excessive expenditure of higher cortical resources when performing TAV activity. In contrast, drivers with IHD showed attenuated selective attentional responses consistent with exhaustion.[51]

Martin, et al. provide yet another view of how TAV activity burdens higher CNS resources. Among amateur drivers they found a differentially greater P300 amplitude and latency, but shorter reaction times (actually preceding the P300), in response to slides of imminent traffic accidents compared to those showing safe scenes. The P300 to the accident slides appeared even under conditions of high signal probability (0.5) and indicates an unusually augmented level of selective attention to these threatening visual stimuli. These findings also suggest that the subjects hastened their motor response to such an extent that information processing was not yet complete.[158] This situation is similar to that described by Fuller, in which "delayed avoidance responses" occur when aversive stimuli appear suddenly and unexpectedly, leaving the driver with limited or perhaps even inadequate time to respond safely.[64] Other ERP findings indicate that under time-pressure, response selection time is accelerated, while stimulus assessment time stays unchanged; consequently, the chances for error are increased.[90,158]

Open-ended queries to workers whose jobs entail a high degree of TAV activity have revealed that it generally is the most difficult part of their work.[15,16] Furthermore, as a corroboration to the neuro- and psychophysiologic data, *progressive sensitization*—not adaptation—appears to be occurring, since this activity is more often cited as the major burden of work with greater number of years on the job.

TAV activity is a relatively fixed feature of a number of occupations. A key strategy for coping with this special exigency is **anticipatory avoidance response** whereby the experienced worker recognizes the precursors to the potentially disastrous stimulus and takes appropriate measures. For example, in traffic this would include slowing down at a blind intersection so as to circumvent a potential collision with an unseen, approaching vehicle.[64] These anticipatory avoidance responses are vital to safety, but they consume a large share of these workers' already overburdened attentional resources.

Lennart Levi has stated: "Real life conditions usually lead to a combination of many exposures. These may become superimposed on each other in an additive way, or synergistically. In this way, the straw that breaks the camel's back may be a very trivial environmental factor which, however, is added to a very considerable existing environmental load."[141] To prevent the potentially disastrous consequences of that "straw," assessment of the total burden of exposure to physical, ergonomic, and psychosocial stressors at the workplace becomes imperative.

MULTIPLE EXPOSURES: TOWARD A MODEL OF TOTAL OCCUPATIONAL BURDEN *by Karen Belkić, MD, PhD, Peter Schnall, MD, Čedo Savić, MD, PhD, Paul Landsbergis, PhD*

Although occupational health research traditionally has relied on a deterministic approach of assessing causal relations between a given exposure and a given outcome, recognition of the complexity of the work environment has obligated a more integrative assessment of physical, ergonomic, and psychosocial stressors on the job.[26,54,78,141,153,163,166,272] Substantial empirical evidence links each of a large number of these diverse stressors to clinically important CV occurrences.

A fairly small, but emerging body of literature has dealt with combined exposure to various types of cardionoxious factors. To cite a few examples: Lercher and colleagues reported a roughly additive effect on blood pressure of exposure to noise and night shiftwork.[135] A diastolic pressor effect has been observed with laboratory exposure to heat together with 90 dB noise.[22] Noise also increases the self-reported stressfulness of muscular work and of exposure to heat and stochastic vibration.[153] The pressor effects of performing a stressful mental task increase when noise is added to the laboratory environment.[150,246]

The Occupational Stress Index

Brabant and colleagues underscore the need for assessing "the globality of the work environment," which includes physical, ergonomic, and organizational stressors.[26] Matsubara and colleagues suggest that additive models with nonspecific scales, such as a linear combination of moderate exposures and higher weight for extreme exposures, would represent an appropriate approach to combined environmental studies.[163]

One attempt to comprehensively assess the panoply of potentially cardionoxious work stressors using such an additive model is found in the Occupational Stress Index (OSI).[19] The OSI integrates several paradigms of stress-related cardiovascular dysfunction and is reflective of cognitive ergonomic and neurophysiologic findings. The OSI contains 58 equally weighted factors, and highest scores are given for extreme exposure. The factors are organized into a two-dimensional matrix (Table 1), with the stress dimensions (underload, high demand, strictness, extrinsic time pressure, noxious physical exposures, threat-avoidant characteristics, and conflict/uncertainty) forming the horizontal axis. The levels of human information transmission—sensory input, central decision-making, and task execution[269]—plus a general level are placed along the vertical axis. Thus, each factor has a set of coordinates, localizing it to the type of stress and the level at which it affects the human operator. Summations can be made by levels and by stress aspects, and a wide variety of combined effects can be assessed. For example, various manifestations of the well-known deleterious combination of underload and high demand[59] can be identified and quite precisely characterized.

The sum of the scores to all 58 factors comprises the total OSI, which represents an attempt to quantitate the overall burden upon the human operator of a given set of working conditions. Criterion validity of the total OSI has been demonstrated with respect to its ability to identify high-risk occupations. For example, professional drivers have approximately twice the total OSI scores compared to those of a heterogeneous group of building trade workers and subway guard attendants.[19,50] The authors stated: "Using the OSI, we find that driving epitomizes a stressful occupation which bears the overwhelming majority of features associated with cardiac risk."[19]

The OSI also has shown within-occupation criterion validity. The overall burden of exacerbating (i.e., nonfixed) stressors in the professional drivers' work environment, as gauged by the total OSI, independently predicts cardio-deleterious behaviors, including smoking intensity, within this group.[19,49] (See Chapter 6 for additional details.) A limitation of the current application of the OSI is the linear nature of the analyses that have been performed. There is a need to explore possibilities for multiplicative interactions and higher level terms, within the model and more generally.

The Concept of Synergy

Lercher and colleagues have emphasized that examination of only main effects may underestimate "the true public health impact" of combined exposures.[135]

TABLE 1. The Occupational Stress Index

Levels of Information Transmission	Stress Dimensions						
	Underload	*High Demand*	*Strictness*	*Extrinsic Time Pressure*	*Aversiveness (Noxious Exposures)*	*Avoidance (Symbolic Aversiveness)*	*Conflict (Uncertainty)*
Input	Homogeneous incoming signals Low frequency incoming signals Works alone	Several information sources Heterogeneous signals Visual modality primary High frequency of incoming signals Three sensory modalities Communication essential	Strict requirements for signal detection	No control over speed of incoming signals	Glare Noise	High level of attention (serious consequences of a momentary lapse)	Signal/noise conflict Signal/signal conflict
Central Decision-making	Decisions automatic from input	Complex decisions Complicated decisions Decisions affect work of others Need for rapid decision-making	Limited number of decision-making strategies Limited number of correct decisions	Decision cannot be postponed		Wrong decision can have serious (potentially fatal) consequences	Missing information needed for decision Contradictory information Unexpected events change work plan
Output/Task Execution	Homogeneous tasks Simple tasks Nothing to do	Heterogeneous tasks Simultaneous task execution Complex tasks Need for rapid task execution	Work must meet a strictly defined standard	No control over task execution rate	Vibration Isometric stress	Hazardous tasks	Conflicting tasks in space and time External factors hamper task execution
General	Fixed pay	Piece rate Overtime work Holds 2 jobs No rest breaks Night work	Fixed body position Work in confined space	Speed up Deadline pressure	Cold Heat Noxious gases/fumes/dusts	Work accident Witness work accident	Emotionally charged work atmosphere (interpersonal conflicts)

From Belkić K, Savić Č, Theorell T, et al: Mechanisms of cardiac risk among professional drivers. Scand J Work Environ Health 20:73–86, 1994; with permission.

According to Rothman and Greenland, it is rare that the effect of exposure to a given factor is completely independent of the effect of exposure to another factor, implying that some kind of interaction is usually taking place.[210] An interaction can be demonstrated insofar as the relative risk of combined exposure to two or more factors is not equal to the sum of the relative risks of each exposure taken separately.[79,210] A greater than additive effect, i.e., synergy, is found when the combined exposure risk exceeds the latter. Various combined exposures to the psychosocial work factors of high psychological demands, low decision latitude, and/or low social support have yielded statistically significant synergistic effects with respect to risk of MI as well as self-reported CVD.[79,99]

More generically, it can be stated that with a synergistic interaction, some cases of disease would occur only if there were combined, and not just singular, exposure to noxins. This principle is illustrated in some (but not all) investigations of psychosocial factors and risk of hypertension, ischemic heart disease (IHD), and progression of carotid atherosclerotic plaque height, in which significant results have been obtained for combined exposure to high psychological demands and low decision latitude[217,254] or to high work demands and low economic rewards.[151] However, there were no significant effects for exposure to each of these stressor dimensions alone.

Rothman and Greenland present some caveats about the practical implementation of analyses for synergy. They note that tests of nonadditivity or statistical interaction of factors "may have limited utility" due to low power for usual sample sizes and low precision of the statistical tests.[210] Dose-response relationships and induction periods further complicate the issue (see Chapter 6). Notwithstanding these difficulties, there is a need for more systematic assessment of synergistic relations between and among cardionoxious factors.

The Total Burden Concept

Hockey elaborates the construct of "resources," or total burden upon the human operator, as an integrative model whose focus is not solely upon performance *per se*, but also encompasses the impact of this burden in relation to fatigue, strain, and health consequences, including those relevant to the cardiovascular system.[89] In this context, some useful inferences can be drawn from laboratory, field, and epidemiologic studies. Cognitive ergonomic and neurophysiologic data demonstrate that there is a limit to the available processing resources, and when the human being is asked to perform multiple tasks, as the primary or prioritized action becomes more difficult, less mental energy is available for subsidiary actions. Exacerbating stressors, of a physical as well as nonphysical nature, further impinge on these processing resources. With multiple exposure to work stressors, attempts to cope may include deliberate mobilization of existing mental resources, e.g., intense concentration, such that concurrent performance proceeds unimpeded. It is known that as demands increase, processing capacity can be augmented up to a certain point. This extra energy is derived from arousal mechanisms.[109] There is residuum, however, which comes after work is over, and can be reflected in difficulty or inability to unwind and/or perform subsequent mental tasks, a decreased likelihood to engage in altruistic behaviors, and delay in return to nonwork baseline of catecholamine levels.[34,54,60,72,98,204]

DURATION AND TIMING OF EXPOSURE

Perhaps the most important practical implication of the total burden concept is that related to duration and timing of exposure. Previously, we have noted that work

requiring continuous mobilization of conscious attentional resources should be performed for very limited periods of time. The data linking impaired selective attention (attenuated P300 amplitude) to long work hours behind the wheel among professional drivers offers insight into the neurophysiologic consequences of prolonged exposure to this heavily burdensome activity. Our suggestion that this finding reflected driver fatigue is corroborated in more detail by Brown.[28] The "causal contributions to fatigue" among this occupational group are cited as "length of continuous work spells and daily duty periods, time available for rest and continuous sleep, and the arrangement of duty, rest, and sleep periods within each 24-hour cycle."[28] The causal relation between accidents and fatigue, particularly related to night work, among road and air transport operators as well as other classes of workers performing threat-avoidant vigilant and otherwise burdensome activity has been well documented.[2,131,169,178,179,240] There is also considerable epidemiologic evidence linking long work hours and night shiftwork to risk of IHD. Another relevant line of investigation demonstrates that extreme fatigue or "vital exhaustion" among working-aged men predicts future MI and cardiac death, after adjustment for standard cardiac risk factors.[8,9]

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