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Mechanisms of cardiac risk among professional drivers[1]

by Karen Belkić, MD,[2,3] Čedo Savić, MD,[4] Töres Theorell, MD,[2] Ljubiša Rakić, MD,[3] Dragoslav Ercegovac, MD,[4] Milan Djordjević, MD[3]

BELKIĆ K, SAVIĆ Č, THEORELL T, RAKIĆ L, ERCEGOVAC D, DJORDJEVIĆ M. Mechanisms of cardiac risk among professional drivers. *Scand J Work Environ Health* 1994;20:73—86.This literature review indicates that professional drivers have excess cardiac risk that is not fully explained by standard risk factors. The contribution of occupation is suggested by two independent methods and by psychophysiological studies during on-the-job driving. Driving has been conceptualized as a threat-avoidance task. Stimuli encountered in traffic are not inherently aversive but become so by association with driving experience, a formulation corroborated by laboratory studies in which stimuli such as car headlights elicit cardiovascular hyperreactivity and electroencephalographic signs of arousal in professional drivers. More-advanced neurophysiological methods (event-related potentials) show higher cortical electronegativity to imperative signals among professional drivers than among nondriver referents. These data are viewed in light of reports of possible associations between event-related slow potentials and cardiac risk. A clinically and ecologically relevant neurocardiological model is proposed, and preventive strategies, including workplace interventions, are suggested.

KEY TERMS — cardiovascular disease, event-related potentials, glare, neurocardiology, professional drivers, review, work stress.

Of the numerous studies performed in various countries on cardiovascular disease and professional driving over a span of almost three decades, nearly all have shown an excess risk of cardiovascular disease among professional drivers. Despite rigorous selection against these disorders at hiring and during periodic medical follow-up (1—4), a risk of hypertension, ventricular arrhythmias, myocardial infarction, and other ischemic heart disease has been observed in 28 of the 32 reports found to consider this question (1—32). (Nonsignificant findings have been reported in references 13, 18, 19, and 23.) Of particular note in many of these studies is the close relation between the number of work years as a driver and the untowardly young age at which these events occur (1, 5, 7, 9 17, 26, 29, 32). For example, in studies of young myocardial infarction patients, for whom profession was determined, an unexpectedly high percentage (up to 40%) comprised professional drivers (9, 17, 26, 29, 32).

While standard risk-factor status tends to be high in this population, these factors have not been clearly shown to distinguish professional drivers from other lower risk groups (1, 15, 16, 33—35) (table 1). Recently, Rosengren and her co-workers (27) demonstrated that the excess risk of coronary heart disease among middle-aged bus and tram drivers occurred independently of standard risk-factor status.

Thus the question arises as to how this excess cardiac risk occurs for professional drivers. A growing consensus indicates that occupational factors must be given careful consideration (1—3). A focus on neural mechanisms promises to offer meaningful insights into the problem (3, 36, 37). In this paper, based upon a review of epidemiologic and field studies, as well as clinical laboratory and experimental data, we have explored these mechanisms. From our findings, a clinical neurocardiological model has emerged, and potential preventive strategies, which are clearly needed for this high-risk cohort (1, 2), are suggested.

Psychophysiological studies on actual driving

Some 25 years ago, Simonson et al (38) noted that the "number of investigations on physiological changes associated with driving ... is very small, and ... that most of these have been based on the psychological characteristics or visual capacities of the driver or the gross physical conditions of the driver as affected by the hours of continuous driving behavior [p 125]." With respect to the investigation of clinical cardiovascular changes, this statement is still

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Table 1. Standard cardiac risk factors for male professional drivers.

Authors and age group	Driver group (N)	Reference group (N)	Current smoking prevalence[a] (%)	Mean total serum cholesterol[a] (mmol · l⁻¹)	Mean triglycerides[a] (mmol · l⁻¹)	Obesity[a] (body mass index)	Leisure physical activity[a]	Hyperglycemia[a]	Dietary fat intake[a]	Family history of cardiovascular disease[a]
Belkić et al (1) Age ≤40 years	258 various driver profiles	227 building trade workers	67% (ø)	5.22 (ø) (N = 29)		25.2 (ø)	ø	Diabetics 0% (ø)	↓↓	ø
Hartvig & Midttun (15) Age 22—66 years	52 bus & truck drivers	52 unskilled industrial workers	63% (control variable)	6.04 (↑)	1.82 (↑)	24.6 (↑)	↓		(control variable)	↓
Heady et al (35) Age 40—64 years (analyzed by decades)	282—301 bus drivers	137—149 conductors				7.97 (↑) 8.03 (↑) 7.98 (↑) (l/ponderal index) × 100				
Hedberg et al (33) Age 25—64 years	392 bus & truck drivers	776 in Monica study	31% (↑↑)	6.32 (ø)	1.85 (ø)	26.3 (↑↑)	↓↓		↑↑	↑↑
Holme et al (16) Age 40—49 years	98 bus drivers, 35 tram drivers, 129 taxi drivers	14 677 in various occupations	55% (↑) 49% (↑) 65% (↑)	7.14 (↑) 7.32 (↑) 7.13 (↑)	2.41 (↑) 2.23 (↑) 2.54 (↑)	79.5 (↑) 78.7 (↑) 79.5 (↑) (kg body wt)				
Rosengren et al (27) Age 47—55 years	103 bus & tram drivers	6 596 in various occupations	50% (ø)	6.57 (ø)		26.3 (↑↑)	↑↑	Diabetics 2.9% (ø)		ø
Rusconi et al (34) Age 21—59 years	200 extra-urban bus drivers	100 conductors	48% (ø)	Age 21—30 years: 5.46 (ø) 31—40 years: 6.10 (ø) 41—50 years: 6.28 (ø) 51—59 years: 6.80 (ø)	1.68 (↑↑) 1.55 (ø) 1.70 (ø) 1.73 (↓↓)	"Obese" 14.5% (↑↑)		Positive glucose tolerance 9% (ø)		
Uglješić et al (39) Age 25—50 years	30 bus drivers	20 clerical workers	63% (↑↑)	40% of drivers >6.40 (ø)	30% of drivers >1.90 (ø)	6.7% of drivers >2.8 g · cm⁻¹ (ø)		0% over 6.0 mmol · l⁻¹ (ø)		

[a] ↑↑ = significantly greater in drivers, ↑ = greater in drivers but reported data insufficient for statistical calculation, ø = no significant difference between drivers and referents, ↓↓ = significantly lower in drivers, ↓ = lower in drivers but reported data insufficient for statistical calculation.

true today. In this section, we review the available literature on cardiovascular and neuroendocrine changes that occur during actual professional and amateur driving.

Blood pressure

Recently, during a workday, Uglješić and her coworkers (39) measured the ambulatory blood pressure of 30 male city bus drivers who had been normotensive in their base-line examination and also the ambulatory blood pressure of 20 matched clerical worker referents. They found that both the systolic and diastolic blood pressures were significantly higher among the bus drivers immediately preceding the driving shift, during most of the driving shift, and just after it than among the referents at matched times. During nonwork hours, the blood pressure of these two groups did not differ significantly. Littler et al (40) performed direct arterial measurement of blood pressure in a small group of healthy subjects, hypertensives, and coronary patients during driving. Overall they found fairly constant blood pressure levels, although some persons in each group showed sudden dramatic rises.

The interaction between individual predisposition towards high blood pressure and high "strain" occupations such as driving has been demonstrated in three investigations by Theorell et al (41—43). In the first, it was found that subjects who were hypertensive at 18 years of age showed the greatest systolic blood pressure rise during high (compared to low) strain work 10 years later. These subjects also had a higher systolic blood pressure during work than previously normotensive subjects in either work category. The second study was a longitudinal follow-up of working men and women in six occupations. It showed that systolic blood pressure during workhours was significantly higher during days of job strain. The third study revealed a significant correlation between job strain and diastolic blood pressure during the work of borderline hypertensives. An association between job strain and elevated systolic and diastolic blood pressure during work has also been reported for healthy men and women (44—46).

Heart rate

Increased heart rate has been consistently reported during professional and amateur driving by healthy

subjects and cardiac patients (4, 38, 47—49). In some studies the increase was in the tachycardiac range and was particularly pronounced during "critical situations" such as sudden stops and passing (48—49). Belkić et al (8) found that heart rate was maximum in professional drivers at the beginning and towards the end of a workshift, the latter most likely reflecting fatigue. Similar findings have been reported for other high-stress groups during work (46, 50—53) .

Studies of heart-rate variability, as a reflection of autonomic outflow and risk of cardiac death (54, 55), during driving are very sparse. Using spectral analysis, Egelund (56) reported that heart-rate variability increased among inexperienced (presumably nonprofessional) drivers. This finding was considered to be related to fatigue. However, no such effect was seen when the standard deviation of heart rate was assessed. Using the standard deviation of heart rate, Belkić (57) found minimum heart-rate variability at the beginning of the driving shift, when compared with the middle and end of the shift. However, this finding was not statistically significant due to the small numbers.

Ischemic electrocardiographic changes

Using ambulatory electrocardiographic monitoring, Taggart et al (49), in their investigation of 32 normal subjects and 24 coronary patients (all amateur drivers) during a 20-min drive in heavy London traffic, reported significant STT changes in three of the normal subjects and 13 of the coronary patients, two of whom experienced symptomatic angina pectoris. Similar results were also reported by Hoffmann (58) in an earlier study of patients with coronary heart disease. Lauwers et al (59) found ST depression in 4 of 13 postmyocardial infarction patients during a drive in peak hours of traffic. A flattening of the T wave was reported for three of four healthy amateur drivers behind the wheel in the study of Simonson et al (38), while no ischemic electrocardiographic changes were seen in 65 healthy young subjects examined during driving by Bellet et al (48) or in the 15 subjects studied by Littler et al (40). In the two available reports on the Holter monitoring of apparently healthy professional drivers (4, 60), 20 subjects in one study and 95 in the other, no significant STT changes were noted. Stressful occupational activity which bears some similarity to driving (eg, aerobatic flying and sea piloting) are reported to elicit ischemic changes in apparently healthy subjects (50, 51). To our knowledge, no ambulatory electrocardiographic monitoring studies of professional drivers with ischemic heart disease have been published.

Cardiac rhythm

Cardiac rhythm disturbances during driving have received surprisingly little attention in the literature. In the study of Taggart et al (49), five of the coronary patients developed complex ventricular arrhythmias during the previously described drive. One of the 15 subjects in the paper of Littler et al (40) also developed multiple ventricular extrasystoles during driving. Belkić et al (8) found that nine of 20 (45%) young, apparently healthy professional drivers had ventricular arrhythmias during Holter monitoring, five (25%) had Lown grade 3 or more, and four (20%) had noteworthy bradyarrhythmias. The total number of ventricular extrasystoles was significantly greater when the recording included a day driving shift compared with nonwork days, and no other factor except driving itself distinguished the two periods. On the other hand a significant correlation was found, for workdays only, for the number of ventricular extrasystoles with smoking, coffee intake, and lack of sleep. Aerobatic flying and sea piloting have also been found to evoke ventricular arrhythmias in apparently healthy subjects (50, 51). We have not encountered any studies comparing the incidence of arrhythmias during driving and nondriving periods among subjects who suffer from rhythm disturbances.

Catecholamines and corticosteroids

Catecholamine excretion is consistently reported to be elevated during exposure to driving among amateurs, professionals, and racers (61—65). Night driving and traffic congestion are particularly associated with increased urinary catecholamine (63, 65). Other occupations with high levels of mental stress, such as air traffic controllers, physicians and nurses, and railway dispatchers, are also associated with an elevated catecholamine excretion during work, especially at night. (66—69). Our group has a study in progress on plasma catecholamine levels immediately after the early morning driving shift of city bus and truck drivers.

Cortisol levels during driving have rarely been examined. Bellet et al (61) found elevated levels when amateurs drove. Theorell et al (70) very recently reported that the subway drivers who, subsequent to a "person under train" incident, experienced the highest level of depression and had a need for long-term sick leave showed high plasma cortisol levels. This finding is congruent with those showing that the cortisol excretion rate is directly proportional to the level of distress (71).

Measures of occupational stress in professional drivers

Describing and quantitating the occupational factors that induce the aforementioned changes in professional drivers and potentially increase cardiovascular risk require appropriate methodological tools. One approach that provides easily obtainable, standardized numerical data is the psychosocial job-exposure matrix, whereby psychological demands, control over work conditions, support, physical work demands,

and job hazards are considered (72). A job-strain index is then computed as the ratio between psychological demands and control (43). According to this system or an older, less sophisticated occupational classification system, professional drivers are classified as a high-strain group (41). In several investigations the job-exposure matrix, or its precursor, has been shown to be a significant marker of cardiovascular disease morbidity and mortality (73—75).

The theoretical constructs upon which the job-exposure matrix is based draw from a long tradition of international psychophysiological research centered heavily in Sweden. A fundamental observation is that a high degree of arousal, together with a high degree of distress, activates both the sympathoadrenomedullary and adrenocortical axes, the result being a maximally deleterious combination (71, 76). Integrating this formulation with Gardell's (77) dimension of "alienation" and noting the association between work stress and risk of myocardial infarction, Karasek proposed that excessive load should be considered together with low decision latitude (78). Karasek and his co-workers (79) then developed the methodology for applying these hypotheses in epidemiologic, field, and clinical laboratory studies which focus strongly upon the cardiovascular system.

Belkić (57) incorporated these and other elements into a comprehensive occupational stress index, which includes a total of 58 equally weighted factors potentially affecting the cardiovascular system. These factors are arranged into a two-dimensional matrix, as shown in table 2. The various aspects are placed along the horizontal axis and include underload, high demand, strictness, extrinsic time pressure, aversiveness, avoidance, and conflict-uncertainty. The vertical axis is comprised of levels of information transmission, a concept presented by Welford (80) and used by Luczak (81) to simulate work conditions. The occupational stress index synthesizes fundamental ergometric concepts with the leading formulations of how stress eventuates in cardiovascular pathology. These formulations include the compelling models of sudden cardiac death vulnerability in experimental animals in response to aversive environments, avoidance task performance and approach-avoidance conflict reported by Lown's (82—84) and Corley's (85, 86) groups, as well as models based upon underload, high demand, strictness, and lack of autonomy presented by Karasek et al (79), Theorell et al (87), and Frankenhaeuser (88). Descriptive studies of occupational stress in subjects at high cardiac risk, as well as investigations of specific physical and general factors implicated in cardiovascular disease, were also used to identify elements for inclusion in the occupational stress index. These elements include a need for high levels of vigilance, extreme time pressure, potentially disastrous consequences of an error or lapse of attention, exposure to hazards and physically noxious agents such as noise, glare, vibration, cold, heat, isometric stress

Table 2. Occupational stress index. [Reproduced with permission from Belkić K, Pavlović S, Djordjović M, Micković LJ, Uglešić M. A comprehensive approach for assessing occupational factors in cardiovascular epidemiologic studies. Kardiologija. In press]

Level	Aspect						
	Underload	High demand	Strictness	Extrinsic time pressure	Aversiveness	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 modality Communications essential	Strict requirements for signal detection	No control over incoming signals	Glare Noise	Primary task = 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	Decisions cannot be postponed		Wrong decision can have serious (potentially fatal) consequences	Missing information needed for decision Contradictory information Unexpected events change work plan
Output or 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 of task execution rate (assembly line-work)	Vibration Isometric stress	Hazardous tasks	Conflicting tasks in space and time External factors hamper task execution
General	Fixed pay	Piece rate Overtime work Holds two or more jobs No rest breaks Night work	Fixed body position Work in confined space	Speed-up Deadline pressure	Cold Heat Noxious gases, fumes or dusts	Work accident Witness work accident	Emotionally charged work atmosphere (interpersonal conflict)

or heavy lifting, toxic chemical agents, long workhours, night shift work, lack of rest breaks, piecework, and holding down two or more jobs (89—104). Thus wide possibilities for hypothesis testing and the identification of key areas for preventive intervention trials are offered with this method. The occupational stress index also allows precise comparisons to be made among groups and individuals of any occupational endeavor.

The occupational stress index is calculated from a self-administered questionnaire. It is based on concrete questions, which, to a great extent, are objectively verifiable. Subjective responses are assessed separately as a job-adaptation index. Collaborative studies are underway to determine the cross-cultural validity of the occupational stress index and to compare the sensitivity and efficacy of the index with the psychosocial job-exposure matrix in predicting cardiac risk.

The occupational stress index has been applied in Belgrade, Yugoslavia, to 258 professional drivers and 227 workers primarily in the building trade (referents), all of whom were actively working (57, 105). The mean total for the occupational stress index was more than twice as great for drivers than for referents, the difference being highly significant. The extremely high total obtained for the occupational stress index suggests that professional driving bears the majority of features associated with cardiac risk. Briefly stated, professional driving is characterized by decision-making underload coupled with input high demand, and it is primarily avoidance activity performed under conditions of conflict, physical and mental constraint, time pressure, and exposure to physically noxious agents (eg, noise, glare, whole-body vibration, lead, carbon monoxide, other combustion products). Occupational stress is the most dramatic in professional drivers at the input level [21.7 (SD 1.3) versus 6.6 (SD 1.7) for professional drivers and referents, respectively]. The signals received are primarily visual.

Coronary-prone behavior of professional drivers

Behavioral indices of cardiac risk have not been extensively studied among professional drivers. Comparing 258 drivers and 227 building worker referents, Belkić et al (1) found that three features of interview type A behavior (hyperalertness, tight facial musculature and explosive speech) were significantly more pronounced among drivers, as was obsessive punctuality. Using a more-extensive interview along the lines of Friedman & Rosenman's (106), Hartvig & Midttun (15) also assessed type A behavior in a group of 52 bus and truck drivers. They similarly found a much higher prevalence of coronary-prone behavior among drivers than among matched industrial worker referents. Evans et al (107) noted that self-reports of occupational stress were more common among male bus drivers exhibiting type A behavior than among their type B counterparts. In addition heavily smoking professional drivers (>40 cigarettes a day) have shown a particularly high prevalence of coronary-prone behavior (1). This high prevalence suggests an interrelation among occupational, behavioral, and standard cardiac risk factors among professional drivers.

The question logically arises of whether individuals who enter this profession are behaviorally or otherwise innately predisposed to cardiovascular disease. The answer to this question is far from resolved. However, two large independent studies provide intriguing data. In 1990 Belkić and her co-workers (7) examined the prevalence of hypertension among 293 Belgrade city mass transit drivers, who were compared with 194 maintenance workers employed at the same company. A significantly greater number of drivers aged 20 to 40 years had high blood pressure when compared with their age-matched referents. Drivers with 6 to 10 years of experience also had a significantly higher prevalence of hypertension than the referents matched for work experience. However, the drivers and referents with one to five years of experience in their respective jobs did not differ significantly in this respect. In the other study of 258 professional drivers of various profiles, compared with 227 building worker referents (1), all aged 40 years or younger, blood pressure was again significantly greater in drivers with 6 to 10 years of experience, and not in those with one to five years of experience, in comparison with referents matched for work experience. The conclusion which emerges from these two studies is that a particular vulnerability exists in young professional drivers with respect to blood pressure and that a threshold period of driving exposure is necessary for these effects to be seen in terms of resting blood pressure.

Potential role of cognitively relevant visual signals in untoward cardiovascular changes in professional drivers

The glare pressor test

As previously discussed, drivers face maximal occupational stress at the input level, and the vast majority of signals they receive are visual. As Fuller (108) has pointed out, these stimuli are not intrinsically aversive, but they become so by association with driving experience. Driving is thereby conceptualized as a threat-avoidance task, since the driver must avoid aversive stimuli or situations such as driving off the roadway, losing control of the vehicle, or colliding with another road user. Thus, for example, an inherently neutral stimulus like a car headlight would attain specific cognitive significance because of its association with impending danger from an approaching vehicle during night driving and the

need for accurate and timely responses to avoid a collision.

In 1984 Belkić (109) performed a comparative study on the blood pressure responses of 22 healthy young subjects to a large battery of diverse procedures, including several standard mental stress tests, aerobic and isometric stress, sensory stimuli such as 90 dB noise, the cold pressor test, and exposure to impulses of glare from an ordinary car headlight. Unexpectedly, the blood pressure rise in response to glare was highly significant, and the diastolic response was among the greatest when compared with the corresponding response to the other maneuvers. Of particular note was a diastolic blood pressure increase of 30 mm Hg (3.99 kPa) in one subject, an amateur driver, who later told of his collision with an oncoming vehicle after having faced glare from a headlight while driving at night.

On the basis of these findings, a new reactive procedure, the "glare pressor test" was introduced into the literature (90). During this test, light impulses from an ordinary car headlight were delivered at 55-s intervals through a dark cylinder, 1 m in length, into which the subject peered. A total of five light flashes were presented so that the entire glare pressor test lasted 5 min.

In a subsequent study (110), four groups of subjects [professional drivers, amateur drivers, nondrivers who were professionally exposed to glare from other sources (welding), and nondrivers with no other professional glare exposure] performed the glare pressor test. A continuous electrocardiogram and blood pressure were recorded. The professional and amateur drivers showed a significantly higher diastolic response to the test than did the nondriver referents. The group exposed to welding glare did not differ from the referents in their response to the test. The test elicited ventricular extrasystoles only in professional drivers who drove at night. These findings appeared to corroborate Fuller's contention, suggesting that headlight glare, as a symbolically aversive visual stimulus for the driver, was indeed capable of evoking a powerful autonomic response.

Continuing with these investigations, the glare pressor test was applied during electroencephalographic (EEG) and polygraphic recording in another group of young professional drivers with night driving experience, and the results were compared with those of nondriver referents (57, 111). Of the 19 tested drivers, 15 showed persistent blockade of spontaneous alpha activity or complete EEG desynchronization after the first glare impulse. This reaction was accompanied by a significant fall in digital pulse amplitude and, as previously seen, a significant rise in diastolic blood pressure, most likely reflecting vasoconstriction, which is reported to occur in response to conditional aversive stimuli (112). The electromyogram (EMG) revealed a significant increase in facial muscle tone. Thus the professional drivers exhibited electrocortical, somatic, and autonomic arousal indicative of a defense reaction in response to exposure to an automobile headlight, whereas no significant effects of the glare pressor test were found in the reference group.

The response of drivers to the glare pressor test typifies the type A reaction to a specific challenge. Hyperalertness is objectively confirmed by the finding of EEG desynchronization. Tight facial musculature is reflected in the increased amplitude of the EMG. Zeier (113) found a significantly greater frontal EMG amplitude in drivers than in persons with passenger status. This finding was said to reflect "readiness for performing motor activity as well as general tension in cognitive tasks [p 800]."

Most of the drivers recovered their base-line levels of alpha activity and showed milder diastolic blood pressure, as well as digital pulse changes, after the final (fifth) glare impulse. In other words, with repeated exposure to the glare impulses, the subjects appeared to distinguish the laboratory exposure from the real exigencies of driving.

However, in two drivers, this last glare stimulus elicited the most pronounced changes. For a 31-year-old truck driver, for instance, it was the fifth glare impulse which most rapidly elicited ventricular arrhythmias. One city bus driver, with extreme type A behavior, demonstrated complete EEG desynchronization during the entire test and a marked rise in diastolic blood pressure at the final, compared with the first, glare impulse. These responses were considered maladaptive and therefore suggestive of hypersensitivity to glare exposure, with a breakdown of protective mechanisms. Both of these drivers, although clinically healthy according to standard screening criteria, as well as to an exercise stress test, showed noteworthy ventricular arrhythmias during Holter monitoring in the aftermath of a driving shift, and they had a very high standard risk factor status. They both worked very long hours (111, 114).

To date, the glare pressor test with electrocardiographic recording has been applied to 74 subjects. A total of 25 professional drivers with night driving experience were included. For three of these drivers, the glare pressor test elicited ventricular arrhythmias, whereas arrhythmias were not evoked in any of the 49 tested subjects who were not professional drivers with night driving experience. This finding is statistically significant and suggests a possible link between the occurrence of ventricular irritability in professional drivers and exposure to cognitively relevant input stress that is transmitted via the visual system.

Event-related potentials in professional drivers

The results presented in the previous section suggest that cognitive aspects of headlight glare are primarily responsible for the central, somatic, and autonomic arousal seen in professional drivers during the glare pressor test. In order to define more precisely the central stress mechanisms which become opera-

tive when drivers are faced with relevant visual signals, more sophisticated neurophysiological methods, event-related potentials, have recently been used by Belkić et al (115). The pattern of response was examined for young, healthy Belgrade city bus drivers and nondriver referents using a GO/NOGO visual contingent negative variation (CNV) paradigm. A tacitly neutral task was compared with one which explicitly mimicked traffic conditions.

Briefly, the GO warning signal (GO_{S1}) was a flash of red light, and the imperative signal (GO_{S2}) was a yellow light 1.5 s later, to which the subject was instructed to press a button. When the NOGO warning signal ($NOGO_{S1}$) appeared (pseudo randomly), the subject was told not to press the button upon the appearance of the imperative (GO_{S2}) signal. During the neutral task, these instructions were given without any additional remarks (ie, no reference was made to traffic conditions). For the second task (traffic paradigm), the subject was told to imagine himself as a driver in heavy traffic and that the red light represented a warning and, when the yellow light appeared, he should press the button as if it were a gas pedal. Failure to react on time would be the equivalent of a serious traffic accident caused by him. He was also told to consider inappropriately reacting to the yellow light that followed a green light, as the equivalent of a serious accident caused by him. Thirty GO sequences and all NOGO sequences were averaged for the neutral and for the traffic CNV paradigms. The following three CNV amplitude measures were then devised: (i) 500- to 800-ms post-GO_{S1} (CNV_1), 1200- to 1500-ms post-GO_{S1} (CNV_2) and 500- to 800-ms post-GO_{S2} (CNV_3).

The CNV results for both paradigms are graphically displayed in figure 1. As can be seen, the GO CNV_1 and CNV_2 amplitudes were significantly more negative than the corresponding values of the NOGO were, an expected finding for normal subjects (116—117). This GO-NOGO difference was accentuated for drivers, a finding suggesting an enhanced capacity for the differentiation between relevant and nonrelevant visual signals. The mean CNV_2 was also significantly greater for drivers than for referents for the GO condition during both the neutral and the traffic paradigm. This late CNV, which has been called the "readiness potential," is associated with preparation for the appearance of an imperative signal, which may have an affective character (118—120). Overall, a high amplitude (negative) GO CNV reflects subjective and objective task difficulty, as well as involvement and tension during task performance (121—122). Anxious subjects, once having learned the association between the warning GO stimulus and the imperative stimulus, show higher GO CNV amplitudes than low anxiety subjects (123). On the other

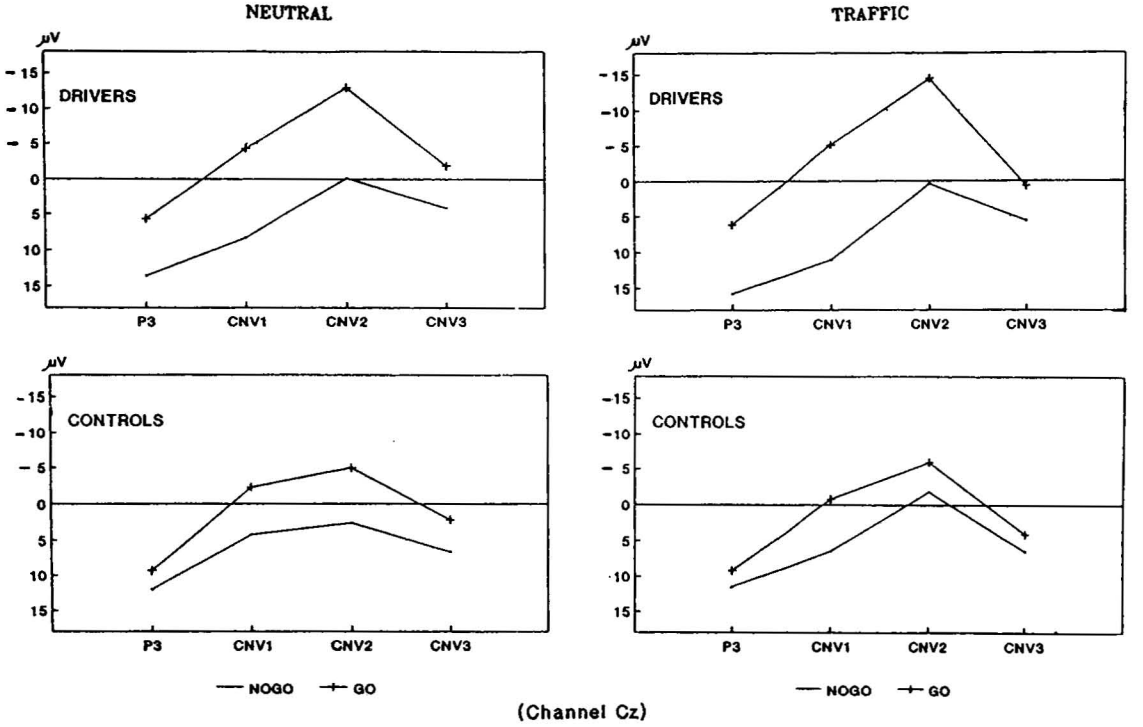

Figure 1. Contingent negative variation (CNV) in professional drivers and their referents (controls) during a neutral GO-NOGO task and one which explicitly mimicked traffic conditions. [Reproduced with permission, Belkić K, Savić Č, Djordjević M, Uglješić M, Micković L. Event-related potentials in professional city drivers: heightened sensitivity to cognitively relevant visual signals. Physiol Behav 1992;52:423—7]

hand, the NOGO CNV becomes more positive with alertness (121).

The drivers reacted in essentially the same manner when performing the tacitly neutral CNV task and that which explicitly mimicked traffic conditions. Thus the pattern of response of these drivers during the two paradigms suggests a generalized heightened sensitivity to the cognitive significance of visual stimuli, with a greater degree of task involvement, tension, and alertness than for nondriver referents. These CNV findings provide an insight therefore into how type A behavior develops in relation to the demands made upon drivers by their profession.

This electrocortical response pattern may also be more directly related to the increased cardiac vulnerability of professional drivers. The importance of this connection has been stated by Skinner (124) as follows: "the study of the set of event-related electrochemical responses of the cerebral cortex may eventually provide an understanding of the complete cerebral mechanism by which a stressful stimulus event is transformed into increased cardiac vulnerability [p 92B]." Skinner and his co-workers (125) have demonstrated a strong positive correlation between the amplitude of the event-related slow potential and ventricular arrhythmia rate in coronary patients in response to antiarrhythmic agents. The CNV, or cerebral event-related slow potential, as a reflection of frontal lobe function, is attenuated after damage to that region (117). In addition to losing the ability to experience stress, these patients fail to show any autonomic changes to cognitively relevant stimuli (124). Simons (126) has also recently emphasized the interrelation between slow cortical potentials and autonomic responses, particularly midinterval heart-rate acceleration associated with displeasure and arousal. Experimental data, explored very briefly in the next section, provide powerful corroboration of the role of this higher neural traffic in cardiac vulnerability.

Brain mechanisms and stress-related cardiovascular changes

A general theoretical model of how brain structures mediate the effect of stress upon the cardiovascular system has been presented by Skinner (124). His group demonstrated experimentally that, during stress, neural traffic from the frontal lobes (neocortex), as well as from the amygdala (limbic system-paleocortex), contributes significantly to the development of hypertension, as well as to life-threatening ventricular arrhythmias in the setting of myocardial ischemia (127—129). Repeated stimulation of the lateral hypothalamus can also produce sustained hypertension (130). The posterior hypothalamus, when electrically stimulated, elicits an alerting response, and, according to some reports, the defense reaction, along with increased cortisol outflow and ventricular arrhythmias (including ventricular tachycardia), and the threshold for ventricular fibrillation are lowered (83, 131—132). In the face of experimentally induced myocardial ischemia, posterior hypothalamic stimulation proves to be the critical factor in cardiac stability. It has induced ventricular fibrillation in 62.5% of coronary occluded dogs, whereas only 6.3% of the dogs with ischemia but no central nervous intervention developed ventricular fibrillation (83). Stimulating the midbrain reticular formation also lowers the ventricular fibrillation threshold and raises blood pressure and heart rate (133—134).

The two monoaminergic systems, the catecholaminergic (dopaminergic and noradrenergic) and serotonergic systems, appear to be important mediators of the connection between the processing of relevant sensory signals and cardiovascular response. Dopaminergic neurons are needed for motivated behavior and orientation to sensory stimuli (135—136). Neuroleptics, which block dopamine receptors, impair conditional avoidance responses and hamper vigilance. These medications also lower blood pressure (137). Cortical noradrenergic and beta-receptor functions are required for the detection of a change in visual input, and they appear to be involved in local event-related slow potential formation (124). Central beta-adrenergic mechanisms have been recently implicated in stress-related lowering of the ventricular fibrillation threshold (138). Serotonergic neurons, on the other hand, appear to attenuate efferent sympathetic neutral activity to the heart and vessels, such that, for example, elevated levels of brain serotonin raise the threshold for ventricular fibrillation (139).

Model for increased cardiac vulnerability caused by visually mediated stress in professional drivers

We have recently proposed one model to show how neural mechanisms might increase cardiac vulnerability, the focus of the model being night driving and exposure to headlight glare (36). The essential elements include: (i) avoidance task performance, (ii) physically aversive exposure (to glare), (iii) uncertainty (due to diminished visibility), (iv) conflicting forces acting upon the level of arousal (darkness plus circadian factors *diminish* arousal, glare exposure plus driving task demands *increase* arousal), (v) abrupt changes in oculomotor autonomic reflexes which involve sympathetic and parasympathetic branches and conflict between the central and reflex tendencies. The first three elements have been associated with a lowered threshold for ventricular fibrillation and with sudden cardiac death in experimental animals (84, 86, 140). The abrupt changes mentioned in the fifth element could disrupt neuroregulation of the autonomic nervous system and, as seen in clinical and experimental studies, increase cardiac electrical instability (141—143).

As discussed, an oncoming headlight represents danger to the driver. It remands him to respond appropriately to avoid a collision. Headlight glare, es-

pecially from a misaimed beam, is unpleasant and can also impair vision for several seconds. It is thereby a specific night driving hazard. It should be recalled that glare is an incongruity between an object in the visual field and the level of light to which the eye is adapted. It is a recurrent stress that occurs impulsively (ie, suddenly) during night driving.

Abrupt changes between dark adaptation and glare exposure occur during night driving, particularly on poorly lit roads. Adaptation to dark and light involve, respectively, sympathetic and parasympathetic reflex pupillary responses, which synapse near the midbrain reticular formation.

Pupillary tone is controlled by reflex, as well as by higher control mechanisms. Central arousal promotes pupillary dilatation (dark reflex). On the other hand, glare elicits a sensory light reflex (pupillary constriction), but it also causes central arousal which favors mydriasis. This a conflicting situation with strong opposing tendencies for the autonomic nervous system.

The ensuing "chaos" can be played out in the midbrain reticular formation (figure 2), which aside from mediating pupillary reflexes, transmitting information to the visual cortex, and controlling cortical arousal, also mediates autonomic outflow from the hypothalamus. Stimulation of the midbrain reticular formation lowers the threshold for ventricular fibrillation and raises blood pressure and heart rate (134, 144).

This model may help explain the untoward cardiovascular changes that occur in professional drivers in response to the glare pressor test, and it suggests mechanisms which may particularly increase cardiac vulnerability during night driving. Detailed exploration of other factors burdening the nervous system of professional drivers, particularly driving in heavy traffic, which is also implicated in cardiac risk (3), is warranted as well.

Clinical relevance and implications of the neurocardiological model

In 1985, Benjamin Natelson (145) first introduced the term "neurocardiology" as an important, new multidisciplinary area of research. He aptly stated that "cardiologists have focused their attention preponderantly on their end organ (i.e. the heart) and neurologists have focused on their organ (i.e. the brain) [p 183]." While breakthroughs in this "interface" have been made in the laboratory, "full appreciation of the importance of the nervous system in the pathogenesis of cardiac dysfunction does not exist at the bedside [p 183]." A crucial barrier to progress in this area has been the lack of appropriate clinical models.

Steptoe & Vögele (146) recently analyzed the methodological problems concerning mental stress tests in cardiovascular research and outlined essential criteria for their validity. These criteria include methodological, ecological, diagnostic, prognostic,

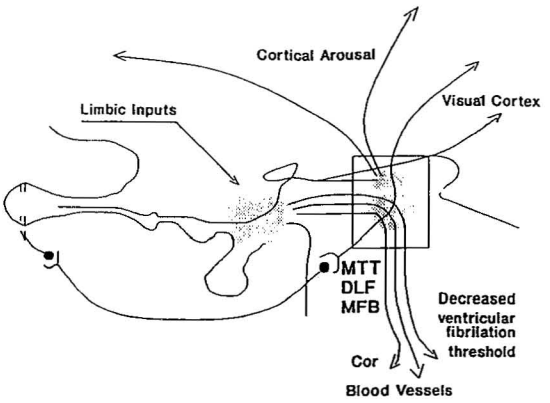

Figure 2. Role of midbrain reticular formation in the connection between the visual system, cortical arousal and cardiovascular changes. (MTT = mamillothalamic tract, DLF = dorsal longitudinal fasciculus, MFB = median forebrain bundle, Cor = heart)

and therapeutic considerations. It can be noted that it is difficult to combine a satisfactory degree of methodological rigor with "ecological" relevance (ie, applicability to real life stressors).

In studying professional drivers, we have had a unique opportunity to develop standardizable methods that are extremely relevant to this high-risk group and that consistently elicit strong cardiovascular responses, with concomitant signs of central arousal. The prognostic significance of these responses remains to be determined. However, it is plausible to consider that cardiovascular hyperreactivity to stressors such as the glare pressor test may precede the development of essential hypertension or other acquired cardiovascular disorders, as outlined in figure 3. The predictive power of other reactive tests suggests, by implication, that this may actually be so (147—148).

Thus far, the glare pressor test, the CNV model, Holter monitoring during driving, and the occupational stress index have been applied to apparently healthy professional drivers. These results need replication in other centers in various countries. They could, however, subsequently form the basis for comparison with responses in drivers with prepathological cardiovascular changes, as well as with responses in young drivers who have already suffered full-blown disease.

Together with mainline cardiological methods, these neurocardiological tests might, in the future, be used to assess cardiovascular driver fitness more accurately. This more accurate assessment may help answer the question of return to work, which is of vital importance, since these drivers often suffer from cardiovascular disease at untowardly young ages. These methods could also be of value in the periodic screening of professional drivers.

However, the most urgent task, as recently stated by Michaels & Zoloth (2) is "to apply specific in-

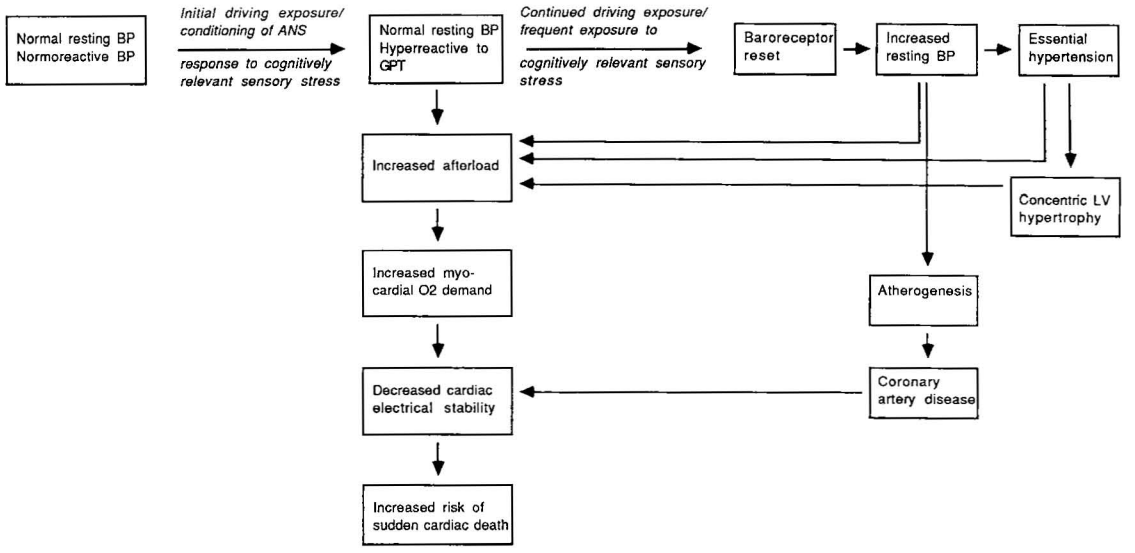

Figure 3. Possible dynamics of blood pressure (BP) changes in professional drivers and the relation between the changes and cardiac risk. (ANS = autonomic nervous system, GPT = glare pressor test, LV = left ventricle, O_2 = oxygen)

terventions designed to reduce job strain and other risk factors for heart disease among . . . drivers [p 403]." Since there is a lack of data concerning workplace intervention and the attenuation of cardiovascular risk, this work will require considerable investigation in order to determine which of the numerous, potential factors affecting the driver's cardiovascular system are most crucial. Some guidelines for this process of reconstructing worklife have been presented by Karasek & Theorell (149). As emphasized therein, job-related monitoring feedback of health is essential in estimating the effectiveness of any intervention. A particularly important area for investigation is that of driving in heavy traffic and night driving, as well as the role of road conditions, sedentary work in a fixed position, and exposure to toxic and physically noxious agents such as lead, noise, glare, whole-body vibration, and carbon monoxide. Transcultural factors, such as norms of behavior for participants in traffic, crowding in mass transit vehicles, and the like, would also be of interest for study with regard to burden upon the driver.

In addition, however, we recommend that certain basic measures be implemented. (Many of these, in fact, are often already established policy but may not be enforced in practice.) The following measures are included in these recommendations:

1. The number of driving hours should be carefully controlled. Overtime work should be the solution of last resort and should be strictly limited. Drivers should be discouraged from accepting overtime for economic reasons, and dispatchers should be discouraged from relying upon the responsible, good drivers to compensate for driver shortages due to absenteeism and the like. Educational work on the hazards of overtime and driver fatigue should be aimed not only at the drivers, but also at the dispatchers.

2. There should be obligatory rest breaks.

3. Any other skill the driver may have should be used for task alternation to minimize the number of hours behind the wheel.

4. Laws should be enforced about disorderly or otherwise disturbing conduct on mass transit, especially for passengers who disturb the driver.

5. Separate traffic lanes should be used, whenever possible, for public transportation and heavy trucks.

6. Traffic laws should be more strictly enforced for private vehicles and, especially, for pedestrians (ie, jay-walking, crossing on a red light, and the like).

Overall, a three-pronged approach aimed at modifiable occupational, behavioral, and standard risk factors is essential to effective primary cardiac prevention among professional drivers. This approach might eventually be combined with pharmacologic measures, such as the use of a beta-blockade, for selected drivers, since these agents appear promising for this group (150—153). Such an approach is being developed and will be the subject of future reports.

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