes the goal rather than resilience (13).

Forcing functions experienced by the individual illuminate the stress response functions and reveal weaknesses in leadership and the social fabric of the organization or culture. Novelty, uncertainty, and uncontrollability cause stress (41, 42), elements that are inherent to red noise.

- *The novelty* comes from the emergence of new properties during the nonlinear interactions of self-organization.
- *Uncertainty* is an inherent principle of linear, time-variant systems, a product of the stochastic frequencies in red noise. (Heisenberg's Uncertainty Principle is an example from quantum mechanics.)

- *Unpredictability* develops from stochastic frequencies and the rate of change in the logistic equation that can develop into deterministic chaos (43).

These elements of stress are within the domain of the brain's executive functions. Temporal organization of behavior is essential for sequencing novel and complex behavior responding to red noise and stress elements. The executive functions integrate between prefrontal cortex *representational* neurons and posterior parietal cortex *operant motor* neurons to accomplish this (44-46). Adaptive stress responses, mediated by cortisol, limit cognition to bring behavioral focus to the threat, support protective actions by inhibiting memory recall in select systems, and enhance memory recall for habits and learned behaviors. The individual will quickly use learned behaviors without losing time thinking and developing plans or actions (7, 47). Because of their essential survival function, behavioral stress responses remain little changed across mammalian species, though conserved within phylogenetic constraints (48).

Problem Characteristics

It is too easy to reduce the fire service to firefighting and EMS today. William J. Corr, Captain, LAFD, and WWII US Navy veteran, South Pacific, viewed the fire service uniquely as a way of thinking and acting. In effect, he modeled motor cognition (thinking *by* acting) in his career from the late 1940s through the 1970s. To expand the frame of reference of firefighters from specialists to specialist-generalists, he often counseled, “We don't fight fires. We solve problems the public cannot or will not solve themselves.” These were not simple problems but ill-structured that might be embedded in a dangerous situation. When trite problems arose, he modeled as a learnable skill how to solve a ‘simple’ problem during a ‘live-or-die’ situation, keeping those around you living while you gave yourself space to think. Today, we might say he took the white noise environment into the pink noise space, giving all equal weight.

“In the beginning, we do not know if the problem is white, red, pink, or brown noise. The trite or straightforward problem could be the appearance of a covert, compensated state that may self-resolve, be straightforward to address, or challenge us on the way to overwhelming us.”

In the beginning, we do not know if the problem is white, red, pink, or brown noise. The trite or straightforward problem could be the appearance of a covert, compensated state that may self-resolve, be straightforward to address, or challenge us on the way to overwhelming us. Like Captain Corr's approach, we treat all problems as ones that cannot be solved. We know that environmental forcing functions alter the qualitative nature of the system's dynamics (10), making every problem a new problem.

There is an ecological hierarchy of problems, however. Problems in a white noise environment tend to be well-structured. In a red noise environment, we can encounter ill-structured problems, and in the pink noise, environment problems embed in the stochastic activity of the environment.

The white noise environment contains Herbert Simon's well-structured problem that is amenable to the algorithm (23, 28), solved much like a puzzle with a set number of pieces fitting into a pattern (22). Abstractions and concepts provide the basis for understanding and prediction. With the Gaussian distribution, problems tend to be information-dependent, and error measures the distance from the model or concept. Classical logic and scientific reasoning are used (5).

The red noise environment is ecological, therefore contextual and pragmatic (15). It contains Simon's ill-structured problem solved with heuristics corrected by error (23, 27, 28, 30). These problems are information-independent. We cannot easily differentiate information from noise. We search instead for clues as in a mystery rather than pieces of the puzzle (22). We will be generating structure as we generate information. Red noise has a power-law distribution.

The pink noise environment is also ecological, but the problem is embedded into the environment, making these problems contextual and pragmatic (49). Problem-solving tends toward practical common sense, focusing on consequences and a broad knowledge base (32). Reciprocal feedback decision-making methods provide flexibility, such as Boyd's OODA Loop (49). Actions through motor cognition (31) generate information by converting uncertainty to certainty (50).

Data collected to understand a reddened environment better quickly becomes difficult to interpret. Variance in the presence of red noise does not form a Gaussian curve. Instead, the variance increases with the period. In pink noise, the variance increases no matter how long the time series (8).

“Data collected to understand a reddened environment better quickly becomes difficult to interpret. Variance in the presence of red noise does not form a Gaussian curve. Instead, the variance increases with the period. In pink noise, the variance increases no matter how long the time series (8).”

That is, dissipating energy to the more extreme degree can achieve chaos.

Classification in Colors

The environmental disorder can become spontaneously ordered through self-organization as a dissipative system. That is, dissipating energy to the more extreme degree can achieve chaos. Social systems direct self-organization through the behaviors of each member. Therefore the self-organization does not become dissipative. Alternatives to self-organization can include a well-informed leader directing the group's activity. Having a leader means the system is not self-organized. The group may follow a blueprint, a representation of the pattern, a recipe, or sequential instructions for each member. Blueprints guide *what* is done but not *how* and do not synchronize workers. Recipes guide *how* it is done but do not coordinate workers' activity or adjust for temporal events (51).

To use an alternative to self-organization, we would need to classify elements of the event. Classifications act as objects for cooperation and create boundary objects for communication across infrastructure during a disaster (40, 52). Classifications build from data, which is not a problem in the gaussian white noise environment where more data narrows the variance to form a norm. Variance in a reddened environment increases with data, and we lose the norm. One solution is to disregard environmental noise (8), but the noise is the disaster.

Classifying the elements gives us an understanding and perception of control. Once we obtain a diagnosis, we know how to manage the disease. Classifying a disease can be for the clinical purposes of prediction, treatment, or data collection through the ICD-10 codes. In his first year (1972) on an ambulance, one of the authors (DvS) stood at the head of a patient with a head injury next to a harried emergency physician. The physician intently looked

at the scalp above the ear. When asked what he was waiting for, the physician said he thought the patient had intracranial bleeding and he should drill a burr hole through the skull to let blood out and relieve the pressure. "Why don't you drill?" the author asked. "Because if I drill and there is no bleeding, then the physicians in a meeting across the hall will take away my job." "If you don't drill and it's bleeding?" the author asked. "He dies."

That was the author's introduction to medicine – the diagnostician in a meeting is revered; the doctor at the bedside sweating over what action to take is the one at risk.

"That was the author's introduction to medicine – the diagnostician in a meeting is revered; the doctor at the bedside sweating over what action to take is the one at risk."

The forcing function of the medical environment within a white noise environment was to find a classification. The physician was operating in a pink noise environment with imminent death possible for the patient. His stress came from what Susan Leigh Star termed "tacking back-and-forth between the expectation for a well-structured problem" and diagnosis and the demand of the ill-structured problem to prevent death (24). Star described how administrators or regulatory agencies would try to control the tacking back-and-forth by making equivalent the ill-structured and well-structured aspects of boundary objects through classification and standardization.

The dichotomy is 'articulation work,' the way things worked out in practice versus

'categorical work,' creating the rules. Articulation work is real-time managing and anticipating contingencies in the face of the unexpected, directing efforts to keep the program running. As its name implies, categorical work classifies for communication, juggling meanings, and seeking conforming actions and compliance (24).

Assumptions of time as the only dependent variable and that space is constant allow for structural web and energy flow diagrams. However, they fail to allow or explain the switching between varying structures. For example, Simon's ill-defined/well-defined problem or Star's dichotomy of operators doing articulation work and administrators doing categorical work. The embedded problem confounds these divisions amidst the qualitative changes from system dynamics.

Evolutionary and Ecological Progression:

In biological systems, external stochastic forcing at different frequencies affects the internal biological rates of change in populations and organisms. Slower or gradual evolutionary processes at the population level dominate in white noise environments, while contextual ecological processes at the individual level dominate in red noise environments. However, the ability of organisms to respond to change has a profound influence over adaptations and population strategies.

"Though the terrestrial environment has greater short-term variability than the marine environment, it is relatively stable over the long term. The marine environment has greater change over long periods but with greater stability in the short term. Terrestrial noise, then, is white and marine noise is red."

Though the terrestrial environment has greater short-term variability than the marine environment, it is relatively stable over the long term. The marine environment has greater change over long periods but with greater stability in the short term. Terrestrial noise, then, is white and marine noise is red. However, the terrestrial environment exposes organisms to reddened noise, driving internal adaptations for short-term variability, which can minimize the effects of long-term variation (13).

In the marine environment, poikilotherms dominate even at higher trophic levels without the need to control their internal environment. Larval and adult phases in fish populations also became decoupled with less supervision and feeding of the young (13). This circumstance illustrates the difficulty of comparing population responses to environmental stochastic forcing. Short-term variability on land creates responsive, robust populations that are better able to withstand long-term change. The marine environment's greater short-term stability creates ill-adapted populations to withstand long-term change.

We can see these differences in healthcare cultures. Medical care exists in a white noise environment, while red noise environments include critical care units and emergency departments. Though rehabilitation medicine and long-term care would be expected to operate in a white noise environment, some programs operate in red noise or have the constitutional ability to adapt despite a white noise environment.

One author (DvS) has extended EMS and critical care into nursing homes to create subacute care facilities capable of 'red-noise' operations (53-55) and has worked with a county public health agency supporting families with disabled children. These groups did not "accept" their operating area as a white noise environment. Instead, they sought out and responded to stochastic variances, even acting into pink noise variances. We must not view these groups as outsiders to reddened environments.

Extension of Nursing Home Care

The extension of a pediatric subacute care facility (San Bernardino, CA, Community Medical Center) into active management of mechanical ventilation reddened the nursing home's white noise environment. Before the change, the response to a medical emergency was 911 notification. One of the authors (DvS), unfamiliar with the concept of white, red, and pink noise, encouraged vigilance for the *loss of a smile* in a child. (Loss of smile as a sign of hypoactive delirium is a sensitive interoceptive marker for physiological dysfunction.) Visual evaluation for covert compensated physiological dysfunction rather than focus on lab studies, x-rays, causes, errors, or mistakes became the norm. The author educated staff to think of consequences rather than diagnoses or risks and encouraged identification and correction of physiological dysfunction.

The way of thinking changed and became appropriate for a reddened environment. What did not change was staff, administration, or infrastructure. This approach moved the facility from a white noise environment to the red noise of management of acute respiratory failure, initiation of mechanical ventilation, and treatment of hypovolemia. As a result, patient mortality and transfers to the PICU decreased. Creating critical and long-term care for what can now be understood as a red noise environment produced new ventilator strategies. Ventilators now enhance the child's life by using *smiling* as the goal of mechanical ventilation (56).

Home Care Support – Children with Severe, Complex Disabilities

A children's service with the Riverside County (CA) Public Health Agency reviews medical support for children with limited ability to ambulate. Physicians order treatments, but exigencies impair care delivery, complicated by all participants' limitations in health, social, and cultural literacies. Healthcare professionals have limited exposure to the unique exigencies of home environments. Problems emerge from local, nonlinear interactions between impaired physiological systems, medical conditions, treatments, and home circumstances.

"The whole situation develops into an embedded problem. What appears to be a white noise environment has become one of red noise and, easily, a pink noise environment. Children miss appointments due to emergency department visits or hospital admissions, while the occasional child arrives with a medical or emotional crisis."

The whole situation develops into an embedded problem. What appears to be a white noise environment has become one of red noise and, easily, a pink noise environment. Children miss appointments due to emergency department visits or hospital admissions, while the occasional child arrives with a medical or emotional crisis. It is challenging to characterize the problem, identify a responding medical specialty, and develop effective treatments. Consequently, unrecognized stochastic forcing functions are not resolved. With no knowledge of the effect of reddened noise or these principles, the review team views the problem within an ecological system of reddened noise and forcing functions. By recognizing the consequences of failure by not acting (20), the review team increases adherence by families to continuous, prolonged treatments and finds direct interventions the families can manage. Irreversible consequences and medical costs are then avoided.

NICU staff having no experience in disasters have demonstrated the ability to extend neonatal care into pink noise despite minimal ability to prepare (2-4). The development of response plans will become more robust and pragmatic with the inclusion of bedside caregivers.

Growth from Pink to White:

A domain grows and develops by gaining control and finding predictability in the environment. Problems become well-structured with fewer ill-structured problems. Algorithms and protocols are developed. The novice entering this domain will not learn the reason behind specific attitudes or rules. The inability to support these attitudes while mentoring and teaching new novices shifts the baseline of attitudes and knowledge.

A Shifting Baseline

Daniel Pauly (34) first identified such a baseline shift in fisheries science, where he noticed that new researchers used their initial observations of the fish catch as a baseline of fisheries productivity and change. Over time, the change in fisheries appeared smaller than when measured over the span of several careers. High-Reliability attitudes and characteristics are lost during this period of shifting baseline.

We can see that as the environment of a domain becomes more controlled, less influenced by entropy, a healthcare system and medical discipline will move from pink to red, then toward a white environment. We see this with the domains of emergency and critical care, operating theaters, and emergency medical services as they move to a more rule-based, algorithmic approach. Neonatology differs in that some NICUs operate in white and red noise while university research NICUs remain within pink noise environments.

Relaxed Selection

A domain shifting toward a white noise environment can also shift from reactive to proactive defenses. The shift to a white noise environment weakens or removes a source of selection that had been important in maintaining behavioral traits. This situation of 'relaxed selection' leads to the disappearance of traits that once were necessary for survival. These traits eventually disappear, but some break down quickly while others linger (57).

"The behaviors necessary for reactive defense come in suites of behaviors and do not simply disappear. The resulting relaxed selection causes slow disintegration of the suites of reactive defense behaviors, leaving some behaviors as remnant behaviors out of place while other behaviors will be needed but lack their suite of supporting behaviors (7)."

The behaviors necessary for reactive defense come in suites of behaviors and do not simply disappear. The resulting relaxed selection causes slow disintegration of the suites of reactive defense behaviors, leaving some behaviors as remnant behaviors out of place while other behaviors will be needed but lack their suite of supporting behaviors (7).

Loss of selection pressure not only occurs from a change in environmental adversity but also because of a change in the nature of the selection pressure. For example, the demands of a supervisor who has not operated in an adverse environment will create an arbitrary selection. In such situations, the supervisor may not obtain the wished-for behaviors; subordinates develop protective behaviors rather than productive behaviors, distinguishing between natural and artificial environments (58). This development is like animal domestication, introducing domesticated traits that, while attractive and productive in a protected space, are unsuitable for survival in the wild condition (59).

Different Levels of Analysis:

The color analysis of environments is confused by the dynamic mixing of the environment with the organization, intertwined through common forcing functions, viewed from different frames of reference and various points of view. The magnitude of change, power of environmental forcing functions, geographic spread, etcetera drive the necessity for voices 'requisite diversity'. Accuracy of the situation supersedes closely held beliefs. "Failure to identify levels of analysis … can create false debates," Scott A. MacDougall-Shackleton (60).

Points of view along the vertical organizational hierarchy are necessary to maintain close contact with contextual changes for logistic support. This support underscores the benefit of common terminology and the development of lexical elements for accurate rendering of the changing circumstances.

Reference frames from within the flow of events and outside fixed points can combine for accurate understanding and preparation of evolving events. Recognizing the ecological nature of pink noise environments will bring attention to effects in smaller, even adjacent areas.

"Reference frames from within the flow of events and outside fixed points can combine for accurate understanding and preparation of evolving events. Recognizing the ecological nature of pink noise environments will bring attention to effects in smaller, even adjacent areas."

Conclusion:

Environmental noise from entropy and stochastic processes disrupts routine operations and corrupts planning. Though the most significant degree of disruption from stochastic environmental noise occurs during a disaster, this dynamic continuously operates at various scales in the environment around us. The pervasiveness of stochastic environmental noise confounds our best efforts to prevent errors and failures through *proactive defenses*.

Inducible *reactive defenses* allow the selection of behaviors with variable expression, increasing behaviors for elevated risks and decreasing their expression as the risk abates (39). The necessary judgment becomes available through a tight coupling of leadership-line authority and fostering leader-leader members. The focus on capability and decision migration result in increased information flow and effective, rapid responsiveness.

The medical conditions of premature infants can also be described with stochastic noise. Rather than focus on an expected physiological weakness or failure, NICU staff remain vigilant for any discrepancy or disruption. This focus is not to characterize error or assign blame but to make the statement, "I don't know." The acknowledgment of doubt is the beginning of inquiry and engagement.

Low-frequency events will always occur. Their strength as forcing functions, though, will vary. We cannot protect ourselves from low-frequency events in our patients or environment. Then, it may not be worthwhile to seek *where* failure will occur. Instead, we may be better served to identify covert, compensated states and engage outliers as if they were signals in the red noise environment rather than random and independent noise in the white noise environment.

> *"Pink noise shows no preference for short or long-timescale disturbances. From seconds to millennia, natural disturbances of various sizes can be seen as part of a seamless l/f-noise process. In this picture, we need not make any special distinction between normal environmental variation and ecological 'catastrophes': it is the same thing seen at different scales."*
>
> *John M. Halley (8)*

An infant in a reddened environment will always have the unexpected. There will always be an unexpected. The unexpected can be managed (61).

References:

1. *van Stralen D, McKay SD, Mercer TA. Disaster Series: Elements of a Disaster. Neonatology Today. 2021;16(10):108-15.*
2. *van Stralen D, McKay SD, Mercer TA. Disaster Series: The Abrupt NICU Evacuation – Disasters without a Plan. Neonatology Today. 2021;16(12):xx-xx.*
3. *van Stralen D, McKay SD, Mercer TA. Disaster Series: The Use of Information for Wildland Fire and the NICU: Combined Evacuation and Sheltering. Neonatology Today. 2021;16(11):105-14.*
4. *van Stralen D, McKay SD, Mercer TA. Disaster Series: Prolonged Improvisation – High Reliability Organizing, the NICU, and Hurricanes. Neonatology Today. in press.*
5. *van Stralen D, Mercer TA. High-Reliability Organizing (HRO) and Abrupt Change from COVID 19: Failure of Scientific Rationality and Classical Logic. Neonatology Today. 2021;16(6): 97-109. doi: https://doi.org/10.51362/neonatology.today/2021616697109*
6. *van Stralen D, Mercer TA. High-Reliability Organizing (HRO) in the COVID-19 Liminal Zone: Characteristics of Workers and Local Leaders. Neonatology Today. 2021;16(4):90-101. doi: 10.51362/neonatology.today/2021416490101.*
7. *van Stralen D, Mercer TA. Pragmatic High-Reliability Organizations (HRO) Modulate the Functions of Stress and Fear Behaviors During Pandemic COVID-19: The Stress-Fear-Threat Cascade. Neonatology Today. 2020;15(10):126-34. doi: 10.51362/neonatology.today/2020101510126134.*
8. *Halley JM. Ecology, evolution and 1f-noise. Trends in ecology & evolution. 1996;11(1):33-7.*
9. *Bak P, Tang C, Wiesenfeld K. Self-Organized Criticality: An Explanation of 1/f Noise.*
10. *Vasseur DA, Yodzis P. The Color of Environmental Noise. Ecology. 2004;85(4):1146-52.*
11. *Ruokolainen L, Lindén A, Kaitala V, Fowler MS. Ecological and evolutionary dynamics under coloured environmental variation. Trends in Ecology & Evolution. 2009;24(10):555-63.*
12. *Fowler MS, Ruokolainen L. Confounding environmental colour and distribution shape leads to underestimation of population extinction risk. PloS one. 2013;8(2):e55855.*
13. *Steele JH. A comparison of terrestrial and marine ecological systems. Nature. 1985;313(6001):355-8.*

14. Grove M, Borg JM, Polack F. Coloured noise time series as appropriate models for environmental variation in artificial evolutionary systems. arXiv preprint arXiv:200616204. 2020.
15. van Stralen D. Pragmatic High-Reliability Organization (HRO) During Pandemic COVID-19. Neonatology Today. 2020;15(4):3-9.
16. Kaitala V, Ylikarjula J, Ranta E, Lundberg P. Population dynamics and the colour of environmental noise. Proceedings of the Royal Society of London Series B: Biological Sciences. 1997;264(1384):943-8.
17. Press WH. Flicker noises in astronomy and elsewhere. Comments on Astrophysics. 1978;7:103-19.
18. Johnson JB. The Schottky effect in low frequency circuits. Physical review. 1925;26(1):71-85. doi: 10.1103/PhysRev.26.71.
19. Musha T, editor 1/f fluctuations in biological systems. Sixth International Conference on Noise in Physical Systems; 1981; Washington, DC: U.S. Department of Commerce and National Bureau of Standards.
20. Weick KE. Enactment and Organizing. The Social Psychology of Organizing. Second ed. New York, NY: McGraw-Hill, Inc.; 1979. p. 147-69.
21. Tetlock PE. Expert Political Judgment. Princeton, NJ: Princeton University Press; 2009.
22. Wolfberg A. Full-spectrum analysis: A new way of thinking for a new world. Military Review. 2006;86(4):35-42.
23. Simon HA. The structure of ill structured problems. Artificial Intelligence. 1973;4(3-4):181-201. doi: 10.1016/0004-3702(73)90011-8.
24. Star SL. This is Not a Boundary Object: Reflections on the Origin of a Concept. Science, Technology, & Human Values. 2010;35(5):601-17. doi: 10.1177/0162243910377624.
25. Weick KE. Remorseless sensemaking: Engaged deliberation sinks the El Faro. in press. 2022.
26. van Stralen D, McKay S, Mercer TA. Flight Decks and Isolettes: High-Reliability Organizing (HRO) as Pragmatic Leadership Principles during Pandemic COVID-19. Neonatology Today. 2020;15(7):113-21. doi: 10.51362/neonatology.today/20207157113121.
27. van Stralen D, Mercer TA. Inductive Processes, Heuristics, and Biases Modulated by High-Reliability Organizing (HRO) for COVID-19 and Disasters. Neonatology Today. 2021;16(9):104-12. doi: 10.51362/neonatology.today/20219169104112.
28. Simon HA, Newell A. Heuristic Problem Solving: The Next Advance in Operations Research. Operations Research. 1958;6(1):1-10. doi: 10.1287/opre.6.1.1.
29. Tversky A, Kahneman D. Judgment Under Uncertainty: Heuristics and Biases. Springfield, VA: Oregon Research Institute, Advanced Research Projects Agency OoNR; 1973 Contract No.: AD-767 426.
30. van Stralen D, Gambino W. Error as a Faulty Failure Signal. Neonatology Today. 2020;15(9):114-7. doi: 10.51362/neonatology.today/20209159114117.
31. van Stralen D, Mercer TA. High Reliability Organizing (HRO) is the Extension of Neonatology during Pandemic COVID-19. Neonatology Today. 2021;16(5):97-109. doi: 10.51362/neonatology.today/2021516597109.
32. van Stralen D, Mercer TA. Common Sense High Reliability Organizing (HRO) in the Response to COVID-19. Neonatology Today. 2021;16(7):90-102. doi: 10.51362/neonatology.today/2021716790102.
33. van Stralen D, McKay S, Mercer TA. Pragmatic Leadership Practices in Dangerous Contexts: High-Reliability Organizations (HRO) for Pandemic COVID-19. Neonatology Today. 2020;15(8):109-17. doi: 10.51362/neonatology.today/20208158109117.
34. Pauly D. Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology & Evolution. 1995;10(10):430.
35. Krulak CC. The strategic corporal: Leadership in the three block war. Center for Army Lessons Learned Fort Leavenworth, KS, Virtual Research Library, 1999.
36. Yates FE. Self-organizing systems: The emergence of order: Springer Science & Business Media; 2012.
37. Bolton P, Dewatripont M. Authority in Organizations. In: Gibbons R, Roberts J, editors. Handbook of Organizational Economics. Princeton, NJ: Princeton University Press; 2013. p. 342-72.
38. Lima SL, Dill LM. Behavioral decisions made under the risk of predation: a review and prospectus. Canadian journal of zoology 1990;68(4):619-49.
39. Creel S. The control of risk hypothesis: Reactive vs. proactive antipredator responses and stress-mediated vs. food-mediated costs of response. Ecology letters 2018;21(7):947-56.
40. van Stralen D, McKay SD, Mercer TA. Disaster Series: Understanding Disasters - Classification and Infrastructure. Neonatology Today. 2021;16(11):9-18.
41. Gagnon SA, Wagner AD. Acute stress and episodic memory retrieval: neurobiological mechanisms and behavioral consequences. Annals of the New York Academy of Sciences. 2016;1369(1):55-75.
42. Mason JW. A review of psychoendocrine research on the pituitary-adrenal cortical system. Psychosomatic medicine. 1968;30(5):576-607.
43. May RM. Biological populations with nonoverlapping generations: stable points, stable cycles, and chaos. Science. 1974;186(4164):645-7. Epub 1974/11/15. doi: 10.1126/science.186.4164.645. PubMed PMID: 4412202.
44. Quintana J, Fuster JM. From perception to action: temporal integrative functions of prefrontal and parietal neurons. Cerebral Cortex. 1999;9(3):213-21.
45. Fuster JnM. Synopsis of function and dysfunction of the frontal lobe. Acta Psychiatrica Scandinavica. 1999;99:51-7.
46. Fuster JnM. Prefrontal neurons in networks of executive memory. Brain research bulletin. 2000;52(5):331-6.

47. van Stralen D, Mercer TA. During Pandemic COVID-19, the High-Reliability Organization (HRO) Identifies Maladaptive Stress Behaviors: The Stress-Fear-Threat Cascade. Neonatology Today. 2020;15(11):113-24. doi: 10.51362/neonatology.today/2020111511113124.
48. Katz PS. Neural mechanisms underlying the evolvability of behaviour. Philosophical Transactions of the Royal Society B: Biological Sciences. 2011;366(1574):2086-99.
49. van Stralen D, Mercer TA. High-Reliability Organizing (HRO), Decision Making, the OODA Loop, and COVID-19. Neonatology Today. 2021;16(8):86-96.
50. Shannon CE. A Mathematical Theory of Communication. Bell System Technical Journal. 1948;27(3):379-423. doi: 10.1002/j.1538-7305.1948.tb01338.x.
51. Sneyd J, Theraula G, Bonabeau E, Deneubourg J-L, Franks NR. –Alternatives to Self-Organization. Self-Organization in Biological Systems: Princeton University Press; 2020. p. 47-62.
52. Star SL, Griesemer JR. Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Social Studies of Science. 1989;19(3):387-420.
53. van Stralen D. High-reliability organizations: Changing the culture of care in two medical units. Design Issues. 2008;24(1):78-90.
54. van Stralen DW, Calderon RM, Lewis JF, Roberts KH. Changing a pediatric sub-acute facility to increase safety and reliability. Patient Safety and Health Care Management: Emerald Group Publishing Limited; 2008.
55. van Stralen D, Calderon RM, King P, Padgett D, Lewis J, Rao R. Initiation of Mechanical Ventilation (MV) in a Pediatric Subacute Care Facility (SCF) v. ICU: Cost Avoidance CHEST. 2002;122(4).
56. van Stralen D, Calderon R, Padgett J, Clements P, Eachus T. Smile and Laughter During Mechanical Ventilation in Children. Mastering the Challenges Across the Spectrum of Long Term Care; March 16-29, 2006; Dallas, Texas: America Medical Directors Association, 29th Annual Symposium; 2006.
57. Lahti DC, Johnson NA, Ajie BC, Otto SP, Hendry AP, Blumstein DT, et al. Relaxed selection in the wild. Trends in ecology & evolution. 2009;24(9):487-96.
58. van Stralen D, Inozu B, Byrum S. High Reliability for a Highly Unreliable World: Preparing for Code Blue through Daily Operations in Healthcare. North Charleston, SC: CreatSpace Publishing; 2017.
59. Post RH. Possible cases of relaxed selection in civilized populations. Humangenetik. 1971;13(4):253-84.
60. MacDougall-Shackleton SA. The levels of analysis revisited. Philos Trans R Soc Lond B Biol Sci. 2011;366(1574):2076-85. Epub 2011/06/22. doi: 10.1098/rstb.2010.0363. PubMed PMID: 21690126; PubMed Central PMCID: PMCPMC3130367.
61. Weick KE, Sutcliffe KM. Managing the Unexpected: Assuring High Performance in an Age of Complexity. Quinn RE, editor. San Francisco, CA: Jossey-Bass; 2001.

Disclosures: The authors have no relevant disclosures

NT

Corresponding Author

Daved van Stralen, MD, FAAP
Associate Professor, Pediatrics
Department of Pediatrics
Loma Linda University School of Medicine
11175 Campus Street
CP-A1121
Loma Linda, CA 92350
Email: DVanStra@llu.edu

Sean McKay
Executive Partner / Director, Disruptive Rescue & Austere Medicine
Element Rescue - Response Solutions within Nonlinear Complex Environments
Greenville, South Carolina, United States

Thomas A. Mercer
Rear Admiral
United States Navy (Retired)

Acknowledgments

Karl Weick, Rensis Likert Distinguished University Professor of Organizational Behavior and Psychology, Emeritus, University of Michigan

William J. Corr, formerly with the Los Angeles City Fire Department, now deceased

Errol van Stralen, Ancora Education

Dan Kleinman, Operations Section Chief, National Incident Management Organization (retired)

T. Allen Merritt, MD MHA, Physician Advisor, Samaritan Health Services