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APPENDIX A

APPENDIX A: Cohen’s Perceived Stress Questionnaire

ID: ……………………. Date ……/………/20…..
Station: ……………… Time of day ……….h………min Shift time: ………………

The following questions ask you about your feelings and thoughts DURING THE LAST MONTH. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between then and you should treat each one as a separate question.

		How Often In the last Month? (Circle your answer)				
		Never	Almost Never	Some-times	Fairly Often	Very Often
1	In the last month, how often have you been upset because of something that happened unexpectedly?	0	1	2	3	4
2	In the last month, how often have you felt that you were unable to control the important things in your life?	0	1	2	3	4
3	In the last month, how often have you felt nervous and "stress"?	0	1	2	3	4
4	In the last month, how often have you dealt successfully with irritating life hassles?	0	1	2	3	4
5	In the last month, how often have you felt that you were effectively coping with important changes that were occurring in your life?	0	1	2	3	4
6	In the last month, how often have you felt confident about your ability to handle your personal problems?	0	1	2	3	4
7	In the last month, how often have you felt that things were going your way?	0	1	2	3	4
8	In the last month, how often have you found that you could not cope with all the things that you had to do?	0	1	2	3	4
9	In the last month, how often have you been able to control irritation in your life?	0	1	2	3	4
10	In the last month, how often have you felt that you were on top of things?	0	1	2	3	4
11	In the last month, how often have you been angered because of things that happened that were outside of your control?	0	1	2	3	4
12	In the last month, how often have you found yourself thinking about things that you have to accomplish?	0	1	2	3	4
13	In the last month, how often have you been able to control the way you spend your time?	0	1	2	3	4
14	In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?	0	1	2	3	4

The following questions ask you about your feelings and thoughts DURING THE LAST SHIFT. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between then and you should treat each one as a separate question.

1	How stressful did you experience the shift? 1 = No stress 5 = Very stressful	1	2	3	4	5
2	Was this shift more or less stressful than usual?	More stressful Less stressful				
3	Was the shift unpleasant /terrible/ very bad?	Yes No				
4	Was the shift pleasant/nice?	Yes No				

Reason(s) why the shift was pleasant/unpleasant:

APPENDIX B

APPENDIX B: TIMELINE ANALYSIS
(EXAMPLE TEMPLATE)

SPOORNET PROJECT: TCO MENTAL WORKLOAD

Timeline Analysis

		Frequency per 15 minute intervals															
Activity	**Total Frequency**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Task preparation for shift																	
Establish trains scheduled for shift																	
Plot planned train movements on train plan																	
Radio communications																	
Plan train movements																	
Update train plan with real time information																	
Issue authorisation																	
Telephone conversations																	
Direct enquiries (in office)																	
Data capturing (ETA,ETD)																	
Write report(s)																	
Personal (bathroom, coffee)																	
Other information																	
Day of the week																	
Shift	From:	To:															
Subjective experience of fatigue		Very tired				Tired				A little tired							

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Addendum to Appendices C and D

The two reports attached as Appendix C and Appendix D has confidentiality requirements set by the writers of the reports. These requirements have been waived by the writers of the reports (see the attached letter), on condition that Spoornet grants permission thereto.

Permission was obtained form Spoornet to use all the data related to this study for the purposes of a PhD dissertation, provided that the following condition is met:
“No individuals may be identified”.

Both reports are therefore attached to the dissertation and may be made available in the public domain.

The role of the candidate in the pilot and validation study was the design of the research parameters and approach, setting the requirements of the protocols to be used, as well as the criteria for testing and the desired outcomes.

Adele Pretorius
30 November 2007

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To whom it may concern

Inclusion of the report, *Validation of Spoornet Mental Workload Index against an Allostatic Load Index,* as appendix to the PhD thesis of Adele Pretorius

We hereby declare that we, Prof M Viljoen and Dr N Claassen, don't have any objection should the candidate wish to attach the above report to her thesis, given that Spoornet grants written permission thereto.

M. Viljoen

Prof M Viljoen

inter

Adele Pretorius
Assistant Manager
Human Resources (Staffing)

Reference:

Telephone: 77-35374 Fax: 77-35378 E-mail: Date: 26 April 20

D.Litt.etPhil – Utilisation of Mental Workload Project Data

Approval is granted to utilise the above data for a dissertation required in fulfillment of the above degree.

The following conditions will apply :

- No individuals to be identified;
- No publication of data (beyond dissertation) without further approval; and
- Two copies of dissertation to be supplied to Spoornet library.

Regards,

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APPENDIX C

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Pilot study to investigate the stress levels in train control officers

Prof M Viljoen en Dr N Claassen

September 2001

CONFIDENTIAL

Introduction

The stress response can be defined as the physiological and psychological changes, which occur as a result of the impact of stressors. It is important to realize that many factors can influence the effect of the environmental factors such as work conditions, i.e., will determine whether conditions will be perceived as stressors or not. Such factors include interpersonal differences such as previous experiences, conditioning, genetics and age, as well as temporal differences where the individual's response to a specific stressor could vary at different occasions. Two factors of major importance in determining whether an individual will perceive a situation as stressful or not are a) the appetitive-aversive qualities and b) the degree to which the individual feels himself in control of the situation. Both these factors will not only influence the cognitive, but also the physiological response to the situation.

The stress response can be measured in terms of acute stress or as the long-term effects of chronic exposure to stressful situations. The latter is generally referred to as the allostatic load and is assessed by measuring the negative impact on a number of physiological factors that represent a fair reflection of the general physical condition (1). The influence of the allostatic load on the cognitive and emotive functions can also be assessed by means of a battery of psychological tests.

Stressors can generally be divided into physical stressors and psychological stressors - with psychological stressors referring to all situations that can induce cognitive and emotional activation states. The stress response resulting from psychological stressors is, with minor variations, relatively non-specific with regard to the original stimulus and the neuroendocrine response. Activation of the two major stress axes, i.e., the sympatho-adrenomedullary axis (SAM-axis) and the hypothalamo-adrenocortical axis (HPA-axis) is, to varying degrees, considered to be characteristic of all psychologically-induced activation states. The activity of these axes can be determined by their hormonal/neurotransmitter status, by changes in the physiological processes under control of the axes or, in the case of the evaluation of the effect of chronic stress, by the relevant pathophysiological changes in the body. In theory the neurohormonal shifts would be the best indicators of acute stress, but in case of the SAM-axis it is often better to ascertain the sympathoadrenomedullary activational state by measuring physiological activities controlled by the system. The best functional parameters for this purpose are probably the registration of heart rate, in case of acute stress, and blood pressure in case of chronic stress determinations. In the case of the HPA-axis the functional alterations require a significant amount of time for full expression and acute variations in activational state are therefore not well reflected in such determinations. The acute reaction is thus best assessed by measuring the level of the major target hormone, cortisol.

A number of important variations in the response of the two major stress axes to psychological stressors have, however, recently been observed. It has for instance been observed that heart rate can fairly consistently be found to increase with mental effort while blood pressure is often very little influence with mental effort without physical involvement like speaking or moving around. Major differences in the stress response have also been reported between a high activational state coupled to aversive emotional experiences and that with neutral or appetitive emotions. An interesting observation, yet to be further substantiated, is the difference observed in the response in the activational state of working in order to avoid a negative outcome and that of an activational state of working for a monatory award (2)

The parameters to be assessed are shortly reviewed at this stage in an attempt to avoid an unnecessary discourse during the discussion of the results.

Blood pressure as stress indicator

Increased blood pressure is a major complication of stressful life styles. However, measurements of blood pressure as an indicator of acute stress often do not yield the information required to assess the magnitude of the stress response (3). The reason for this is multi-factorial, but the major confounding factors include the fact

a) that intermittent behavioural stress often leads to sustained, potentially pathogenic increases in both systolic and diastolic pressures. The major underlying physiological mechanism is the stress-induced increases in plasma lipids – a phenomenon closely related to the development of atherosclerosis.

b) that relatively chronic psycho-social stress negatively influence endothelium-dependent vasodilatory responses

Heart rate as a stress indicator

Heart rate is largely the product of direct sympathetic nervous system responses, or indirect sympathetic system responses (via activation of the adrenal medulla and the circulating catecholamine pool), and of the involvement of neurohormonal factors of the HPA-axis in the regulation of the sympathetic system. In contrast to blood pressure, the sensitivity of heart rate to stress-induced central nervous system activation is generally considered to render it a justified index of acute psychological stress. The rationale for this lies in the fact that transient changes in heart rate can be detected superimposed on chronic, pathophysiological increased heart rates. Consistent high baseline heart rate values are usually the result of factors like genetics, cardiovascular problems or anaemia and hardly ever the direct effect of psychological stress. Transient, stress-induced increases in pulse rate therefore offer a reliable index of acute conditions of stress. According to the cardiovascular reactivity hypothesis cardiovascular reactivity to chronic stressor exposure contributes to the development of hypertension, myocardial infarctation and stroke. While heart rate fluctuations are probably amongst the best indicators of acute stress, it appears not to be of prognostic value – this in contrast to blood pressure which is a poor reflection of transient stress but a good prognostic parameter of eventual pathophysiology (4).

A number of factors should be considered before heart rate variations are summarily taken as the status quo of the cognitive-emotive status of the individual. The two most important of these include:

a) the manner in which the heart rate assessments are performed. Heart rate values obtained by palpitation of a second person over an artery can have several disadvantages. The first disadvantage entails the fact that the manual collections of heart rate counts can only be done intermittently and a continuous recording would thus not be available. Important shifts in heart rate may therefore be missed. The second problem is that of accuracy of the palpitation counts – anyone ever involved with this procedure over an extended period of time is well aware of the pitfalls. The third, and probably the major, confounding factor, is the influence of the proximity of the observer on the psychology and therefore not only on the heart rate, but also on the ability of the test person to continue with normal activities required for task performance. It is thus of paramount importance that additional confounding aspects, such as manual assessments of the heart rate response, should not be introduced into the already problem-riddle field of research.

b) the type of emotional and cognitive response to a stressor.
The typical flight-or fight response generally leads to in increase in blood pressure – the underlying physiological mechanisms are well known. It was shown that heart rate generally increases with most types of emotional experiences, with the exception of disgust. Heart rate increases are generally to be expected with cues for punishment or reward, especially reward. The response is naturally influence by the perception of coping or the inability to cope. This is especially true if some physical action is involved, During a period of anticipatory attention, before the individual goes into action, it is a fairly common occurrence to find that the heart rate is slowing down. This fact is supported by results obtained in experiments where the stressor or stimulus comprised computer games that contain periods of anticipation. It is a common error in stress research to expect the same type of pulse rate reaction form all types of emotion. Examples that substantiate the variation in heart rate responses to different types of psychological stressors are seen in

- ☐ *The startle response* sometimes referred to as the orientating response and by some seen as the “what is it response?” This alerting-related bradycardia can be seen in conditions when the physical fight-or-flight response is not appropriate – when physical activity does not form part of the defense pattern.

- ☐ The cardiovascular changes associated with the *conditioned emotional response* to a stressor are also known not to conform to expectations. It may result in either bradycardia or tacycardia (5).

In the present experimental test results the heart rates were determined by two independent electronically monitored recording apparatus.

Cortisol as indicator of stress

In response to stress the hypothalamus would secrete corticotropin releasing hormone which would stimulate the anterior pituitary to release adrenocorticotropin which in turn would stimulate the adrenal cortex to release the glucocorticoid hormone, cortisol. Together these structures and their hormones represent the HPA-axis. Cortisol is secreted in a diurnal rhythm that is reflected in the plasma concentration of cortisol. Cortisol concentrations in the peripheral blood, and in secretions like saliva, reach a peak in the early morning hours between 06:00 and 08:00, falls progressively towards noon, with a small rise occurring just before lunch, to eventually reach the lowest level around 20:00 to 21:00 hours. This rhythm can be disturbed by a number of factors. Of importance for this study is the fact that it may be disturbed by shift work where the natural day/night time pattern of being awake and being asleep is not observed (6).

Activation of the cardiovascular responses, particularly heart rate can, as discussed in a previous paragraph, occur during mental and emotional stressful tasks, regardless of the negativity or positivity of the emotional tone. In the case of cortisol the emotional quality of the task would appear to determine the magnitude of the response. It is becoming ever more evident that potently aversive situations can lead to prompt and substantial increases in cortisol secretion. It therefore seems feasible to see the cortisol response as a distinguishing feature of distressing events (7).

The brief for this pilot study was: a) to compare the magnitude of acute stress induced by high work loads to that induced by low work load shifts, in terms of physiological variables, and b) to assess whether any correlation could tentatively be observed between the physiological indices of acute stress and that of the work loads. The latter in order to assist in the quest for finding guidelines in the development of a formula, based on the frequency of various activities, by which the various centers can be rated

Methods

Methods

Four male train control officers situated at [redacted] Train Control center were used in this study. After explaining all relevant procedures to the train control officers, they signed a volunteer informed consent form. Their anthropometric data are depicted in table 1. Table 2 depicts the work shifts of the train control officers under investigation at [redacted] train control center during the period of investigation. Subject 1 and 2 worked at the "low" (L) and "high" (H) stress work loads respectively for a time period of one month preceding the evaluation. Their shift schedule followed a seven-day day-shift period (Sunday to Sunday), followed by a seven-day night shift period. S3 and S4 alternated on a day-to-day basis between the L and H work loads. The same weekly shift regime was followed as described for S1 and S2. Due to personnel shortages, S4 worked additional hours from 12:00 – 06:00 the night before the low stress evaluation.

In order to get the maximum experimental information from the four available train control officers, each officer was tested over 2 full shifts. Two were on the same load shift and two on a cross over basis between high and low shifts.

Measurements:

Before the evaluation started the subjects completed the Cohen's perceived stress scale (PSS) to assess their non-specific, appraised stress during the last month.. This questionnaire consists of 14 items of which 7 are positively formulated (eg, "In the last month, how often have you felt that things go your way?") and 7 are negatively formulated (e.g. "In the last month, how often have you felt that you were unable to control the important things in your life?") (Appendix A).

After each day of evaluation the subjects completed a questionnaire to assess their feelings they have experienced during the previous shift (Appendix B).

Heart rate was measured with Polar heart rate monitors at a 15 second interval (Polar Electro). Each subject was issued with a chest harness consisting of two "dry" electrodes, connected to a miniature radio signal transmitter. Electrical activity of the heart is processed and transmitted to a receiver to allow data sampling of the test subject's heart rate during exposure.

Blood pressure, i.e., diastolic (DBP) and systolic (SBP) blood pressure, were measured with a digital electronic blood pressure meter (ALP K2, model DS-125D, Japan). This device was calibrated against a calibrated mercury blood pressure manometer. Two consecutive blood pressure measurements were taken at the beginning of each work session and every two hours there after during the shift. The average of the two measurements is reported.

Saliva was collected in clean collection test tubes, after each blood pressure measurement. Salivary collections were sampled at 06:00, 08:00, 10:00, 12:00, 14:00, 16:00 and 17:30, and stored on ice after collection. The collected saliva was centrifuged at 1000 g for 10 minutes. An aliquot of the supernatant was transferred into two 1.5 ml eppendorf tubes and stored at –20°C until analysis. Free salivary cortisol was determined with a Salivary Cortisol ELISA kit (SLV-2930, DRG Instruments GmbH, Frauenbergstrasse, Marburg, Germany). The principle of the cortisol ELISA kit is based on the competition principle and microplate separation. An unknown amount of salivary cortisol and a fixed amount of cortisol conjugated with horse-radish peroxidase compete for binding sites of a polyclonal cortisol antiserum coated onto the wells. After one hour of incubation, the microtiterplate was washed to stop the competition reaction. The absorbance of each well was determined at 450 nm. The free cortisol levels are inversely proportional to the optical density measured.

A time line analysis, a measurement of mental work load, was recorded during the 12 hour work shift. The same observer was responsible for the time line analysis at specific work loads respectively. The main activities recorded were the updating time schedules, train orders, number of trains, radio communication and telecommunications.

Table 1: Anthropometric data of the train control officers taking part in the study at the [redacted] train control center.

Subject	Age (y)	Mass (kg)	Length (m)	Body mass index (kg.m^{-2})
S1	31	85.5	1.74	28.2
S2	41	124	1.73	41.4
S3	37	64	1.60	25.1
S4	39	95	1.71	32.4
Average	37.0	92.1	1.70	31.8
Standard deviation	4.3	24.9	0.07	7.1

Table 2: Work shifts of train control officers under investigation at [redacted] train control center.

Subject	Date	Time of shift	Work load classification
S1	13 June 2001	06:00 – 18:00	“Low”
S1	15 June 2001	06:00 – 18:00	“Low”
S2	13 June 2001	06:00 – 18:00	“High”
S2	15 June 2001	06:00 – 18:00	“High”
S3	19 June 2001	06:00 – 18:00	“High”
S3	20 June 2001	06:00 – 18:00	“Low”
S4	19 June 2001	06:00 – 18:00	“Low”
S4	20 June 2001	06:00 – 18:00	“High”

Results

Tables 3 to 13 summarize the data measured and calculated from four train control officers. The tables include individual and average work load of each work load level.

Table 3: Perceived stress evaluation score (PSS), number of trains and train orders issued and post shift evaluation of train control officers at the [redacted] train control centre. (L = “Low stress, H = “High stress, R = Repeat, ND = Not determined)

					Post shift evaluation remarks questionnaire			
Person ID	Workstation ID	PSS	Trains	Train orders	How stressful was the shift 1 = No stress 5 = Very stressful	Was the shift more or less stressful than usual	Was the shift unpleasant	Was the shift pleasant
1	L	11	12	14	3	Less stressful	No	Yes
1	LR		8	8	3	Less stressful	No	Yes
Mean	L	11	10	11				
Stdev	L		2.8	4.2				
2	H	20	12	22	1	Less stressful	No	Yes
2	HR		16	24	1	Less stressful	No	Yes
Average	H	20	14	23				
Stdev	H		2.8	1.4				
3	L	28	5	5	ND	ND	ND	ND
3	H		13	34	3	More stressful	No	Yes
4	L	19	5	5	1	Less stressful	No	Yes
4	H		20	22	ND	ND	ND	ND
Average	L	23.5	5.0	5.0				
Stdev	L		0.0	0.0				
Average	H	23.5	16.5	28.0				
Stdev	H		4.9	8.5				

Table 4: Systolic blood pressure (mm.Hg^{-1}) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = "Low stress, H = "High stress, R = Repeat)

		Time (hh:mm)						
Person ID	Workstation ID	06:00	08:00	10:00	12:00	14:00	16:00	17:30
1	L	138	127	131	125.5	132	116.5	128
1	LR	130	122	126	127	115	139	135
Average	L	134	124.5	128.5	126.25	123.5	127.75	131.5
Stdev	L	5.7	3.5	3.5	1.1	12.0	15.9	4.9
2	H	140	140	149	153	147	147	154.5
2	HR	134.5	143	135	154	136.5	138	146.5
Average	H	137.25	141.5	142	153.5	141.75	142.5	150.5
Stdev	H	3.9	2.1	9.9	0.7	7.4	6.4	5.7
3	L	141.5	143.5	135	141.5	145.5	153.5	137
3	H	158	152	147	139	157	147	154
4	L	124	120.5	123	133	130.5	129	128.5
4	H	133.5	129	135.5	118	122	128	130
Average	L	132.8	132.0	129.0	137.3	138.0	141.3	132.8
Stdev	L	12.4	16.3	8.5	6.0	10.6	17.3	6.0
Average	H	145.8	140.5	141.3	128.5	139.5	137.5	142.0
Stdev	H	17.3	16.3	8.1	14.8	24.7	13.4	17.0

Table 5: Diastolic blood pressure (mm.Hg^{-1}) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = "Low stress, H = "High stress, R = Repeat)

		Time (hh:mm)						
Person ID	Workstation ID	06:00	08:00	10:00	12:00	14:00	16:00	17:30
1	L	93	90	88	86	87	82	93.5
1	LR	98	91	93.5	95	89	104.5	85
Average	L	95.5	90.5	90.75	90.5	88	93.25	89.25
Stdev	L	3.5	0.7	3.9	6.4	1.4	15.9	6.0
2	H	86	115	88.5	109.5	99.5	94	90.5
2	HR	100	94.5	96	97	91	86.5	113.5
Average	H	93	104.75	92.25	103.25	95.25	90.25	102
Stdev	H	9.9	14.5	5.3	8.8	6.0	5.3	16.3
3	L	97.5	94.5	92.5	102	86.5	102	97.5
3	H	107.5	127.5	91.5	96	102	101.5	112.5
4	L	87	95	95.5	85	83	86.5	87.5
4	H	97	89.5	90	88.5	83.5	91	104
Average	L	92.3	94.8	94.0	93.5	84.8	94.3	92.5
Stdev	L	7.4	0.4	2.1	12.0	2.5	11.0	7.1
Average	H	102.3	108.5	90.8	92.3	92.8	96.3	108.3
Stdev	H	7.4	26.9	1.1	5.3	13.1	7.4	6.0

Table 6: Pulse pressure (mm.Hg^{-1}) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = “Low stress, H = “High stress, R = Repeat)

		Time (hh:mm)						
Person ID	Workstation ID	06:00	08:00	10:00	12:00	14:00	16:00	17:30
1	L	45.0	37.0	43.0	39.5	45.0	34.5	34.5
1	LR	32.0	31.0	32.5	32.0	26.0	34.5	50.0
Average	L	38.5	34.0	37.8	35.8	35.5	34.5	42.25
Stdev	L	9.2	4.2	7.4	5.3	13.4	0.0	11.0
2	H	54.0	25.0	60.5	43.5	47.5	53.0	64.0
2	HR	34.5	48.5	39.0	57.0	45.5	51.5	33.0
Average	H	44.3	36.8	49.8	50.3	46.5	52.3	48.5
Stdev	H	13.8	16.6	15.2	9.5	1.4	1.1	21.9
3	L	44.0	49.0	42.5	39.5	59.0	51.5	39.5
3	H	50.5	24.5	55.5	43	55	45.5	41.5
4	L	37.0	25.5	27.5	48.0	47.5	42.5	41.0
4	H	36.5	39.5	45.5	29.5	38.5	37.0	26.0
Average	L	40.5	37.3	35.0	43.8	53.3	47.0	40.3
Stdev	L	4.9	16.6	10.6	6.0	8.1	6.4	1.1
Average	H	43.5	32.0	50.5	36.3	46.8	41.3	33.8
Stdev	H	9.9	10.6	7.1	9.5	11.7	6.0	11.0

Table 7: Mean blood pressure (mm.Hg^{-1}) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = “Low stress, H = “High stress, R = Repeat)

		Time (hh:mm)						
Person ID	Workstation ID	06:00	08:00	10:00	12:00	14:00	16:00	17:30
1	L	107.9	102.2	102.2	99.0	101.9	93.4	104.9
1	LR	108.6	101.2	104.2	105.6	97.6	115.9	101.5
Average	L	108.2	101.7	103.2	102.3	99.7	104.6	103.2
Stdev	L	0.5	0.7	1.4	4.6	3.0	15.9	2.4
2	H	103.8	123.3	108.5	123.9	115.2	111.5	111.6
2	HR	111.4	110.5	108.9	115.8	106.0	103.5	124.4
Average	H	107.6	116.9	108.7	119.8	110.6	107.5	118.0
Stdev	H	5.3	9.0	0.3	5.7	6.5	5.7	9.0
3	L	112.0	110.7	106.5	115.0	106.0	119.0	110.5
3	H	124.2	135.6	109.8	110.2	120.2	116.5	126.2
4	L	99.2	103.4	104.6	100.8	98.7	100.5	101.0
4	H	109.0	102.5	105.0	98.2	96.2	103.2	112.6
Average	L	105.6	107.0	105.6	107.9	102.3	109.8	105.8
Stdev	L	9.1	5.1	1.4	10.0	5.2	13.1	6.7
Average	H	116.6	119.1	107.4	104.2	108.2	109.9	119.4
Stdev	H	10.7	23.4	3.4	8.5	16.9	9.4	9.6

Table 8: Heart rate (beats.min^{-1}) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = “Low stress, H = “High stress, R = Repeat)

		Time (hh:mm)						
Person ID	Workstation ID	06:00	08:00	10:00	12:00	14:00	16:00	17:30
1	L	65.0	47.0	45.0	51.5	50.0	55.0	49.0
1	LR	68.5	52.5	50.5	54	65	68.5	55.5
Average	L	66.8	49.8	47.8	52.8	57.5	61.8	52.3
Stdev	L	2.5	3.9	3.9	1.7	10.6	9.5	4.6
2	H	87.0	79.0	89.0	96.0	84.0	82.0	92.0
2	HR	80.0	83.0	81.5	96.5	80.0	86.0	84.5
Average	H	83.5	81.0	85.3	96.3	82.0	84.0	88.3
Stdev	H	4.9	2.8	5.3	0.4	2.8	2.8	5.3
3	L	72.0	73.0	58.0	72.5	66.5	79.0	61.0
3	H	75.5	71.5	79.0	78.0	71.0	64.0	72.5
4	L	91.5	81.0	82.5	82.0	88.5	90.5	87.5
4	H	92.5	84.0	95.5	80.0	77.5	75.5	87.5
Average	L	81.8	77.0	70.3	77.3	77.5	84.8	74.3
Stdev	L	13.8	5.7	17.3	6.7	15.6	8.1	18.7
Average	H	84.0	77.8	87.3	79.0	74.3	69.8	80.0
Stdev	H	12.0	8.8	11.7	1.4	4.6	8.1	10.6

Table 9: Cortisol (ng.mL^{-1}) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = "Low stress, H = "High stress, R = Repeat)

		Time (hh:mm)						
Person ID	Workstation ID	06:00	08:00	10:00	12:00	14:00	16:00	17:30
1	L	10.5	5.5	4.5	4.75	4.5	4.0	2.5
1	LR	11.0	4.0	5.5	5.5	3.5	7.5	5.0
Average	L	10.8	4.8	5.0	5.1	4.0	5.8	3.8
Stdev	L	0.4	1.1	0.7	0.5	0.7	2.5	1.8
2	H	32.0	11.5	7.5	6.5	7.0	7.5	9.0
2	HR	12.0	10.0	8.0	6.0	5.0	4.0	5.0
Average	H	22.0	10.8	7.8	6.3	6.0	5.8	7.0
Stdev	H	14.1	1.1	0.4	0.4	1.4	2.5	2.8
3	L	14.5	8.5	12.5	11.0	12.0	10.0	6.5
3	H	12.5	12.0	11.5	10.5	7.5	2.5	6.5
4	L	13.0	16.0	10.5	12.0	14.0	7.5	3.0
4	H	16.0	14.5	7.0	7.0	10.0	3.5	2.5
Average	L	13.8	12.3	11.5	11.5	13.0	8.8	4.8
Stdev	L	1.1	5.3	1.4	0.7	1.4	1.8	2.5
Average	H	14.3	13.3	9.3	8.8	8.8	3.0	4.5
Stdev	H	2.5	1.8	3.2	2.5	1.8	0.7	2.8

Table 10: Radio communication (Number per 2 hours) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = "Low stress, H = "High stress, R = Repeat)

		Time (hh:mm)					
Person ID	Workstation ID	06:00 – 08:00	08:00 – 10:00	10:00 – 12:00	12:00 – 14:00	14:00 – 16:00	16:00 – 17:30
1	L	17	13	8	16	7	4
1	LR	12	4	16	0	22	5
Average	L	14.5	8.5	12.0	8.0	14.5	4.5
Stdev	L	3.5	6.4	5.7	11.3	10.6	0.7
2	H	30	33	46	36	51	15
2	HR	51	67	58	62	64	45
Average	H	40.5	50.0	52.0	49.0	57.5	30.0
Stdev	H	14.8	24.0	8.5	18.4	9.2	21.2
3	L	0	0	19	8	17	17
3	H	49	59	66	56	84	34
4	L	0	2	23	14	10	12
4	H	47	43	56	60	57	32
Average	L	0.0	1.0	21.0	11.0	13.5	14.5
Stdev	L	0.0	1.4	2.8	4.2	4.9	3.5
Average	H	48.0	51.0	61.0	58.0	70.5	33.0
Stdev	H	1.4	11.3	7.1	2.8	19.1	1.4

Table 11: Telecommunications (Number per 2 hours) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = “Low stress, H = “High stress, R = Repeat)

		Time (hh:mm)					
Person ID	Workstation ID	06:00 – 08:00	08:00 – 10:00	10:00 – 12:00	12:00 – 14:00	14:00 – 16:00	16:00 – 17:30
1	L	1	2	5	2	3	0
1	LR	0	5	7	0	6	0
Average	L	0.5	3.5	6.0	1.0	4.5	0.0
Stdev	L	0.7	2.1	1.4	1.4	2.1	0
2	H	6	15	9	6	5	1
2	HR	5	7	15	6	4	3
Average	H	5.5	11.0	12.0	6.0	4.5	2.0
Stdev	H	0.7	5.7	4.2	0	0.7	1.4
3	L	2	3	9	1	4	2
3	H	11	8	8	3	4	5
4	L	3	0	5	6	2	9
4	H	6	2	7	8	6	1
Average	L	2.5	1.5	7.0	3.5	3.0	5.5
Stdev	L	0.7	2.1	2.8	3.5	1.4	4.9
Average	H	8.5	5.0	7.5	5.5	5.0	3.0
Stdev	H	3.5	4.2	0.7	3.5	1.4	2.8

Table 12: Routine notations (Number per 2 hours) of train control officers at the [redacted] train control centre during a twelve hour shift. (L = “Low stress, H = “High stress, R = Repeat)

		Time (hh:mm)					
Person ID	Workstation ID	06:00 – 08:00	08:00 – 10:00	10:00 – 12:00	12:00 – 14:00	14:00 – 16:00	16:00 – 17:30
1	L	0	3	3	6	5	3
1	LR	2	0	11	0	11	5
Average	L	1.0	1.5	7.0	3.0	8.0	4.0
Stdev	L	1.4	2.1	5.7	4.2	4.2	1.4
2	H	15	30	39	25	35	9
2	HR	31	40	37	33	42	30
Average	H	23.0	35.0	38.0	29.0	38.5	19.5
Stdev	H	11.3	7.1	1.4	5.7	4.9	14.8
3	L	0	0	15	5	10	12
3	H	24	33	39	40	66	23
4	L	0	0	14	6	1	11
4	H	37	30	36	39	44	19
Average	L	0.0	0.0	14.5	5.5	5.5	11.5
Stdev	L	0.0	0.0	0.7	0.7	6.4	0.7
Average	H	30.5	31.5	37.5	39.5	55.0	21.0
Stdev	H	9.2	2.1	2.1	0.7	15.6	2.8

Table 13: Correlation between selected physiological variables with radio communication, telephonic inquiries and routine notations over the 12 hour exposure time.

Physiological variable	Radio communication		Telephonic communication		Routine notations	
	r	p	r	p	r	p
Low stress						
Heart rate	0.0373	0.6649	0.1576	0.0659	0.0823	0.3392
Cortisol	-0.1250	0.6212	0.0764	0.7633	-0.0421	0.8684
SBP	0.2355	0.3469	0.1221	0.6294	00.3859	0.1138
DBP	0.0122	0.9617	0.0762	0.7638	0.1876	0.4559
Mean arterial BP	0.1334	0.5978	0.1154	0.6485	0.3294	0.1819
Pulse Pressure	0.2419	0.3336	0.0800	0.7522	0.2875	0.2474
High stress						
Heart rate (2 hour value)	-0.5164	0.0282	-0.0081	0.9745	-0.4343	0.0717
Heart rate (Polar)	0.2290	0.3607	-0.0534	0.8334	0.2552	0.3068
Cortisol	-0.0648	0.7984	0.4221	0.0810	-0.2375	0.3427
SBP	-0.0764	0.7631	0.0749	0.7677	-0.0883	0.7276
DBP	-0.2921	0.2395	0.0976	0.6999	-0.3580	0.1447
Mean arterial BP	-0.2366	0.3446	0.0979	0.6991	-0.2878	0.2467
Pulse Pressure	0.2362	0.3454	-0.0180	0.9436	0.2960	0.2330
Low & High stress						
Heart rate (2 hour value)	0.3312	0.0485	0.3396	0.0427	0.3314	0.0483
Heart rate (Polar)	0.4550	0.0053	0.2880	0.0885	0.4610	0.0047
Cortisol	-0.1299	0.4501	0.1752	0.3068	-0.1668	0.3308
SBP	0.3482	0.0374	0.2396	0.1593	0.3463	0.0385
DBP	0.2367	0.1645	0.2298	0.1775	0.1990	0.2447
Mean arterial BP	0.3071	0.0685	0.2572	0.1300	0.2804	0.0976
Pulse Pressure	0.1951	0.2542	0.0664	0.7002	0.2310	0.1753

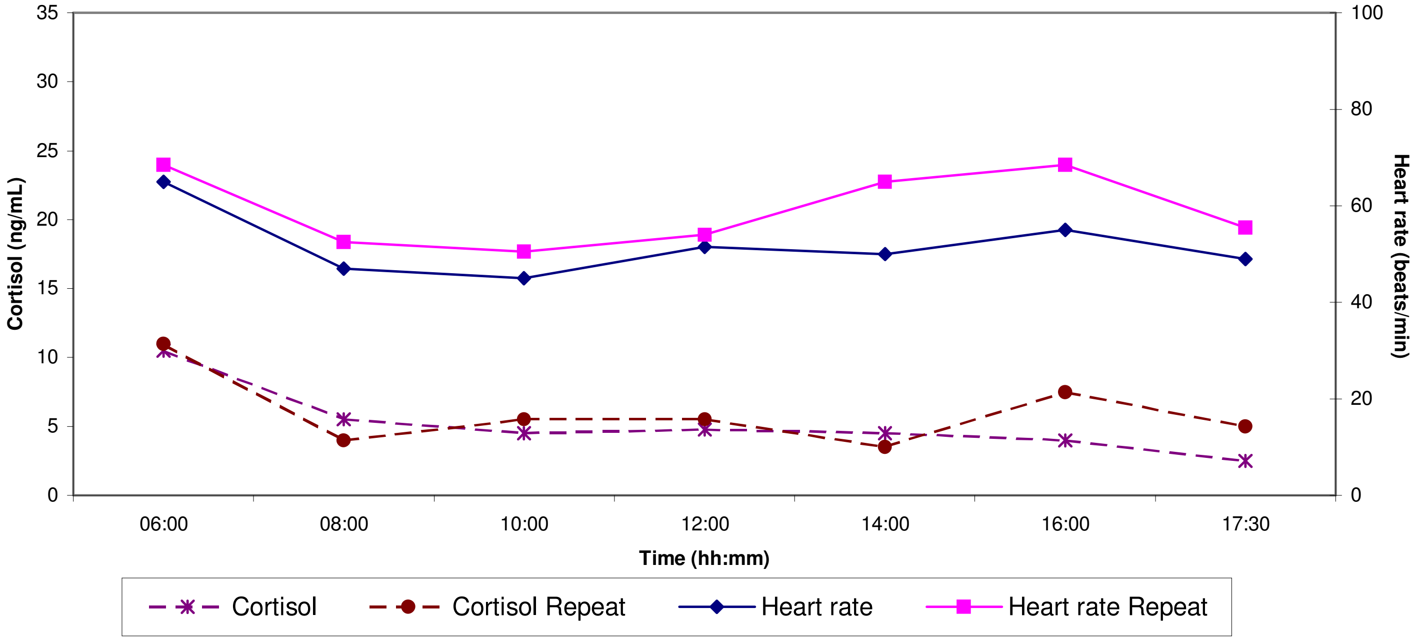

Figure 1: Cortisol and heart rate responses of S1 to a low work load

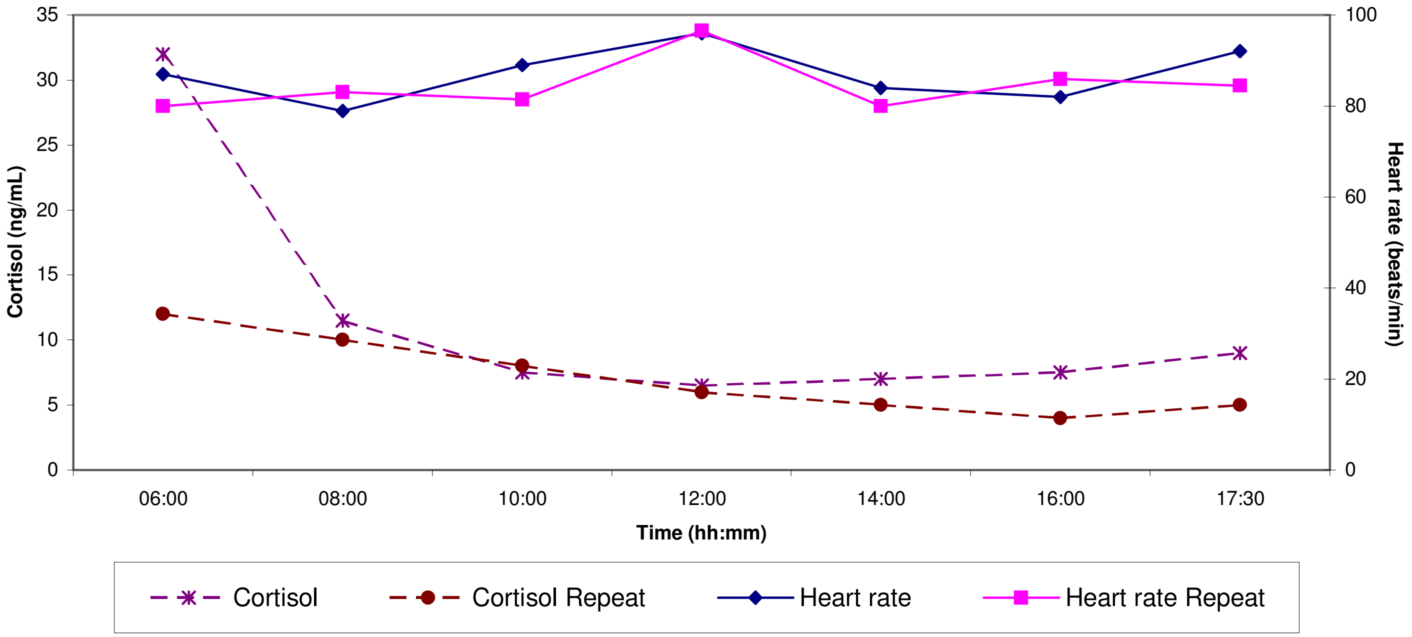

Figure 2: Cortisol and heart rate responses of S2 to a high work load

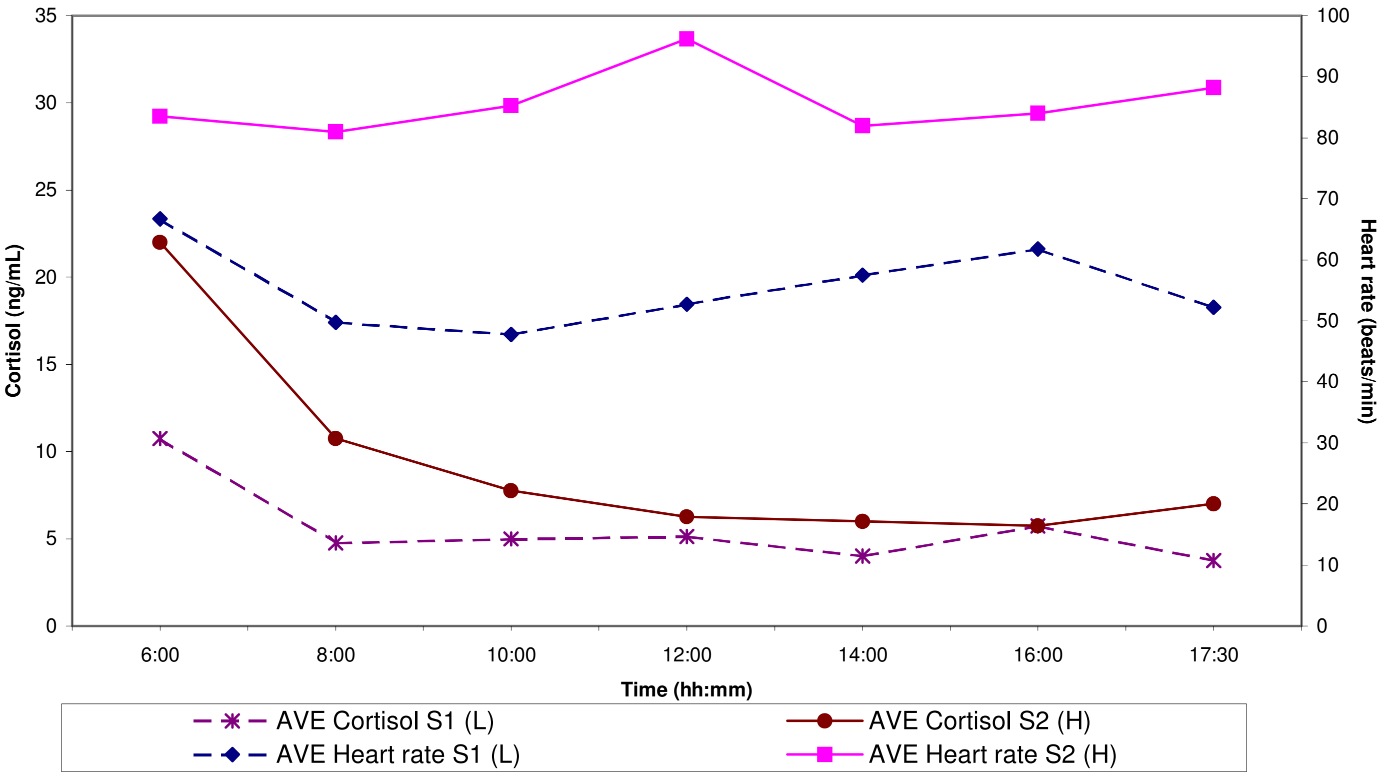

Figure 3 Mean cortisol and heart rate responses of S1 and S2 at a low and high work loads respectively.

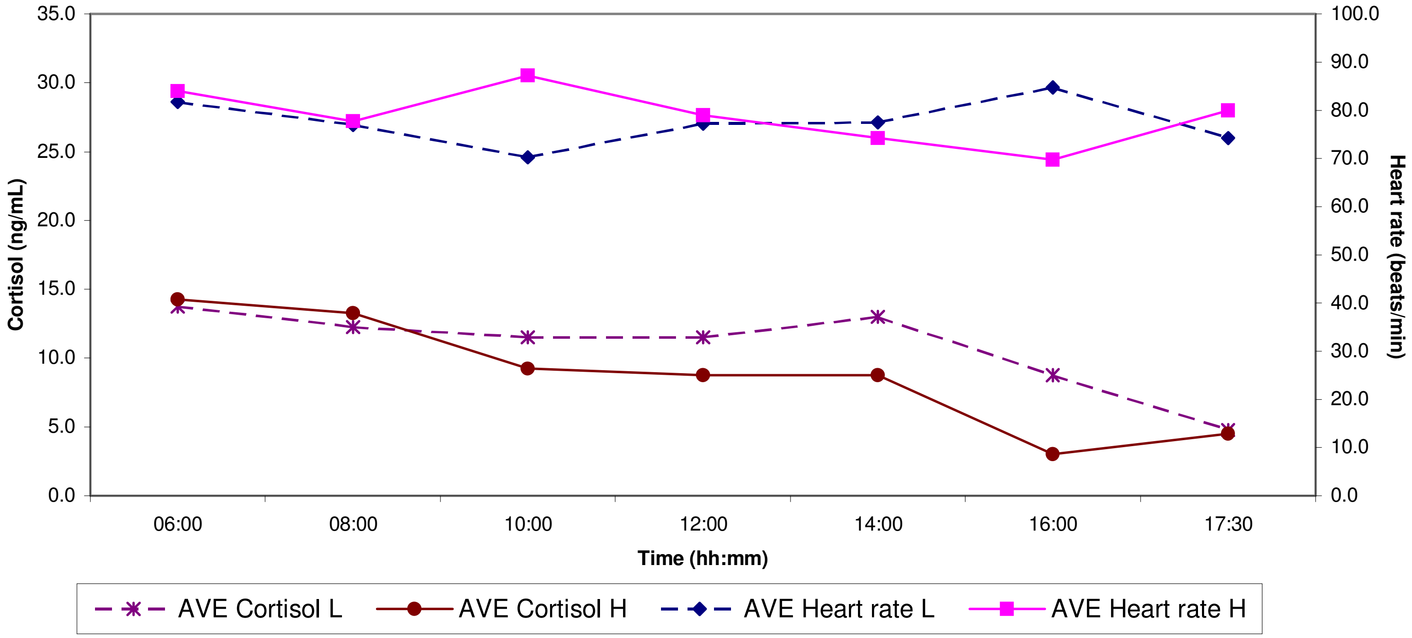

Figure 4: Mean cortisol and heart rate responses of S3 and S4 at a low and high work loads respectively.

Discussion

The brief for this pilot study was to a) compare the magnitude of acute stress induced by low work load shifts to that induced by high work load shifts, in terms of physiological variables and b) to assess whether any correlation could tentatively be observed between the physiological indices of acute stress and that of the work loads.

Theoretically, the effect work stress in situations like this, should be assessed by determining the allostatic load in a statistically valid number of individuals who were consistently on high work load shifts for an extended period of time and comparing their values to those of the same number of individuals consistently on low load shifts for an extended period of time. Factors like hours per shift, number of shifts per month and several other variables should then also be taken in consideration. In this study the number of workers, the work stations and the work conditions were beyond the control of the investigators. For this reason the current study should be seen as a pilot study. Nevertheless, a number of indications and important guidelines were observed.

The results are presented as Part A, which deals with the stress comparisons at different work loads, and Part B, which deals with the correlations between the numerical assessment of work load and the magnitude of the physiological stress response.

To facilitate the reading of this report the reader is at this stage presented with the outlay of the discussion:

Part A: A comparison between the physiological stress responses at high work loads to that at low work loads

a) Difference in work intensity between high and low load shifts
b) Reproducibility of results
c) Differences in the responses to high work load and to low work load when all the high load values were pooled into one group and all the low load values into another.

d) Differences in the responses to high work load and to low work load when the values of individuals were analysed.
e) Differences in the responses to high work load and low work load as seen during a cross-over comparison.
f) Conclusions on the rating of work loads in terms of the physiological response

Part B of study: Activity levels or work load versus physiological indicators of stress

a) Activity levels or work load versus physiological indicators of stress for the total group
b) Activity levels or work load versus physiological indicators of stress, observed during low load shifts
c) Activity levels or work load versus physiological indicators of stress observed during high load shifts
d) Conclusions on the correlation between activity scoring and physiological stress response scoring

Part C: Tentative indications of high allostatic loads

Part D: Final conclusions and recommendations

Part A: A comparison between the physiological stress responses at high work loads to that at low work loads

The aim was to examine the stress levels in terms of the physiological response at low work loads compared to that at high work loads. In looking at the data it is imperative to remember that every individual already carried the effects of the allostatic load, a factor which may have a confounding effect on the values.

The discussion to follow is based on the information in the Tables and Figures under the results section.

a) Difference in work intensity between high and low load shifts

To ascertain whether the work loads were indeed different between the presumed high and low load shifts, the number of trains, train orders and the frequency of the three major activities were compared (one-way ANOVA).

:

Number of trains per high load shift: mean = 15.7; SD = 3.8
Number of trains per low load shift: mean: = 6.7; SD = 2.9
Statistical significance of difference: p = 0.0307

Train orders per high load shift: mean = 26.3; SD = 6.7
Train orders per low load shift: mean = 7.0: SD = 3.5
Statistical significance of difference: p = 0.0111

Routine notations of scheduled work per high load shift: mean = 34.1; SD = 11.1
Routine notations of scheduled work per low load shift: mean: = 5.5; SD = 5.2
Statistical significance of difference: p = 0.00001

Telecommunications per high load shift: mean = 6.1; SD = 3.2
Telecommunications per low load shift: mean = 3.4; SD = 2.8
Statistical significance of difference: p = 0.0104

Radiocommunications per high load shift: mean = 51.2; SD = 13.0
Radiocommunications per low load shift: mean = 10.2; SD = 6.9
Statistical significance of difference: p = 0.00001

c) Reproducibility of results

The reproducibility of the determinations over one entire shift was tested by evaluating the values from duplicate shifts by the same individual on which all parameters were measured at 2hrs interval. This was done on one volunteer at a low load station and one at a high load station. The reproducibility of the two main stress measurements, i.e. cortisol levels and heart rate for each can be seen in Figures1-2 of the results section. The first determination of each shift was ignored as it reflected not only the peak of the circadian rhythm but also the physical and psychological activities before the initiation of the work session. The reproducibility between the duplicate shifts was good and no significant difference was found.

d) Differences in the responses to high work load and to low work load when all the high load values were pooled into one group and all the low load values into another.

The mean values over time and the statistical differences between the values for high and for low work loads, obtained when the one-way ANOVA was applied were as follows:

> The mean arterial blood pressure (mmHg) for the high load shifts (112 ± 9.9; n = 18) was significantly higher than that for the low load shifts (105 ± 5.5; n = 18): p = 0.0139 (Kruskal-Wallis)
>
> The diastolic blood pressure (mmHg) for the high load shifts (98 ± 10.5; n = 18) were significantly higher than that for the low load shifts (91 ± 5.4; n = 18): p = 0.0376 (Kruskal-Wallis)
>
> The systolic blood pressures (mmHg) for the high load shifts (140 ± 11.5; n = 18) were significantly higher than for the low load shifts (132 ± 8.8;n = 18): p = 0.0215
>
> No significant difference were found between the high and low load shifts for the salivary cortisol (ng/ml): p = 0.5432

> The average heart rate over time (beats/min) for the high load shifts (90 ± 3.1; n = 18) were significantly higher than for the low load shifts (81 ± 10.7; n = 18):
> p = 0.0169 (Krushkal-Wallis)

From the above values one would at first glance conclude that the physiological stress response is indeed significantly higher during the high work load shifts. This would be based on the significant differences in the cardiovascular responses – in this case representative of the activation of the SAM-axis. Cortisol levels, a HPA-axis stress indicator is usually expected to be elevated by aversive psychological experiences. According to the results obtained when the values of all determinations were pooled into two activity groups, no difference existed between the appetitive-aversive perceptions of the two work load individuals.

The next step was to analyse the values of the individuals in both groups to test whether the statistical significance of the differences observed for the total group were indeed valid.

e) Differences in the responses to high work load and to low work load when the values of individuals were analysed.

The differences between the response to high and low loads were first statistically analysed on the values obtained from one individual (#2) twice on high, and one individual (#1) twice on low work loads.

In Figure 3 the graphs for the mean cortisol and mean heart rate of the duplicate determinations are presented for both the low and the high work load candidates. The visible differences were confirmed by the results of the statistical analysis (one-way ANOVA) of the data. In comparing the mean over time values obtained from the high load to the values of the low work load shifts it was shown that cortisol values for the 2 high load shifts (mean = 7.25; SD = 1.9; n = 6), when compared to salivary cortisol values for the low load shifts (mean = 4.73; SD = 1.4; n = 6) were significantly higher: p = 0.0117

and

heart rate/min values for the 2 high load shifts (mean = 91; SD = 1.7; n = 6), when compared to average heart rate values for the low load shifts (mean = 68; SD = 3.4; n = 6) were significantly higher: p = 0.00001

This would once again seemed to support the existence of a significantly higher physiologically stress response during high activity shifts. It should, however be kept in mind that the individuals who were each tested twice over their respective work loads were not age, BMI, race and allostatic load matched and the results should therefore be viewed with caution. The non-matching of candidates were the result of the limitations on the availability of matching subjects at the particular venues and the restrictions in the number of candidates imposed on the study. For this kind of comparison to be accepted without reservations one of two improvement to the study design should be made: a) either the experimental procedure should be performed on at least 200 individuals - each, preferably, confined to one type of work load or even better, b) a cross-over study should be performed where the values of each candidate involved in the study are obtained at both high and low work schedules.

The next step in this pilot study was indeed a cross-over assessment where each of two candidates was evaluated on both high and low load shifts.

f) Differences in the responses to high work load and to low work load as seen during a cross-over comparison.

In this comparison the values of two candidate (#3 & #4) were in the first place analysed by comparing the values of the same candidate at high and at low work loads, and in the second place by pooling (calculating the mean) the values over time obtained at the two high load sessions and comparing that to the mean of the two low load sessions. Only the statistics of the two major acute stress indicators are presented here. The other values and raw data can be found in the results section.

Mean over time of the cortisol levels for subject #3 at high work load: 8.4ng/ml (SD = 3.6; n = 6)

Mean over time of the cortisol levels for subject #3 at low work load: 10.1ng/ml (SD = 2.3; n = 6)

No significant difference existed between the series of values: p = 0.3635

Mean over time of the cortisol levels for subject #4 at high work load: 7.4ng/ml (SD = 4.4; n = 6)

Mean over time of the cortisol levels for subject #4 at low work load: 10.5ng/ml (SD = 4.7; n = 6)

No significant difference existed between the series of values: p = 0.2674

The standard deviations for the cortisol values pointed towards large fluctuations in cortisol levels which, when translated into terms of stress, may indicate periods of aversive experiences. It is of interest that the tendency is only found during high load shifts.

Mean over time for the heart rate values for subject #3 at high work load: 88/min (SD = 3.5; n = 6)

Mean over time of the heart rate values for subject #3 at low work load: 84/min (SD = 2.8; n = 6)

The difference bordered on statistical significance and would most probably have been significant with larger experimental groups: p = 0.0656

Mean over time for the heart rate values for subject #4 at high work load: 91/min (SD = 2.9; n = 6)
Mean over time of the heart rate values for subject #4 at low work load: 92/min (SD = 2.6; n = 6)
No statistical difference was found between the two series of values: p = 0.4639 –
in fact, the standard deviations were very small reflecting only minor deviation in the heart rate over both the high and low load shifts

g) Conclusions on the rating of work loads in terms of the physiological response

The results presented in this section of the study confirmed the statistically significant differences between the workloads of the high and low shifts. In evaluating the reproducibility of results it was shown that the physiological responses, obtained during duplicate evaluations at both high and low loads, did not differ significantly and that it should generally not be considered a problem area of the research. In comparing the physiological parameters at high workloads to that at low workloads it was shown that the values were indeed uniformly higher during the high load shifts. However, this may be a reflection of allostatic load rather than acute stress.

Values of individuals were subsequently analysed. The differences were, however, confirmed by comparing the values of one individual tested twice on high load, and one individual tested twice on low load.

To try and eliminate non-matching in personal allostatic loads and other factors, a crossover study was performed with two workers – each doing a low load and a high load. From the results it can with a fair amount of confidence be said that the heart rate response can be an indicator of differences in workload, but that larger experimental groups should be tested to absolutely confirm this. An interesting observation was that high workload does not appear to be experienced as an aversive factor.

Part B of study: Activity levels or work load versus physiological indicators of stress

This part of the study was performed in an attempt to find guidelines for the development of a formula, based on the intensity of the work schedule, which could differentiate between high and low stress station. The information on which this discussion is based can be seen in under results in Table 13.

a) Activity levels or work load versus physiological indicators of stress for the total group

In the present study positive correlations were found between the activity scores and some of the physiological parameters of stress if the values of all experimental subjects were taken into account. The activity levels were assessed by subdividing activity into three subclasses, i.e., radio communications, telecommunications and routine notations of scheduled train traffic and related events. It should be stressed that telecommunications are often the means of communications if there is a breakdown in the standard lines of communications or if special request or enquiries beyond the duties of the worker take place.

The radio-communication scores correlated positively with the mean arterial blood pressure values, the systolic blood pressure and the heart rate

Radio communication versus SBP: $r = 0.3482$; $p = 0.0374$
Radio communication versus Mean arterial BP: $r = 0.3071$; $p = 0.0685$
Radio communication versus HR: $r = 0.3312$; $p = 0.0485$

The validity of the stat recorded heart rate values were tested by means of continuous recordings of heart rates by a polar watch. The validity of the positive correlations just shown was supported by the values of the correlations obtained when the mean values of the continuous recordings were used in the statistical analysis

Radio communication versus HR polar: $r = 0.4550$; $p = 0.0053$

This statistically significant correlation between magnitude of activity and physiological activation was also observed when telecommunications for the total group were compared to heart rate. Again increases in telecommunication correlated positively with increases in heart rate

Telecommunication versus HR: $r = 0.3396$; $p = 0.0427$

Again the validity of the significance was confirmed by alternative heart rate recordings. The correlations between the telecommunications and heart rates as obtained by means of the polar heart rate monitor recordings were

Telecommunication versus HR polar: $r = 0.2880$; $p = 0.0885$

The correlation between activity scoring and physiological activation for the total group was once more confirmed when comparing the activities involved in the routine work such as notation of the schedules.

Correlations as obtained from stat heart rate values automatically recorded by blood pressure monitor were

Routine notations versus SBP: $r = 0.3463$; $p = 0.0385$
Routine notations versus HR: $r = 0.3314$: $p = 0.0483$

When once again testing the validity by polar watch recordings the correlation was also confirmed.

Routine notations versus HR polar: r = 0.4610: p = 0.0047

No statistical significant correlations were found between cortisol and activity scores when the experimental group as a whole were considered.

In analysing the data for the experimental subjects as a total group it can be concluded that a correlation does indeed exist between the activity scoring and the physiological scoring of stress as depicted by cardiovascular responses. The fact that this was found mainly for heart rate and for cardiovascular parameters that involved cardiac function (systolic blood pressure and mean arterial pressure) rather than purely vascular reactivity, and that no correlations could be found between activity and cortisol levels, is of significance. It is known, as discussed in the introduction, that the emotional characteristics of a stress response are of paramount importance for determining the autonomic and endocrine responses. Emotionally positive, activating challenges will result in heightened cardiovascular responses – and in the case of acute stress situations, more specifically acute transient heart rate responses that coincide with the time of stressor application. As long as no significantly aversive reaction is experience during the work related activity-induced stress response, cortisol levels will normally not increase to any significant level. The total picture seen in the response of the group to increases in work activity can thus be summarised by saying firstly that, as would be expected, a good correlation does indeed exist between the work load as measured by activity scores and the degree of psychologically-induced physiological activation. This is a normal phenomenon and would generally occur, even if the activity happened to be recreational or pleasurable in nature. Secondly, and of great importance, is the fact that the transient increases in physiological activation were not accompanied by negative emotional experiences – in other words the workers would not seem to have experience any marked degree of distress as a result of an increase in work load. The latter deduction, based on the results of the objective results, is further confirmed by the subjective score sheets filled in by the workers at the end of each shift.

The next step was to subdivide the experimental values into values obtained during high workloads and that obtained during low work loads.

b) Activity levels or work load versus physiological indicators of stress, observed during low load shifts

No relevant statistical significant correlations were found either for the SAM-axis stress indicators (cardiovascular reactivity) or HPA-axis stress indicators (cortisol) when the values obtained at all low load shifts were pooled. As before the validity of the heart rate recordings were confirmed by a second series of determinations by polar watch.

When the values obtained from individual workers were examined it was noticeable that for one specific individual (#1), the one with generally the lowest basal values in terms of stress indicators, the comparisons between activities involving verbal communications and cortisol levels were just marginally non-significant

Radio communications versus cortisol: r = 0.7999; p = 0.0561
Telecommunications versus cortisol: r = 0.7945; p = 0.0590

With a larger n-value it is highly likely that the p-value would have been significant. The conclusion to be reach from this observation is that verbal communication presents a degree of thread to this individual.

c) Activity levels or work load versus physiological indicators of stress observed during high load shifts

In comparing the physiological stress parameter values obtained during the high load shifts, with the exception of one parameter, no correlations could be found between physiological stress indicators and the frequency of the various activities. A statistical significant negative correlation was observed between radio communication and heart rate with the single automatic recording system.

Radio communications versus HR: r = - 0.5164; p = 0.0282

Polar recordings of heart rates were then compared to the frequency of radio communications. These recordings recorded no correlation with radio communication.

Radio communications versus HRpolar: r = 0.2290; p = 0.3607

It is a fairly common occurrence to find that the heart rate is slowing down during a period of anticipatory attention, i.e., before the individual goes into action. The possibility therefore existed that such a phenomenon could have been the cause of the initial negative correlation seen between heart rate and the frequency of radio communications. However, in testing the correlations by using the mean of the continuous recordings the correlation falls away and it become obvious that a high variability in heart rate may be the more feasible explanation. This observation stresses the suspicion that continuous recordings of heart rate give a more accurate reflection and should be the technique of choice.

Indications of a positive correlation were seen between cortisol and the number of telecommunications per high workload shift when all the values obtained over high load shifts were considered. The correlation was only marginally not significant and indications are that with larger experimental groups it would be shown that the handling of telecommunications, superimposed on an already high workload schedule, is the one activity found to have the most aversive quality.

Telecommunications versus cortisol levels: r = 0.4221; p = 0.0810

When examining the values of individual workers the mean values for cortisol of subjects #2 and #3, taken intermittently at predetermined times over their shifts, showed a statistically significant positive correlation with telecommunications. These two workers alternated between high and low work stations and a crossover comparison could therefore be made between their values at high and that at low work loads. It is important to note that no correlation could be found between telecommunication and cortisol levels at low work shifts

High work load(S3&S4): telecommunications versus cortisol: r = 0.6487; r = 0.0225
Low work load (S3&S4): telecommunications versus cortisol: r = -0.1852; r = 0.5645

In these individuals it can, with a fair degree of certainty be said that telecommunications are experienced as an aversive intrusion when already taxed with a high workload.

d) Conclusions on the correlation between activity scoring and physiological stress response scoring, it can be said that

In, conclusion on the correlation between activity scoring and physiological stress response scoring: when the values of all subjects on both high and low load shifts are compared to the work activity, excellent correlations were found for all parameters indicative of activation of the SAM-axis. This should be seen as a reflection of work-induced mental activation. However, no significant correlations were seen with cortisol, an indicator of HPA-axis activation. This could generally be interpreted as a lack of correlation between the intensity or frequency of work activities and negative emotional experiences. In other words, the subjects did not find the increase in workload aversive. This conclusion supports the results of the subjective scoring comments. When analysing the low and high load results separately, no correlations were found by assessment according to activities and assessments according to physiological parameters. The fact that good correlations were found for the total number of subjects, but not for the subgroups can, with a fair amount of confidence, be ascribed to the fact that the experimental groups were too small. Indications repeatedly surfaced that telecommunications may be the one factor that is disliked when superimposed on the high load shifts

Part C: Preliminary indications of high allostatic loads

Although the determination of the indicators of accumulated long-term stress was beyond the brief for this work, a number of relevant observations were made. In normal populations salivary cortisol levels, as performed by the same standardised method used in this study vary between 4 and 10ng/ml at 08:00, and between 0.7 and 1.5ng/ml at 20:00hrs. The cortisol levels of the subjects in this study were generally much higher and varied between 4.0 and 16 ng/ml, with an average for all values, independent of work intensity, of 11.1 ± 4.1 ng/mL. The correlation between cortisol levels and BMI – indicators of acute as well as chronic, and chronic stress *per se* , was highly significant ($r = 0.8277$; $p=0.0420$) when values for the total group were analysed. This strong correlation as well as the high cortisol levels could reflect work stress, but could otherwise very well be a reflection of the life style of the workers. The mean blood pressure values of the total group were also above that of the normal range with systolic pressure of 136.7 ± 10.8 mm.Hg^{-1}, diastolic values of 95.1 ± 8.5 mm.Hg^{-1} , mean arterial pressures of 108.8 ± 8.5 mm.Hg^{-1} and pulse pressures of 41.6 ± 8.3 mm.Hg^{-1}. The average heart rate for the group was 85.7 ± 8.8 beats.min^{-1}. The limited number of individuals on high and low work loads, respectively, as well as the fact that workers often alternate between high and low loads, unfortunately precludes the statistical comparison between high and low work loads. From the comparisons presented in this paragraph it is obvious that the physiological values of chronic stress parameters of the experimental group is above that of normal healthy population values. It is, however, highly likely that it reflects the total life style of the individuals rather than the work load and that such values would be found in many other work environments with life styles particular to the occupation. What was very obvious is the fact that low stress values, with regard to cardiovascular responses were consistently seen in the individual who gets regular exercise by walking to work.

Part D: Final conclusions and recommendations

The following conclusions can be reached

- ☐ That the work load between the presumed high load work station are indeed significantly different, not only in terms of trains and train orders, but also in terms of routine schedule notations, radio communications and telecommunications.
- ☐ The differences seen between workload activities and physiological responses are valid and not due to do to technical or design errors.
- ☐ The two parameters that were shown to be consistent indicators of acute workload increases and negative emotional experiences, respectively, were heart rate and cortisol. Blood pressure-related factors would, as reported in literature, seem to more reliant as a chronic stress indicator.
- ☐ The workload in terms of frequency of activities is reflected in the physiological stress response. However, this could be a reflection of the effect of allostatic load plus acute stress rather than merely acute stress as blood pressures are also increased.
- ☐ The increases in work load and psychological stress system activation is hardly ever accompanied by increases in a negative stress condition, i.e., the workers don’t seem to resent high loads.
- ☐ The one factor, which would appear to cause negative stress and resentment, is telephonic communication when superimposed on a high intensity work schedule. It should be remembered that telecommunications are mostly the communication means when the normal routes fail or when special requests, beyond the work description, are made. Telecommunications would appear to be better tolerated at low workloads.
- ☐ When examining the possibility of the classification of stations into low and high stress areas it would appear if such a classification is indeed feasible as a good reflection of the physiological activation. This was seen in the activity score when the subjects as a whole were considered. As this impression was not supported by the results when the group was subdivided, the evaluation should be expanded to a larger number of subjects before absolute certainty can be reached.

- Not part of the brief of this study, but noticeable was the fact that these workers generally have allostatic loads, which, in the long run, could have health complications. This may, however, merely be the result of their life styles.

Recommendations:

It should be kept in mind that this was a pilot study with a limited number of experimental subjects and that the recommendations are based on the results thus obtained.

The major brief of this study was to physiologically assess the possibility of designing a formula, based on the activities of the train controlling officers, which could be used to assess the work load. The results of this pilot study showed that such a formula is feasible but that the following aspects should be addressed in creating the formula:

- **The activity-frequency of the different activities must be calculated separately and the appetitive-aversive quality must, where relevant, be a factor in subdividing the activities.**

- **Various activities must carry different weights in the formula.**
  This is supported by the fact that telecommunications, which often entails responsibilities beyond the job description of the train control officers, were found to be aversive when superimposed on a high workload. Indications were that telecommunications, as well radio communications, can become stressful when the first language is not the communication medium. The fact that radio communication can become stressful may very well be the result of the poor sound quality received by radio communication.

- **Assessment of the train control officers' perception of the stressfulness of the various activities is essential in the evaluation of the activities – and therefore in the compilations of the final formula. Ideally all control officers should complete a properly designed psychologically based score in which they rate the various activities in terms of stressor impact.** This recommendation is based on the fact that different activities have, on a physiological basis, already tentatively been shown to carry different stressor impacts**.** It was further noticed that what we would have thought to be aversive or non-aversive not always corresponded with the perceptions of the TCO's. The results of the psychologically based scores can, if necessary be verified physiologically, but the results should then be analysed against the allostatic load of the workers.

- **Personal aspects, such as ability and coping skills should be incorporate into the formula.** Although the aim is to evaluate the workload and not the worker such factors would become confounding aspects to the rest of the evaluations. Indications pointing towards this effect were borne out by results of this study. It is often good to have a system where the workload is specified at a certain competency or experience level.

- **The different shifts could very well carry different stress loads and should first be assessed by a subjective scoring system and, if needed, by heart rate, blood pressure and cortisol.** It is possible to assess the effect of continuous night shifts on the circadian secretory pattern of at least cortisol.

- **Allostatic loads**: It would only be fair, where relevant, to inform the workers about their high allostatic loads – especially their blood pressures – and to counsel them on the effect of life style on future health.

- **In conclusion it can be said that the results of the physiological-based pilot study indicated that a formula based on workload can, with certain prerequisites, give a fair reflection of the work stress. It is recommended that**

  a) The workload formula, based on the frequencies of the various activities as well as the results of operational research that considers the perceptions of the workers, be developed.

  b) The stations be evaluated in terms of the final formula and a distribution curve for each station be compiled

  c) At least 6 high stress and 6 low stress stations be identified and the validity of the activity-based scores be tested physiologically – in terms of a stat assessment of allostatic load and full shift heart rate, blood pressure and salivary cortisol – on each worker at the identified stations.

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APPENDIX A

Perceived stress measure

ID: …………………….. Date ……/………/20…..
Station: ……………… Time of day ……….h………min Shift time: ………………

The following questions ask you about your feelings and thoughts DURING THE LAST MONTH. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between then and you should treat each one as a separate question.

		How Often In The Last Month? (circle your answer)				
		Never	**Almost Never**	**Some-times**	**Fairly Often**	**Very Often**
1	In the last month, how often have you been upset because of something that happened unexpectedly?	0	1	2	3	4
2	In the last month, how often have you felt that you were unable to control the important things in your life?	0	1	2	3	4
3	**In the last month, how often have you felt nervous and "stress"?**	0	1	2	3	4
4	In the last month, how often have you dealt successfully with irritating life hassles?	0	1	2	3	4
5	In the last month, how often have you felt that you were effectively coping with important changes that were occurring in your life?	0	1	2	3	4
6	In the last month, how often have you felt confident about your ability to handle your personal problems?	0	1	2	3	4
7	In the last month, how often have you felt that things were going your way?	0	1	2	3	4
8	In the last month, how often have you found that you could not cope with all the things that you had to do?	0	1	2	3	4
9	In the last month, how often have you been able to control irritation in your life?	0	1	2	3	4
10	In the last month, how often have you felt that you were on top of things?	0	1	2	3	4
11	In the last month, how often have you been angered because of things that happened that were outside of your control?	0	1	2	3	4
12	In the last month, how often have you found yourself thinking about things that you have to accomplish?	0	1	2	3	4
13	In the last month, how often have you been able to control the way you spend your time?	0	1	2	3	4
14	In the last month, how often have you felt difficulties were piling up so high that you could not overcome them?	0	1	2	3	4

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APPENDIX B

Maatstaf van die persepsie van stress

Perceived stress measure

ID: ……………………..   Datum   ……/………/20……
Stasie: ………………   Tyd van die dag……….h………min   Skoftyd: ………………

Die volgende vrae handel oor u gevoelens en gedagtes GEDURENDE DIE AFGELOPE SKOF. In elke geval word u gevra hoe u gedink of gevoel het oor 'n besondere onderwerp. Alhoewel sekere van die vrae oënskynlik ooreenstem, verskil hulle tog en moet u asseblief elkeen as n afsonderlike vraag benader.

The following questions ask you about your feelings and thoughts DURING THE LAST SHIFT. In each case, you will be asked to indicate how often you felt or thought a certain way. Although some of the questions are similar, there are differences between then and you should treat each one as a separate question.

1	Hoe spanningsvol het u die skof gevind? 1 = Geen stres 5 = Baie stresvol How stressful did you experience the shift? 1 = No stress 5 = Very stressful	1	2	3	4	5
2	Was die skof meer of minder spanningsvol as gewoonlik? Was this shift more or less stressful than usual**?**	Meer spanningsvol Minder spanningsvol More stressful Less stressful				
3	**Was die skof vir u onaangenaam?** **Was the shift unpleasant / terrible / very bad?**	Ja Yes Nee No				
4	Was die skof vir u aangenaam / lekker? Was the shift pleasant / nice?	Ja Yes Nee No				

Rede waarom skof vir u aangenaam / onaangenaam was:
Reason why the shift was pleasant / unpleasant:

APPENDIX D

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REPORT

Validation of Spoornet Mental Workload Index Against an Allostatic Load Index

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1. INTRODUCTION

1.1 An Introduction to Workload as a Stressor

This work looks at the workload, and the environmental demands associated with it, as stressors that can lead to stress, or the stress response. The physiological parameters, which represent the peripheral expression of the stress condition in response to workload and demands, are investigated. In addition allostatic load is determined as a measure of the accumulated consequences of the stress impact on the body. Comparisons are made with the intensity of the occupational activity during the working period, and with the perceived stress of the working environment. The next couple of paragraphs provide a background to the investigation.

1.2 Meaning of the Word Stress

The meaning of the word "stress" has evolved from a) the early understanding of the word as referring to a stimulus, to b) stress seen as the response to a stimulus, to c) stress as a transaction. The stimulus model of stress saw stress as something that puts demands on the individual, for instance a heavy workload. This understanding of the word is generally considered to be wrong and the demands are now referred to as stressors rather than stress. The response model of stress refers to stress as the experiential and behavioural outcomes and includes the underlying physiological reactions. The response model thus sees stress as the reaction to a stimulus – a definition that includes acute reactions as well as the negative effects of chronic activation of the stress response. In terms of the response model, workload would be seen as the stressor and the physiological and psychological reactions as the stress or stress response. The transactional model of stress, also referred to as the process model, sees stress as a transaction between the individual and the environment and attempts to give a more holistic person-in context perspective (1). It should be obvious that the stress response is dependent on the nature of the stimulus and that the response may alter the characteristics of the stimulus, or the perception the individual has about the stimulus or stressor. However, the word stress is generally still used to refer to the response rather than to the transaction – while keeping in mind that the stress response is not static but a response that can change from moment to moment depending on the environmental demands and that the individual's reactions to the demands can influence the stressor value of the demand.

Many factors contribute to stress in the working environment. One of the major factors that determine stress in this environment is the workload. It is, however, important to remember that stress, as in this case caused by the workload, should not necessarily be seen as negative. In fact, stress underlies cognitive development, adaptation and the development of skills. It is now generally accepted that a controllable degree of stress is necessary for optimal performance. Too little stress as a result of a suboptimal workload may thus lead to a low performance or work output, while too much stress as a result of a heavy or uncontrollable workload may lead to a decline in performance level (2). One very important aspect that influences the effect of workload on both performance, and on health, is the perception of the individual. All stressors, including work, will necessary lead to a degree of psychobiological activation. The outcome is, however, strongly influenced by the individual's perception of the stressor. The negative feelings that the individual experience in the face of psychobiological activation, can be referred to as distress, while the high that individuals experience when the psychobiological activation is pleasurable is known as eustress (1,2). This would necessarily influence the work performance, as well as the degree to which the physiological stress response is activated.

1.3 Mediators of the Physiological Stress Response

The mechanisms through which a) stressful events and circumstances influence the homeostasis or internal stability of the mind and body, b) through which they influence performance, c) through which they impose wear and tear, and d) through which they can lead to disease, are multifactorial. Two of the main mechanisms through which these effects are mediated are known as the two main stress axes, i.e., the sympathodrenomedullary axis or SAM-axis and the hypothalamo-pituitary-adrenocortical axis or HPA-axis. Activation of the HPA-axis during stress leads to an increase in, amongst other cortisol, which in turn leads to increased access to energy stores from the conversion of other substances like lipids to glucose. Activation of the SAM-axis, which involves the activation of the sympathetic nervous system and release of catecholamines from the adrenal medulla, also helps to increase energy availability and, in addition, leads to an increase in cardiac output (through increased stroke volume and heart rate) an increase in blood pressure and a differential increase of blood flow and perfusion.

The stress response is supposed to be of limited duration and intended to help the individual to cope with demands. It is therefore adaptational in nature. The non-specific adaptive reactions are directed towards the mobilisation of the individual's reserves for energy and plastic modulation of the homeostatic responses and for a high level of functional activity (3). However, when demands on the individual become excessive the neuroendocrine activation associated with the stress response can become chronic with adverse effects on performance and health. Performance is, however, often maintained at the cost of health. The difference between the specific stress response and the non-specific stress response lies in the degree of specificity. Stressors that are very specific such as cold or hunger have their own specific stress responses that bring the internal homeostasis of the body back to normal through the normal negative feedback mechanisms of the body. However, any stressor that leads to psychobiological activation can give rise to the so-called non-specific stress response that involves, with minor variations, a relative non-specific neuroendocrine activation (4). This so-called non-specific stress condition or response can be see as a new homeostasis meant to enable the individual to cope, mentally and physically with the demands that initiated the response. Although the non-specific stress response involves virtually the whole body, two major neuroendocrine systems, as previously mentioned, are involved in the peripheral expression of the response, i.e., the sympathoadrenomedullary system and the hypothalamo-pituitary-adrenocortical axis.

In the following paragraphs we will shortly deal with the stress response in terms of the two main stress axis. It will also be shown that although we refer to the response as the "non-specific stress response" to distinguish it from small specific homeostatic deviations, with their individual correctional mechanisms, the non-specific stress response varies widely from individual-to-individual (interpersonal differences) and even within one individual at different times (intrapersonal). This makes it very difficult to be emphatic about the stress levels and stress responsivity of any individual. The discussion that follows will be limited to those physiological parameters which were possible to measure within the limitations set by the brief of the investigation, i.e., a non-intervention study within the working hours of the individuals.

1.3.1 The Sympathetic Nervous System and it's Relationship to the Rest of the Autonomic System

The sympathetic nervous system forms part of the autonomic nervous system, which consists of the sympathetic nervous system, the parasympathetic nervous system and the enteric nervous system. The sympathetic nervous system is so called because it is often concurrently activated or "in sympathy" activated during emotional and cognitive events. It is also associated with, and supports energy-requiring functions such as work. In this study three functions that is primarily associated with the sympathetic nervous system, i.e., heart rate, heart rate variability, and blood pressure are monitored. The second division of the autonomic system, i.e., the parasympathetic system, subserves energy-conserving functions and regulates energy intake such as feeding, digestion, absorption, as well as reproductive functions. It is more active during routine and vegetative functions, in contrast to the sympathetic system that is associated with action and stress. Although the main purpose of the study does not include assessment of parasympathetic function, an indication of its activation would be gained through heart rate variability analyses. Of more importance in terms of workload would be the balance between sympathetic and parasympathetic activation. The third division of the autonomic system is known as the enteric system. It is perhaps the only part of the autonomic system that is really autonomic and is involved exclusively with organs of digestion. The activity of the enteric division of the autonomic nervous system is partially modulated by the sympathetic and parasympathetic nervous systems (5).

The present study looks at the effects of work on the sympathetic nervous system as well as on autonomic balance - mainly in terms of sympathetic/parasympathetic activation.

1.3.2 The Sympathoadrenomedullary System

The sympathoadrenomedullary system, also referred to as the SAM-axis, consists of the sympathetic nervous system and the adrenal medulla. The sympathetic nervous system, as just discussed, comprises that part of the autonomic nervous system that is activated in the face of stressors, such as a heavy workload, in order to help coping with the demands on the person.

The effects of the sympathetic nervous system are mediated through the influence of its major neurotransmitter, i.e., noradrenaline (a catecholamine) on different kinds of adrenergic receptors. The adrenal medulla also secretes, amongst others, catecholamines such as noradrenaline and adrenaline and can in so-doing strengthen the effects of the sympathetic nervous system. When mass activation of the sympathoadrenomedullary system occurs it is often referred to as the fight-or-flight reaction. The overall effect is to aid the individual with coping with environmental and other demands mainly through an increase in perfusion of the vital organs with blood and an increase in blood sugar. These effects can, however become pathological in the chronic situation.

1.3.3 The Adrenal Medulla

The adrenal medulla is stimulated by sympathetic nervous system preganglionic fibres and can in a way be seen as an extension of the sympathetic nervous system. The adrenal medulla produces catecholamines, amongst others, adrenaline and noradrenaline, as well as other substances. This relatively simple view of adrenal medulla function is what is still being described in the majority of text books but over the last decade it has become clear that the adrenal medulla is not exclusively regulated by the sympathetic nervous system and that a host of other substances may modulate the influence of the sympathetic nervous system on medullary secretory activity and that differences in medullary function may in this way be accomplished, depending on the characteristic of the stressor (6). It is important to note that the secretory response of the adrenal medulla to stressors is dependent on the previous stress history of the individual. For instance, with exposure to the same stressor each day over an extended period of time subsequent exposure to the same stressor may induce a lower adrenal medullary response. This response could be seen as habituation. However, if the same individual which has been stressed by a particular stressor over an extended period of time is suddenly, in addition to the previous stressor, being exposed to yet another, i.e., novel, stressor the adrenal medullary secretory response may be significantly larger. This response would be known as sensitisation. The possible molecular mechanisms underlying habituation and sensitisation is largely beyond this writing but can be found in an overview by Kvetnansky (6). In terms of stress levels, or more specifically adrenal medullary stress response, of train control officers (TCOs) the implications from the above would be that individuals could adjust to the same workload when exposed to it over a period of time (habituation), but that introduction of significant changes could once again lead to higher stress levels than before (sensitisation). It should, however, be remembered that the workload and work environment are not the only potential stressors and that despite a degree of habituation the accumulative effects of long term above normal stress levels may adversely influence health – both mentally and physically. This will be addressed in more detail under allostatic load, a term that refers to the wear and tear of accumulative stress.

1.3.4 The Hypothalamo-Pituitary-Adrenocortical Axis (HPA-Axis)

In addition to the SAM-axis the other major stress axis is the hypothalamo-pituitary-adrenocortical axis or HPA-axis. This system is responsible for the glucocorticoid stress response. In humans cortisol is the major glucocorticoid. In the HPA-axis corticotropin-releasing hormone from the hypothalamic paraventricular nucleus, through it actions on the CRFR-1, stimulates the production of POMC with the subsequent release of adrenocorticotropic hormone or ACTH form the anterior pituitary gland. ACTH in turn stimulates the synthesis and release of cortisol from the zona fasciculate of the adrenal cortex. The H(hypothalamus)-P(pituitary)-A(adrenal cortex)-axis has a basal circadian rhythmicity or circadian rhythm, is sensitive to negative feedback by cortisol to the hippocampus, hypothalamus and pituitary gland, and is sensitive to stressors (7).

The circadian rhythm of cortisol secretion shows peak secretion in the early morning just before getting up and during early morning activity. It levels off later in the day but can increase as a result of meals or any of a variety of stressors. One of the major effects of stress including heavy workloads, unpleasant working environments or even continuous shift changes between day and night shifts, is, in fact, alterations of the circadian cortisol secretory pattern. Stress has several effects on the circadian rhythmicity of cortisol. The negative feedback of cortisol on the hippocampus, hypothalamus and pituitary (through which normal levels and changes in cortisol levels at different times of the day are regulated) appears to change under conditions of chronic stress and the sensitivity to feedback through cortisol seems to be reduced. One of the mechanisms may be through receptor downregulation with subsequent decreases in the sensitivity to cortisol (8). Acute stressors can cause acute increases in cortisol levels, which usually return to normal again within 2hrs. This is especially marked in the case of aversive stressors. Although acute stress can cause an increase in the basal-to-peak difference of cortisol the amplitude of the rhythm decreases in conditions of chronic stress as a result of the increase in baseline levels. As in the case of the SAM-axis, bouts of heterotypic acute stressor application during periods of chronic stress alter the response. It would seem that acute stress superimposed on chronic stress is dependent on the familiarity with the type of stressor. As in the case of the SAM-axis it appears that the response to an acute stressor in the chronically stressed would be less than expected if the stressor is homotypic (a repetition of what caused the chronic stress response). In contrast, if a heterotypic stressor is applied to a chronically stressed individual the response would be bigger (7). It is however possible that cross-tolerance to stressors may develop – especially stressors that involve the same neurological pathways (9). This once again can in theory be extrapolated to the working situation where high cortisol levels would then not be as significantly increased by increased levels of homeotypic stressors such as increases in the amount of work to which the individual is accustomed. In contrast, the response can be exacerbated when stressors other than the typical work stressors to which the individual is accustomed to are encountered. The implication that can be deduced from the previously mentioned fact (i.e., that the amplitude of the stressor-induced increase in cortisol levels, as well as the circadian amplitude difference to additional homeotypic stressors may be lower during chronic high stress) would be that those individuals with chronic high cortisol levels will not show the expected increase from basal trough values when stress levels increase and that this could be ascribed to the fact that the trough values are higher than normal.

There are many factors that influence the basal as well as the stimulated cortisol response to stress. One major factor is perinatal programming of the stress response that represents a major influence on the stress vulnerability of the individual and most probably can be held responsible for the largest part of the interindividual differences in the basal circadian levels of the individual (9). There are indications that gender is another contributor to interindividual differences and that distinct sexually dimorphic patterns of cortisol secretion may exist in the adult. There are indications that the cortisol levels are consistently higher in females than in males with further increases towards the middle of the menstrual cycle, just prior to ovulation (9). There are, however, some contradictions. Cortisol levels are further said to be increased in aging individuals with exaggerated responses to stress. This may, as in the case of chronic stress be the result of receptor down regulation. Such age-dependent increased cortisol levels and exaggerated responses to stressors can contribute to the development of many age and stress related disorders such as non-insulin dependent diabetes mellitus, osteoporosis, low immunocompetence and cognitive decline (9). Although this aspect may theoretically implicate that older workers could perhaps be less resistant to workplace stressors it is highly likely that the age-effect may be nullified by the fact that older workers may already be more familiar with the work, that they therefore perceive stressful events as less harassing, and that a degree of habituation may have developed.

1.4 Allostasis, Allostatic Systems, Allostatic Responses, Allostatic Load

Although the aforegoing part of this discussion was based on the principles of homeostasis, i.e., the relatively stable internal environment where deviations are corrected by negative feedback, it was also mentioned that in case of non-specific stressors the response may transiently give rise to a new homeostasis intended to help to cope with the stressful situation and that the homeostasis usually returns to normal when the stressful situation is over or the demand has been met. The latter situation implies flexible set points. The regulatory processes of the more flexible set point values around which the internal homeostasis can be regulated in the adaptive response, as seen during the transient development of a new homeostasis, and the regulation of the various functions around these new set points, should perhaps be referred to as homeodynamic rather than homeostatic regulation. There are however individuals that find even the homeodynamic concept too limiting and prefer to refer to allodynamic rather than homeostatic and homeodynamic regulation of the internal balance. In this categorisation it has become conventional to refer to the negative effects of the chronic stress response, as well as that of the cumulative effects of day-to-day activation of neuroendocrine systems as a result of intermittent heterotypic stressors, as the allostatic load. In this study we will be looking at the allostatic load as a measure of accumulated stress. It is thus necessary to shortly review the meaning of the different terms. The short overview that is to follow on allostasis, allostatic responses, allostatic systems and allostatic load is based on a number of publications (10,11,12,13,14,15,16) that are relatively freely available.

1.4.1 Allostasis

Allostasis can be seen as the ability to achieve stability through change. In terms of homeostasis one can compare this to the new homeostasis through which the mind and body attempt to cope with a stressor. In terms of coping with a heavy workload as the stressor, one can see it as the neuroendocrine changes that would help the individual to increase performance.

1.4.2 Allostatic Systems

The allostatic systems are those neuroendocrine systems that are activated in order to optimise coping and performance. In terms of homeostasis the allostatic systems can be equated with the stress systems.

1.4.3 Allostatic Response

The allostatic response could be seen as the stress response, in other words the response to stressors – the pattern of activation of the stress systems. The allostatic response varies from individual to individual and there are slight differences in the response to different stressors but the broad outline of the response is virtually the same as the broad outline for the non-specific stress response.

Various types of allostatic responses can occur. With the normal acute allostatic response, that is intended to be of benefit to the individual, the response which usually includes activation of the SAM-axis and the HPA-axis with subsequent increases in heart rate, blood pressure, blood sugar and other physiological changes, the response is shut off after the stressful event and the physiology of the body will return to normal. As long as the allostatic response is limited to the period of the work, or the demands on the individual are not excessive, protection via adaptation predominates over adverse consequences. However, exposure over extended periods of time to the allostatic response can have pathophysiological, and sometimes also psychopathological, consequences. Chronic stressful situations and other factors may lead to abnormal allostatic responses which can, in turn, give rise to a high allostatic load. The concept of allostatic load will briefly be discussed after dealing with the various types of allostatic responses.

Examples of abnormal allostatic responses that may lead to abnormal allostatic loads include a) chronic activation of the stress or allostatic systems as a result of frequent different stressful situations (heterotypic stressors) where there is hardly any time for the stress systems to operate at baseline values, b) chronic activation of the stress systems as a result of non-habituation of the individual to homeotypic stressors where once again the stress systems continuously operate at high levels, c) the inability of stress systems to appropriately shut down once they have been activated, and d) the inability of the body to mount the necessary stress response in the face of a stressor. Although the latter is often dependent on early childhood development of the stress systems, pathological hyporesponsivity is also found with long-term subordinance and the feeling of hopelessness that accompanies it. It is said that the type of hyporesponsiveness where low reactivity and basal activity of the HPA-axis are found could be a characteristic of the chronic fatigue syndrome – this is however still controversial. In the first three situations the body would chronically be subjected to high levels of, amongst others, activation of the SAM-axis and HPA axis with physiological disturbances such as increases in heart rate, blood pressure, cortisol levels and abnormal or low heart rate variability. The potential end-result of this chronic activation includes, depending on other factors such as genetics, feelings of constant fatigue and perhaps demoralization and hostility, the inability to concentrate, irritability, depression, hypertension or in those so inclined hypotension, non-insulin dependent diabetes mellitus, deposition of abdominal fat, osteoporosis, increased risk for cardiovascular incidences such as myocardial infarcts, artherosclerosis and other cardiovascular pathology, as well as an increased vulnerability to infection and cancer due to a suppression of immune function. There are indications that allostatic responses can become more intense with aging and it would take longer for the body to recover to baseline value. However, one should perhaps ask whether this is the effect of chronological aging *per se* or not merely a result of the general decline over long-term exposure to allostatic responses. Although there are indications that females are perhaps more stress responsive than males, there are certain factors that protect females against the negative effects of high stress system activation. Oestrogen, for instance is said to protect the cardiovascular system of females against the effects of high activation of stress systems, but this effect is naturally lost in postmenopausal women. It would further appear that a decline in oestrogen levels might contribute to cognitive decline as a result of increases in the activity of the HPA-axis.

1.4.4 Allostatic Load

The allostatic load can in a sense be seen as the same as the effect of the long-term or chronic so-called non-specific stress response. It is the price you pay for the repeated or chronic activation of the allostatic response – a response which in the short term is intended to be advantageous. Another way of putting it would be to define it as the wear and tear that results from chronic overactivity or underactivity of the allostatic systems. The allostatic load is the product of the accumulated stressors over an extended period. This includes the effects of minor day-to day stressors and the more dramatic or traumatic events. There can be no doubt that the type of work, the working environment and the working hours could be seen as major determinants. In this the perception of the individual plays a significant role. It is one of the major factors that determine whether he or she will be sensitised or will habituate to a certain stressor, i.e., how he or she will cope with the different day-to-day stressors and for how long the neuroendocrine systems will remain activated. Other factors which can be seen as instrumental in modulating the characteristics of the stress or allostatic response are the general physical health and the life style of the individual – including exercise, the diet, alcohol intake and smoking.

Some psychosocial factors that may influence allostatic responses and the allostatic load have previously been touched upon in this writing. Other psychosocial factors that may have a bearing on this study include observations that the effects of increased allostatic load such as artherosclerosis are more prevalent in socially dominant males of unstable social hierarchies and in subordinate females, observations that low job control predicts an increased risk for coronary heart disease and that high job strain can lead to a chronic increase in ambulatory blood pressure, left ventricular mass index and the progression of artherosclerosis.

In summary, to quote, Bruce S McEwen, Rockefeller University, Bethesda, 2000 (17):

allostasis *The ability to achieve stability, or homeostasis, through change, as defined by Sterling and Eyer, is critical to survival of an organism by promoting adaptation, or the reestablishment of homeostasis, to an environmental challenge. Through allostasis, the autonomic nervous system, the hypothalamic-pituitary-adrenal (HPA) axis, and cardiovascular, metabolic, and immune systems protect the body by responding to internal* *and external challenges. Allostasis is achieved through the action of mediators, such as the catecholamines and glucocorticoids. Allostatic load is the price of this accommodation and constitutes the wear and tear on the body from the chronic overactivity or underactivity of allostatic systems.*

allostatic load *The excessive level, over weeks, months and years, of mediators of allostasis, resulting either from too much release of these mediators or from the inefficient operation of the allostatic systems that produce the mediators and fail to shut off their release when not needed.*

McEwen 2000 (17)

1.5 Activities of the Two Main Stress Axes as Indicators of Workload

1.5.1 Heart Rate

Heart rate could very well be one of the most general mechanisms through which the stress response is assessed. From a research point of view heart rate can give an indication of sympathetic activation or autonomic balance. Heart rate can be determined by a variety of methods ranging from counting the pulse by palpitation over an artery, to counting the QRS waves per unit time on an electrocardiogram (ECG), to electronic monitors designed specifically for heart rate determinations. The palpitation-dependent determinations of heart rate is not an option for research purposes as it requires the constant presence of another individual and a possible influence on baseline and other responses. It also prevents the individual being tested from doing any work. With ECG determinations of heart rate the QRS waves per unit time are counted or the time between the waves (interbeat intervals) measured and the rate calculated from that. An interval between heart beats of 1000 msec would, for instance, give a heart rate of 60 beats per minute, that is 60 times the 1000 msec intervals which would equal 60 000 msec or one minute. In measuring the beat-to-beat interval one would perhaps expect to measure the P-wave-to-P-wave interval as the P-wave is initiated from the sinus node region that initiate cardiac contraction. The major reason for measuring the QRS intervals is that the QRS is easier to detect whereas the p-wave, which initiates the cardiac activation, is smaller. The p-wave starts form the sinus node of the heart and its discharge depends on the depolarization of neural tissue, modulated by the accelerating influences of the sympathetic nervous system and the slowing influences of the parasympathetic nervous system. Monitoring of the beat-to-beat changes in heart rate intervals could therefore give an indication of the sympathetic/parasympathetic balance and of the activity of the SAM-axis (18).

From a stress perspective it is necessary to note that the sympathetic nervous system, and by implication the adrenal medulla, is activated by most stressors and that the sympatho-adrenomedullary system, in turn, does not only stimulate heart rate through its effects on the sinus node, but can also influence the contractility of the cardiac muscle and thereby the systolic blood pressure. Acute reactions to stressors can be judged by observing the increase from baseline in heart rate. What is interesting is the fact that heart rate increases, despite the fact that significant transient increases may occur upon stressor application, do not seem to predict disease onset and cause. It would appear that increases in blood pressure could be more predictive in nature (18). It is suggested that the parasympathetic (vagal) influence which slows the heart down and which is the primary regulatory factor during resting conditions, may be a contributing factor to this phenomenon.

Although heart rate can serve as an index of stress, especially of short-term stress, it is necessary to note that many factors can influence the recordings, amongst others physical activity. This makes it problematic to distinguish between the emotional-cognitive aspects and the more physical aspects. In the present study the volunteers were not exposed to overt physical activity, as their job is more of a cognitive nature with some emotional stress factors superimposed by problems in the controlling of trains. It is, however, true that factors which do form part of the execution of their work can also influence the heart rate, including minor forms of motor activity such as writing, reaching for instrumentation and moving between points, as well as changes in respiratory patterns such as breath holding, transient shifts in attention and muscle tension (18). Luckily many of these phasic changes disappear after a while and the heart rate recordings that were performed in this study were of a continuous nature. Should continuous increases in muscle tension be present it could have influenced the heart rate, but it is to remember that increased muscle tension is yet another expression of stress.

1.5.2 Heart Rate Variability

Heart rate variability (HRV), which is based on small changes in the beat-to-beat QRS intervals (also referred to as R-R intervals), provides a non-invasive indication of autonomic function. It is generally thought that increased sympathetic stimulation decreases heart rate variability and that increased parasympathetic stimulation increases heart rate variability (19). Of perhaps greater importance is the implication of this, i.e., that the degree of variability may be indicative of cardiac health. Decreased variability is, for instance, being associated with increased mortality after myocardial infarct. This would make sense in view of the effects of autonomic influences on heart rate variability and the fact that heart failure is characterized by increased sympathetic and decreased parasympathetic nervous system activity (19). It would therefore be valid to suggest that not only would heart rate variability determinations be a good tool for the assessment of stress-induced sympathetic activation, but also that a decrease in baseline heart rate variability could also be a measure of the allostatic load.

As instantaneous changes in beat-to-beat intervals often become obscured during analysis by means of standard deviations, histograms and spectral analyses of HR-recordings, specialized techniques such as Poincaré plotting, can be employed to assess HRV and autonomic nervous system shifts.

1.5.3 Blood Pressure

Blood pressure is the outward force exerted against the walls of the blood vessels. When we talk about blood pressure we usually refer to the pressure in the arteries. When we talk about the pressure in the veins we specifically talk about venous pressure. Four pressures are of important for the purpose of this study, i.e., systolic pressure, diastolic pressure, pulse pressure and mean arterial pressure. The blood pressure varies depending on whether the heart is in contraction or relaxation and we thus refer to systolic pressure (when the heart contracts), or diastolic pressure (when the heart is in relaxation). The mean systolic pressure, as conventionally measured, is about 120mmHg in a young adult male and the diastolic pressure about 80mmHg. The term pulse pressure is the amount the pressure increase from diastole to systole. The formula for the calculation is thus: pulse pressure = (systolic pressure – diastolic pressure), or 120 – 80 = 40mmHg. It is obvious that the pulse rate is the same as the heart rate (20). The mean blood pressure or rather the mean arterial pressure is the average pressure throughout the cardiac cycle or, put in a different way, the average pressure to which the walls of the blood vessels are being subjected. As the period of each contraction of the heart is slightly shorter than the associated period of relaxation, the mean arterial pressure or MAP is slightly lower than the sum of the two divided by 2. The mean arterial pressure can be calculated by the formula: mean arterial pressure = diastolic pressure + ((systolic – diastolic)/3)

Blood pressure is the result of the pressure of the blood against the blood vessels which offers resistance to expansion of their diameter. The volume of the blood being pumped out of the heart, that is the activity of the heart, as well as the degree of resistance offered by the blood vessels, i.e., the peripheral resistance, determine the blood pressure. Both cardiac output and peripheral resistance are influenced by stress hormones and the autonomic nervous system (20). The effects of stress on blood pressure will be returned in a later paragraph.

Blood pressure can be measured in different ways. Two commonly used techniques, the auscultatory and oscillometric techniques employ an occlusion cuff through which pressure is applied over the artery to first interrupt and then progressively restore blood flow through the artery. A number of research-orientated techniques, including cuff-tracking, vascular unloading, arterial tonometry and pulse transit time provide methods to determine blood pressure beat-by-beat, non-invasively, each with its own advantages and disadvantages. Blood pressure in humans are routinely, for clinical purposes, measured by the auscultatory method by means of an instrument known as the sphygmomanometer where an inflatable rubber cuff that is connected to a mercury-containing pressure meter is place round the upper arm. Blood pressure varies depending on where it is taken but is most commonly taken over the brachial artery. To measure the systolic and diastolic pressures a stethoscope is placed on the brachial artery at the elbow fold and the cuff inflated to above the expected systolic pressure. At this stage blood flow through the brachial artery is stopped during cardiac relaxation as well as during cardiac contraction – due to the occlusion by the inflated cuff. The cuff is then slowly deflated while listening with the stethoscope over the brachial artery. At the point that the systolic pressure becomes equal to the cuff pressure blood will start flowing through the artery during systole but not during diastole and this intermittent flow can be heard as a tapping sound. The pressure reading on the sphygmomanometer now represents the systolic pressure. As the cuff is deflated further the pressure in the cuff eventually becomes lower than the diastolic pressure and blood can now also flow through the brachial artery during diastole, i.e., blood flow is now continuous and the tapping sound disappears. This pressure is taken as the diastolic pressure (21).

Stress can lead to high blood pressure or hypertension. Although not all cases of hypertension can be associated with stress, and the cause of hypertension is no doubt multifactorial, the evidence that stress can exacerbate the influence of most other factors involved in an increased blood pressure is overwhelming (21). The contribution of stress to high blood pressure is largely mediated through the influence of the sympathetic nervous system. It has now become clear that there are high and low responders and that people whose blood pressure increase significantly in the face of stress could be more prone to the development of hypertension. According to the diathesis-stress model of essential hypertension (22), hyperreactivity to stress is said to lead to hypertension only in the presence of other predisposing negative psychosocial factors, and individual differences in personality or other stable behavioural traits should be seen as mediators of the reactivity-psychosocial hypertension relationship (22). This assumption is supported by finding showing that sympathetic reactivity could very-well be a function of interactions between job stress, other environmental demands, family history of hypertension, ethnicity and emotional disposition. Family history of hypertension includes a possible genetic contribution but also dietary aspects like sodium intake, and the family psychosocial environment. With reference to ethnicity, there are indications that individuals of non-Caucasian origin may show a greater vascular reactivity to challenges, may excrete less sodium relative to intake, and other signs that they may be at greater risk for hypertension (23,24,25).

With reference to the effect of acute and chronic stress in the work place it should be remembered that it is not only the work load that influences blood pressure but that emotions like anxiety, negative moods, depression and lack of social support can also be risk factors for the development of hypertension (21,23). The increase in blood pressure induced by the work environment may be carried over and blood pressure would not necessary returned to normal when leaving the premises. This would surely reflect as an increase in allostatic load.

1.5.4 Cortisol

The HPA-axis as one of the two major stress axes was briefly discussed in an earlier section. In this study the levels of cortisol were measured as an indication of the activation of the HPA-axis. In the previous paragraphs we briefly looked at the effect of stress on heart rate, heart rate variability and blood pressure and although the HPA-axis does have an influence on these factors the influence of the sympathetic nervous system is much more significant. Before any further discussion on the cortisol response it should be mentioned that, in contrast to the cortisol response, the reactivity of the sympathetic nervous system to stress would appear to be less dependent on the nature of the stressor. Although cortisol levels can to a degree increase in the face of different kinds of stress, high cortisol- reactivity appears to be associated with aversive situations, the anticipation of aversive events, subjective states of fear, frustration, negative emotions accompanying failure, effort without positive outcomes, situations with potential negative evaluations of the self, loss of status amongst equals, low controllability and similar situations. (26).

A wide range of individual differences can be found with regard to cortisol reactivity. In younger subjects (20-29) women seem to have lower 24hr plasma cortisol secretion as well as lower morning cortisol peaks, but their age-related increases in basal output would appear to be more significant than men. In contrast to some reports about a higher stress responsitivity in women, other publications also showed cortisol stress responsiveness, similar to sympathetic responsiveness, that appear to be lower in women than in men – indicating perhaps that men are more responsive to threatening or challenging cues. (26).

Cortisol can be measured in blood, urine or saliva. In human research the collection of blood samples may, however, be problematic as venipuncture in itself is experienced as a stressful event by many and the taking of blood samples, especially serial blood samples would become a confounding factor. In the present study cortisol was determined in saliva. Saliva is considered an unobtrusive specimen source for cortisol – especially for studies performed outside the laboratory situation. Salivary cortisol represents the unbound fraction of cortisol, i.e., the biological active part and the correlation between salivary cortisol and the unbound fraction of cortisol extracted from serum or plasma is very good.

1.6 Stress Reactivity in General

Early on in this writing it was referred to the fact that the complex neuroendocrine activation in the face of stress is often referred to as the non-specific stress response merely to differentiate between this complex stress response and the specific homeostatic mechanisms that operate in the face of specific disturbances for which specific feedback mechanisms (specific stress responses) exist. It was also shown that individual stress reactivity and general health often form the basis of the eventual outcome of stressful events or periods. It is perhaps necessary to briefly touch upon some aspects, not discussed before, which influence stress reactivity.

1.6.1 Differential Response Patterns

It can for instance now be taken for granted that differential responses of the HPA-axis and the SAM-axis, i.e., differential metabolic and cardiovascular stress responses, can occur depending on access to and activation of appropriate coping mechanisms. Two typical responses can be distinguished, i.e., the activational pattern, also referred to as the defense pattern and the inhibitory or vigilance pattern. There is also a pattern referred to as the defeat pattern where the individual feels totally out of control and gives up on any form of coping with dire physical and psychological consequences, but this is not to be discussed here. It is said that the type-1 pattern (the activational pattern) is marked by increased skeletal muscle vasodilation, increased cardiac output, increased systolic blood pressure and beta-1-adrenergic tone, while type-2 (the inhibitional pattern) response is marked by skeletal muscle vasoconstriction, increased diastolic blood pressure, increased total peripheral resistance and increased alpha-adrenergic tone (23). Although increases in blood pressure during stress are generally of a type-1 or type-2 pattern, a mixed response pattern may also occur which appears to be dependent on the demands of the task itself, its context, differences in the person's history, his perceptions, response styles and other factors (23,27). Of interest is the fact that these reactions are very much dependent on the personality type and that many of the differential blood pressure responses are expressed when individuals are harassed in the work place.

1.6.2 Anticipation as Stressor

Emotions like anticipation, anxiety and fear can also drive the stress response. Such negative emotions can act as acute stressors and often have adaptational and coping value, but chronic anticipatory anxiety can, because it drives the stress response, lead to chronic high levels of stress hormones and sympathetic nervous system activation. The HPA axis and the amygdala are two of the major systems involved in the development of anticipatory angst (28).

It is known that this type of anticipation may contribute to the chronicity of stress response activation. The measurement of the stress or allostatic response to a stressful situation is often confounded by the fact that individuals would arrive at a situation already stressed in anticipation of the stressful situation. In theory this can, in the short-term, be seen as a reactions that prepare the individual for the job to come or the stressor about to be faced. If the period of anticipation is prolonged, such as in the case where a worker finds his work extremely stressful and starts worrying about it long before his day or shift starts it will eventually contribute to a chronic high allostatic load and the associated health consequences The anticipatory response makes it extremely difficult to assess the impact of job strain on the individual but it can with a fair degree of confidence be assumed that the anticipation will be relatively low in low stress working environments and high in high stress working environments (17,28).

1.6.3 The Orienting Reflex

In addition to anticipation, another factor that may influence the stress level determinations at the onset of a work shift is the orienting reflex. This reflex was first described by Pavlov in 1927 (29) who preferred to refer to it as the “investigatory” or “what-is-it” reflex. Sokolov (30), who applied a cognitive approach to the reflex, initiated the idea that the orienting reflex has a comparator component, comparing present observations or input to past representations or past input. The orienting reflex would especially be elicited when there is a discrepancy between current and past or stored input – that is, when the situation is new or has changed from the previous occasion or presentation (30). The equivalent in the work environment is easily imagined. The orienting reflex is associated with an increase in sympathetic activity. Although it is often measured by the skin conductance response – neurally it reflects exclusive sympathetic control of palmar sweat glands (31) - other techniques of sympathetic nervous system activity can also be used. There may be habituation of the orienting response and it can surely be expected that novices will show a stronger orienting reflex under the same conditions where a more experienced worker may show more habituation.

1.7 Aim of the Study

The primary aim of the study was to validate the developed MWL-index against certain parameters of stress.

Secondary aims were to:

1) examine the physiological changes in terms of the two main stress axes as measures of the work stress at different train controlling venues in order to assess workload or work stress at the different stations,
2) assess measures of the allostatic load in an attempt to validate the wear and tear of accumulated stress on the individuals – another approach to work stress at the different venues and
3) compare the MWL-index to the subjective perceptions of the observer and ratings based purely on time line analysis.

2. Materials and Methods

2.1 Subjects

Twenty train control officers from seventeen stations across South Africa took part in this study. Anthropometric measurements of participants are listed in Table 1.

2.2 Experimental Trials

Testing commenced at the start of the train control officers shift at 06h00. In four of the cases the officers had reached a ‘gentlemen’s agreement’ and only started at 07h00. The results of these subjects then only begins at 07h00. The subjects performed their handing over shift duties and were then informed about the nature of the study. Once the subjects were set the experimental procedures and aims were explained to them and testing commenced.

2.3 Measurements

2.3.1 Cohen's Measure of Perceived stress

Subjects completed the Cohen's perceived stress scale to assess their non-specific, appraised stress during the last month. This questionnaire consists of 14 items of which 7 are positively formulation (e.g. "In the last month, how often have you felt that things go your way?") and 7 negatively formulated (e.g. "In the last month, how often have you felt that you were unable to control the important things in your life?").

2.3.2 Blood Pressure

Blood pressure i.e. diastolic and systolic blood pressure was measured with a digital electronic blood pressure meter (ALP K2, model DS-125D, Japan). Three consecutive blood pressure measurements were taken at the commencement of the shift and every two hours thereafter during the shift till 14h00. The average of the three measurements is reported.

2.3.3 Heart Rate Recording and Analysis

A Direct Wired POLAR® (Mini Mitter Co, Inc. Bend, OR USA) heart rate belt was attached to the subject. The electrodes were first primed with distilled water. Heart rate data is transferred instantaneously via a direct wire to the Mini-Logger® Series 2000 (Mini Mitter Co, Inc. Bend, OR USA) and stored until download. Inter-beat interval is sampled by timing the number of milliseconds between triggering's of the Polar heart rate transmitter. The number of milliseconds between adjacent pulses from the transmitter are counted by the logger and recorded.

Heart rate data recorded continuously during the 8 hour exposure was then downloaded to a laptop computer using the Mini-Log^{TM} 2000W for Windows® (Mini Mitter Co, Inc. Bend, OR USA). The binary file created was then converted to an ASCII file where it was edited in Microsoft Excel in order for heart rate variability analysis. The text file created was imported into HRV analysis software (biomedical Signal Analysis Group, Finland). The program generates a report sheet and exports results as a text file.

2.3.4 Cortisol Collection and Analysis

Cortisol is found in the blood bound to protein or free (3 – 5 %). It is common to measure cortisol in either blood (where total cortisol is measured) or in saliva where the free fraction is measured. The rhythm or cortisol secretion corresponds to the sleep-wake cycle rather than the day-light cycle of melatonin secretion. Cortisol is a steroid hormone and therefore relatively stable.

Saliva was collected in a clean collection test tube, at the start of the shift and every two hours thereafter till 14h00, and then stored on ice for centrifugation. The collected saliva was centrifuged at 3300 rpm for 30 minutes. An aliquot of the supernatant was transferred into two 1.5 Ml eppendorf tubes and stored at –70 °C until analysis.

Cortisol concentration was determined by ELISA using a DX-SLV-2930 cortisol saliva kit (AEC Amersham Pty, Ltd., South Africa).

2.3.4.1 Principles of the Test

The solid phase enzyme immuno-assay for cortisol is a competitive type immuno-assay wherein horseradish peroxidase-labeled cortisol (HRP-cortisol) competes with cortisol present in the subject sample for a fixed and limited number of antibody sites immobilised on the wells of the microstrips.

Once the competitive immunoreaction has occurred, the wells are rinsed, and the HRP-cortisol fraction bound to the antibody in the solid phase is measured by adding a chromogen/substrate solution that is converted to a blue compound. After 15 minutes of incubation, the enzymatic reaction is stopped with sulphuric acid that also changes the solution to a yellow colour. The absorbance of the solution, photometrically measured at 450 nm, is inversely related to the concentration of cortisol present in the sample. Calculation of cortisol content in the sample is made by reference to a calibration curve.

Expected values range from 0.4 – 1.0 µg / dL (11 – 28 nl / L) if the samples were taken at 08h00.

2.4 Estimation of Mental Workload

Time line analyses, as indicator of mental workload, were recorded during the 8 hour testing periods. The same observer was responsible for the time line analysis of all the subjects tested. The main activities recorded were updating of train diagrams (scheduling), radio and telephone communications, as well as the number of trains and authorisations during the 8 hour testing period.

2.5 Statistics

All values are represented as mean ± standard deviation. A Two Sample T-test was used to determine if differences exist in terms of allostatic load variables between the identified Low and High stress groups respectively. A two-way repeated measures Analysis of Variance (AOV) was used to evaluate between subject groups (Low and High stress) differences and within subject differences (responses over an 8 hour work shift). Group*Time interaction was also evaluated to determine whether both groups respond in a similar fashion over the 8 hour work shift. If between and/or within subject analysis indicates any significant differences, but Group*Time interaction exists, then the two groups respond differently to the stressor over time and care must be taken in the interpretation of the main effects e.g. groups and time. Statistix Ver. 8 program was used for the statistical analysis. Prof PJ Becker (MRC) consulted on the statistical analyses.

3. RESULTS

Twenty train control officers at various venues were selected by Spoornet to take part in the physiological validation of MWL-index by assessment of stress levels in the train control officers stationed at various venues. Selection was performed on the basis of an estimation of the stressor impact at the different venues as calculated by the MWL-index. Although the investigators (researchers involved in the present study) new that the workloads at the different venues differed, i.e., ten were high workload stations and ten low workload stations, the investigators did not have insight into which venues were high stress and which low stress until completion of the practical and statistical analyses of their own results.

The results are being presented in the following order:

1. Anthropometric data and absolute recorded values (3.1)
2. Comparisons between Spoornet models of workload at the different venues and the physiological indicators of individuals working at the respective venues (3.2)
3. Physiological parameters: Separation of work stations into high and low stress as extrapolated from the stress levels of the individuals at the work stations (3.3)
4. Integration of Spoornet model and combinations of experimental test parameters and online time analysis (3.4)

3.1 Anthropometric Data and Absolute Values of Physiological Stress Indicators

The experimental group consisted of seventeen men and three women. Other anthropometric details of the twenty experimental persons are presented in Table 1.1.

Table 1.1: Anthropometric data of TCOs selected by Spoornet to participate in the validation of the MWL-index.

Subject	Gender	Age (y)	Mass (kg)	Length (m)	BMI (kg/m^2)	SA (m^2)
1	Male	32	94.0	1.841	27.7	2.20
2	Female	23	50.8	1.565	20.7	1.50
3	Male	31	84.1	1.738	27.8	2.03
4	Male	48	120.4	1.731	40.2	2.44
5	Male	34	119.5	1.820	36.1	2.48
6	Male	44	88.6	1.776	28.1	2.11
7	Male	45	76.8	1.643	28.5	1.89
8	Male	49	88.4	1.763	28.4	2.10
9	Male	41	84.5	1.672	30.2	2.00
10	Male	38	82.6	1.703	28.5	2.00
11	Male	43	145.0	1.760	46.8	2.70
12	Male	31	119.3	1.870	34.1	2.51
13	Male	52	86.5	1.781	27.3	2.08
14	Male	42	81.0	1.737	26.8	1.99
15	Male	59	113.6	1.799	35.1	2.41
16	Male	54	94.1	1.743	31.0	2.16
17	Male	35	95.9	1.840	28.3	2.23
18	Male	46	71.2	1.635	26.6	1.82
19	Female	28	48.7	1.504	21.5	1.44
20	Female	29	59.2	1.635	22.1	1.65
Mean		40.2	90.2	1.728	29.8	2.09
SD		9.7	24.3	0.095	6.2	0.33
Min		23	48.7	1.504	20.7	1.44
Max		59	145.0	1.870	46.8	2.70

BMI = Body Mass Index (kg / m^2); SA = Surface Area (Mass$^{0.425}$ x Height$^{0.725}$ x 71.84)

The salivary cortisol levels at 06:00, 08:00, 10:00, 12:00 and 14:00, the mean and standard deviation of cortisol levels for each train controlling officer from 06:00 to 14:00, the mean and standard deviation of cortisol for each from 08:00 to 14:00 and the minimum and maximum values for each individual, as well as the means, standard deviations, minimums and maximums for the total group at each of the five time intervals respectively, can be seen in Table 1.2. It is graphically represented in Figure 1.1.

Table 1.2: Cortisol levels of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of cortisol values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Min and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Cortisol (ng/ml)								
Subject	06:00	08:00	10:00	12:00	14:00	Indv. Mean 06:00-14:00	Indv. Mean 08:00-14:00	Min.	Max.
1	5.5	3.0	5.0	2.5	4.0	4.0 ± 1.3	3.6 ± 1.1	2.5	5.5
2	6.0	3.0	3.0	2.0	2.0	3.2 ± 1.6	2.5 ± 0.6	2.0	6.0
3	3.5	3.5	2.0	3.5	4.0	3.3 ± 0.8	3.3 ± 0.9	2.0	4.0
4	5.5	3.5	3.5	4.0	2.0	3.7 ± 1.3	3.3 ± 0.9	2.0	5.5
5	4.5	5.5	3.5	1.0	2.0	3.3 ± 1.8	3.0 ± 2.0	1.0	5.5
6	7.5	5.0	4.0	3.0	1.5	4.2 ± 2.3	3.4 ± 1.5	1.5	7.5
7	6.0	3.5	2.0	8.0	2.5	4.4 ± 2.5	4.0 ± 2.7	2.0	8.0
8	11.0	7.5	5.0	4.0	3.5	6.2 ± 3.1	5.0 ± 1.8	3.5	11.0
9	8.0	4.5	4.0	2.0	2.5	4.2 ± 2.4	3.3 ± 1.2	2.0	8.0
10	9.0	3.5	6.5	5.0	5.0	5.8 ± 2.1	5.0 ± 1.2	3.5	9.0
11	12.0	8.0	6.5	7.5	6.5	8.1 ± 2.3	7.1 ± 0.8	6.5	12.0
12	6.5	2.0	1.5	2.5	1.5	2.8 ± 2.1	1.9 ± 0.5	1.5	6.5
13		5.0	3.5	5.0	5.5	4.8 ± 0.9	4.8 ± 0.9	3.5	5.5
14	10.0	5.0	8.0	2.0	6.0	6.2 ± 3.0	5.3 ± 2.5	2.0	10.0
15	17.5	9.0	6.0	4.0	4.5	8.2 ± 5.6	5.9 ± 2.3	4.0	17.5
16	9.0	8.5	7.5	4.5	4.0	6.7 ± 2.3	6.1 ± 2.2	4.0	9.0
17	6.5	3.5	3.0	3.0	2.0	3.6 ± 1.7	2.9 ± 0.6	2.0	6.5
18	5.0	2.5	3.0	3.5	3.5	3.5 ± 0.9	3.1 ± 0.5	2.5	5.0
19		3.0	3.0	5.0	3.0	3.5 ± 1.0	3.5 ± 1.0	3.0	5.0
20		3.5	2.5	2.5	4.0	3.1 ± 0.8	3.1 ± 0.8	2.5	4.0
Mean	7.8	4.6	4.2	3.7	3.5				
SD	3.4	2.1	1.9	1.8	1.5				
Min	3.5	2.0	1.5	1.0	1.5				
Max	17.5	9.0	8.0	8.0	6.5				

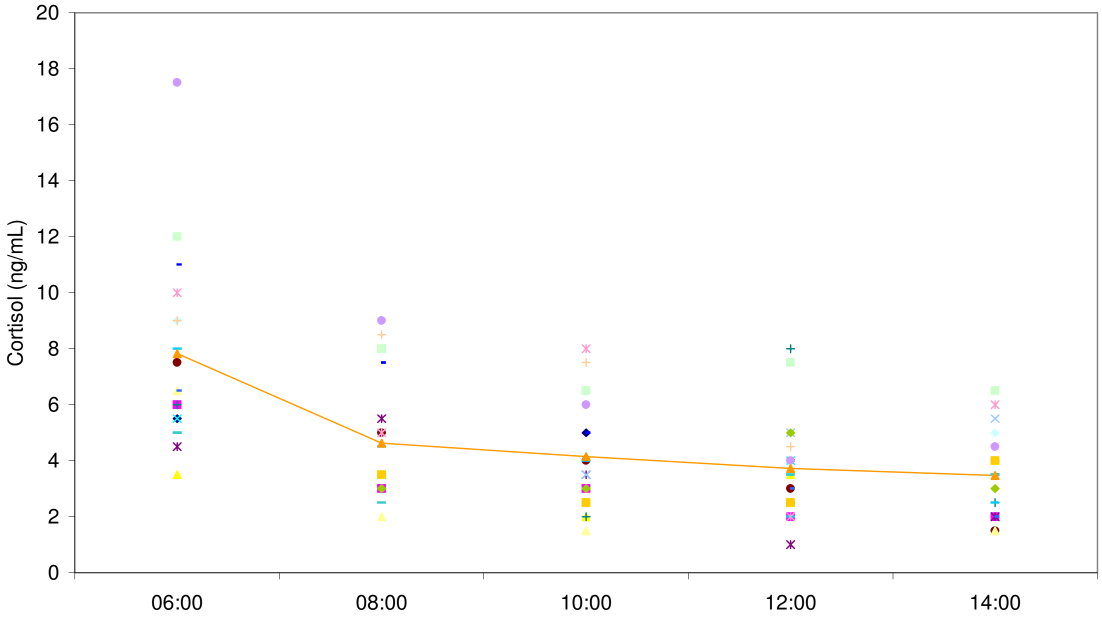

Figure 1.1: Cortisol levels for each individual from 06:00 to 14:00.

Table 1.3 presents the results of Cohen's perceived stress measurement

The means, standard deviations, as well as minimum and maximum values for blood pressure were calculated in the same way as that for cortisol. The systolic blood pressure can be seen in Table 1.4, a graphic presentation of the systolic blood pressure in Figure 1.2, the diastolic blood pressure in Table 1.5, a graphic presentation of the diastolic pressure in Figure 1.3, the mean arterial blood pressure in Table 1.6, a graphic presentation of it in Figure 1.4, the mean pulse pressure in Table 1.7, a graphic presentation of it in Figure 1.5, the heart rate values as recorded by Minimitter in Table 1.8, the graphic presentation of it in Figure 1.6, and a graphic presentation of the heart rates as determined by automatic blood pressure monitor in Figure 1.7

Table 1.3: Cohen’s perceived stress measure completed by TCOs at the beginning of their shift on the day of validation.

Subject	Cohens perceived stress measure	Associated level of stress
1	22	Average to low level of stress
2	17	Average to low level of stress
3	25	Mild to moderate level of stress
4	33	Mild to moderate level of stress
5	14	Average to low level of stress
6	14	Average to low level of stress
7	26	Mild to moderate level of stress
8	21	Average to low level of stress
9	23	Average to low level of stress
10	31	Mild to moderate level of stress
11	17	Average to low level of stress
12	17	Average to low level of stress
13	11	Average to low level of stress
14	18	Average to low level of stress
15	23	Average to low level of stress
16	17	Average to low level of stress
17	16	Average to low level of stress
18	23	Average to low level of stress
19	12	Average to low level of stress
20	16	Average to low level of stress
Mean	19.8	
SD	5.9	
Min	11.0	
Max	33.0	

Table 1.4: Systolic blood pressure of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of systolic blood pressure values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Systolic blood pressure (mmHg)								
Subject	06:00	08:00	10:00	12:00	14:00	Indv. Mean 06:00-14:00	Indv. Mean 08:00-14:00	Min.	Max.
1	122.7	121.3	115.0	119.7	119.7	119.7 ± 2.9	118.9 ± 2.7	115.0	122.7
2	91.7	89.0	93.7	94.7	95.0	92.8 ± 2.5	93.1 ± 2.8	89.0	95.0
3	129.0	118.7	115.3	122.3	120.7	121.2 ± 5.1	119.3 ± 3.0	115.3	129.0
4	130.3	125.3	122.7	133.7	140.7	130.5 ± 7.1	130.6 ± 8.2	122.7	140.7
5	141.0	130.7	133.7	138.7	148.3	138.5 ± 6.8	137.8 ± 7.7	130.7	148.3
6	114.3	116.0	116.0	117.7	117.3	116.3 ± 1.3	116.8 ± 0.9	114.3	117.7
7	133.7	132.3	136.7	130.7	137.0	134.1 ± 2.7	134.2 ± 3.2	130.7	137.0
8	135.0	121.0	120.3	128.3	128.3	126.6 ± 6.1	124.5 ± 4.4	120.3	135.0
9	121.0	125.7	118.3	114.0	121.3	120.1 ± 4.3	119.8 ± 4.9	114.0	125.7
10	117.3	110.3	111.0	114.3	121.3	114.9 ± 4.6	114.3 ± 5.0	110.3	121.3
11									
12	143.7	144.0	145.0	141.3	145.0	143.8 ± 1.5	143.8 ± 1.7	141.3	145.0
13	125.3	119.7	112.3	119.7	102.7	115.9 ± 8.7	113.6 ± 8.1	102.7	125.3
14	120.3	116.3	118.3	122.0	113.0	118.0 ± 3.5	117.4 ± 3.8	113.0	122.0
15	156.7	137.3	141.0	138.3	158.7	146.4 ± 10.4	143.8 ± 10.0	137.3	158.7
16	137.3	118.3	117.0	108.0	109.0	117.9 ± 11.8	113.1 ± 5.3	108.0	137.3
17	115.0	129.3	125.0	118.3	113.0	120.1 ± 6.9	121.4 ± 7.2	113.0	129.3
18	139.3	150.3	120.7	134.0	132.0	135.3 ± 10.8	134.3 ± 12.2	120.7	150.3
19		109.5	108.3	94.3	111.0	105.8 ± 7.7	105.8 ± 7.7	94.3	111.0
20	108.7	102.0	101.7	102.3	97.0	102.3 ± 4.2	100.8 ± 2.5	97.0	108.7
Mean	126.8	122.0	119.6	120.6	122.7				
SD	15.0	14.3	12.8	14.0	17.5				
Min	91.7	89.0	93.7	94.3	95.0				
Max	156.7	150.3	145.0	141.3	158.7				

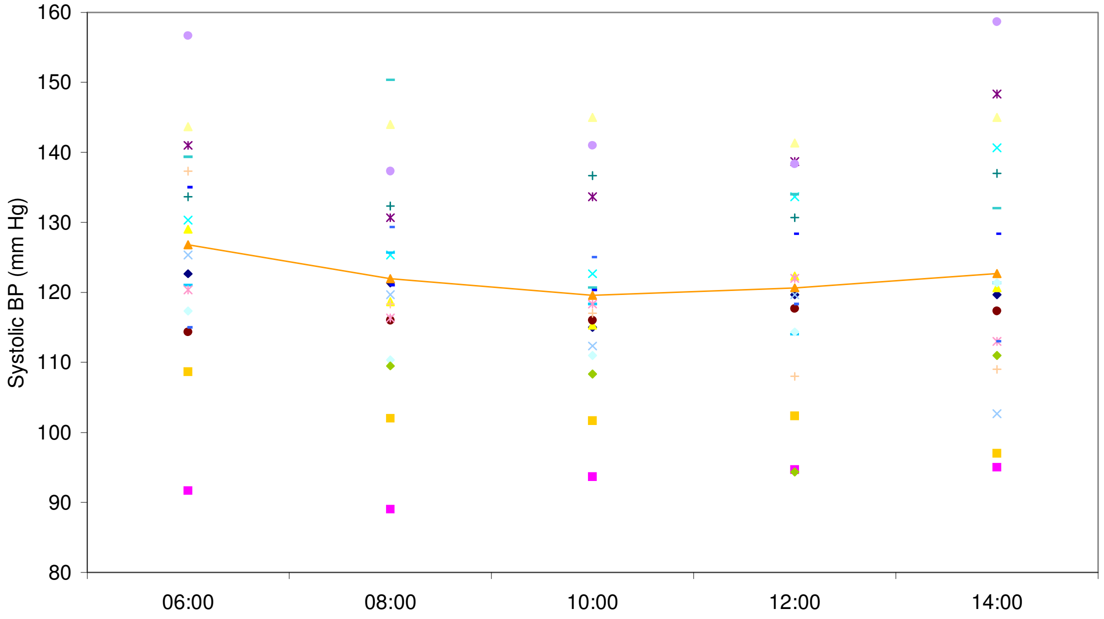

Figure 1.2: Systolic blood pressure for each individual from 06:00 to 14:00.

Table 1.5: Diastolic blood pressure of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of diastolic blood pressure values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Diastolic blood pressure (mmHg)								
Subject	06:00	08:00	10:00	12:00	14:00	Indv. Mean 06:00-14:00	Indv. Mean 08:00-14:00	Min.	Max.
1	85.7	97.7	77.3	79.7	89.0	85.9 ± 8.1	85.9 ± 9.3	77.3	97.7
2	65.0	65.3	65.0	66.3	69.0	66.1 ± 1.7	66.4 ± 1.8	65.0	69.0
3	105.0	80.3	95.3	87.3	83.7	90.3 ± 9.9	86.7 ± 6.4	80.3	105.0
4	102.0	92.3	92.7	105.0	99.0	98.2 ± 5.6	97.3 ± 6.0	92.3	105.0
5	92.0	99.3	95.7	86.7	103.0	95.3 ± 6.3	96.2 ± 7.0	86.7	103.0
6	82.7	87.7	88.3	75.7	82.3	83.3 ± 5.1	83.5 ± 5.9	75.7	88.3
7	94.0	93.3	96.3	93.3	93.3	94.1 ± 1.3	94.1 ± 1.5	93.3	96.3
8	95.0	89.0	87.3	92.7	90.7	90.9 ± 3.0	89.9 ± 2.3	87.3	95.0
9	87.0	81.7	82.7	79.3	82.3	82.6 ± 2.8	81.5 ± 1.5	79.3	87.0
10	81.3	79.0	78.0	75.3	80.7	78.9 ± 2.4	78.3 ± 2.2	75.3	81.3
11									
12	100.3	97.3	97.7	98.7	99.7	98.7 ± 1.3	98.3 ± 1.1	97.3	100.3
13	87.7	78.7	71.7	77.7	75.0	78.1 ± 6.0	75.8 ± 3.1	71.7	87.7
14	85.0	82.7	84.7	83.7	85.7	84.3 ± 1.2	84.2 ± 1.3	82.7	85.7
15	86.7	78.0	86.7	83.0	81.7	83.2 ± 3.7	82.3 ± 3.6	78.0	86.7
16	92.0	87.0	85.7	75.0	78.3	83.6 ± 6.9	81.5 ± 5.8	75.0	92.0
17	80.0	89.7	87.0	78.3	81.3	83.3 ± 4.8	84.1 ± 5.2	78.3	89.7
18	94.7	106.0	93.0	98.0	87.7	95.9 ± 6.8	96.2 ± 7.8	87.7	106.0
19		75.0	76.7	70.0	74.0	73.9 ± 2.8	73.9 ± 2.8	70.0	76.7
20	66.7	63.3	66.7	62.0	52.3	62.2 ± 5.9	61.1 ± 6.2	52.3	66.7
Mean	87.9	85.4	84.6	82.5	83.6				
SD	10.7	11.2	9.9	11.4	11.7				
Min	65.0	63.3	65.0	62.0	52.3				
Max	105.0	106.0	97.7	105.0	103.0				

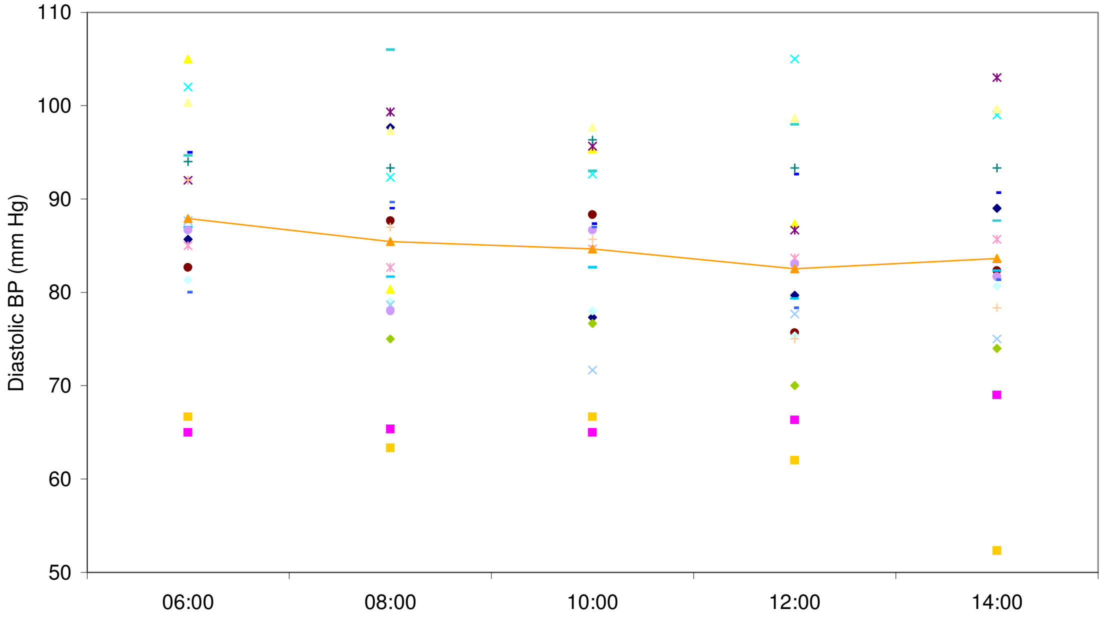

Figure 1.3: Diastolic blood pressure for each individual from 06:00 to 14:00.

Table 1.6: Mean arterial blood pressure of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of mean arterial blood pressure values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Mean arterial blood pressure (mmHg)								
Subject	06:00	08:00	10:00	12:00	14:00	Indv. Mean 06:00-14:00	Indv. Mean 08:00-14:00	Min.	Max.
1	98.0	105.6	89.9	93.0	99.2	97.1 ± 6.0	96.9 ± 6.9	89.9	105.6
2	73.9	73.2	74.6	75.8	77.7	75.0 ± 1.8	75.3 ± 1.9	73.2	77.7
3	113.0	93.1	102.0	99.0	96.0	100.6 ± 7.7	97.5 ± 3.8	93.1	113.0
4	111.4	103.3	102.7	114.6	112.9	109.0 ± 5.6	108.4 ± 6.2	102.7	114.6
5	108.3	109.8	108.3	104.0	118.1	109.7 ± 5.2	110.1 ± 5.9	104.0	118.1
6	93.2	97.1	97.6	89.7	94.0	94.3 ± 3.2	94.6 ± 3.6	89.7	97.6
7	107.2	106.3	109.8	105.8	107.9	107.4 ± 1.6	107.4 ± 1.8	105.8	109.8
8	108.3	99.7	98.3	104.6	103.2	102.8 ± 4.0	101.4 ± 2.9	98.3	108.3
9	98.3	96.3	94.6	90.9	95.3	95.1 ± 2.7	94.3 ± 2.4	90.9	98.3
10	93.3	89.4	89.0	88.3	94.2	90.9 ± 2.7	90.3 ± 2.7	88.3	94.2
11									
12	114.8	112.9	113.4	112.9	114.8	113.8 ± 1.0	113.5 ± 0.9	112.9	114.8
13	100.2	92.3	85.2	91.7	84.2	90.7 ± 6.4	88.4 ± 4.2	84.2	100.2
14	96.8	93.9	95.9	96.4	94.8	95.6 ± 1.2	95.3 ± 1.1	93.9	96.8
15	110.0	97.8	104.8	101.4	107.3	104.3 ± 4.8	102.8 ± 4.1	97.8	110.0
16	107.1	97.4	96.1	86.0	88.6	95.0 ± 8.3	92.0 ± 5.6	86.0	107.1
17	91.7	102.9	99.7	91.7	91.9	95.6 ± 5.3	96.5 ± 5.6	91.7	102.9
18	109.6	120.8	102.2	110.0	102.4	109.0 ± 7.6	108.9 ± 8.7	102.2	120.8
19		86.5	87.2	78.1	86.3	84.5 ± 4.3	84.5 ± 4.3	78.1	87.2
20	80.7	76.2	78.3	75.4	67.2	75.6 ± 5.1	74.3 ± 4.9	67.2	80.7
Mean	100.9	97.6	96.3	95.2	96.6				
SD	11.3	11.6	10.3	11.8	12.8				
Min	73.9	73.2	74.6	75.4	67.2				
Max	114.8	120.8	113.4	114.6	118.1				

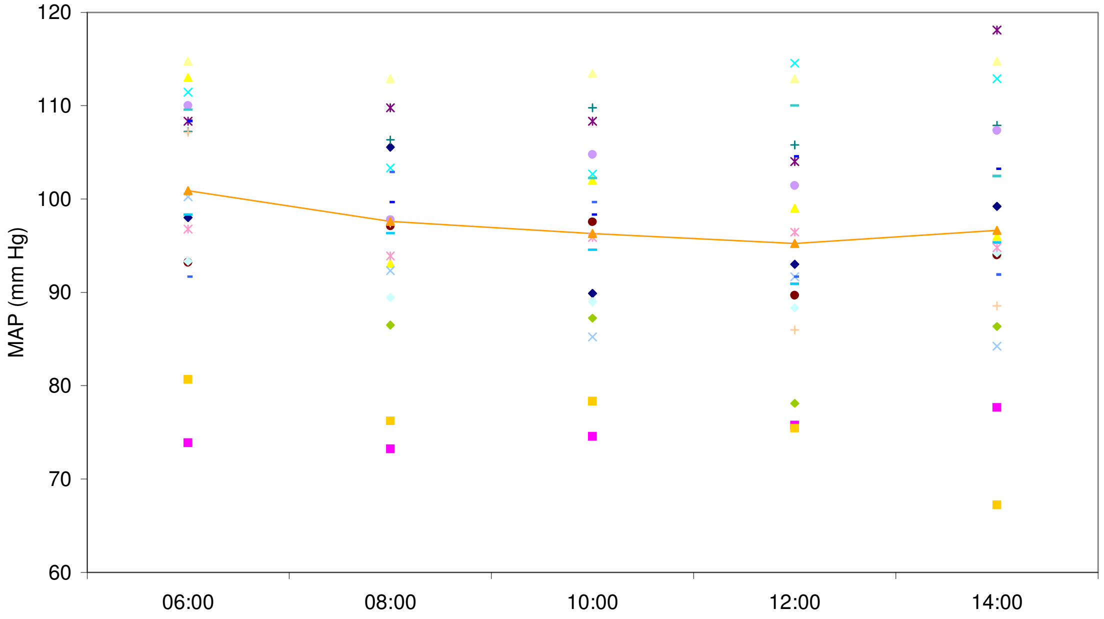

Figure 1.4: Mean arterial blood pressure (MAP) for each individual from 06:00 to 14:00.

Table 1.7: Mean pulse pressure of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of pulse pressure values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Pulse pressure (mmHg)								
Subject	06:00	08:00	10:00	12:00	14:00	Indv. Mean 06:00-14:00	Indv. Mean 08:00-14:00	Min.	Max.
1	37.0	23.7	37.7	40.0	30.7	33.8 ± 6.6	33.0 ± 7.4	23.7	40.0
2	26.7	23.7	28.7	28.3	26.0	26.7 ± 2.0	26.7 ± 2.3	23.7	28.7
3	24.0	38.3	20.0	35.0	37.0	30.9 ± 8.3	32.6 ± 8.5	20.0	38.3
4	28.3	33.0	30.0	28.7	41.7	32.3 ± 5.5	33.3 ± 5.8	28.3	41.7
5	49.0	31.3	38.0	52.0	45.3	43.1 ± 8.4	41.7 ± 9.0	31.3	52.0
6	31.7	28.3	27.7	42.0	35.0	32.9 ± 5.9	33.3 ± 6.7	27.7	42.0
7	39.7	39.0	40.3	37.3	43.7	40.0 ± 2.3	40.1 ± 2.7	37.3	43.7
8	40.0	32.0	33.0	35.7	37.7	35.7 ± 3.3	34.6 ± 2.6	32.0	40.0
9	34.0	44.0	35.7	34.7	39.0	37.5 ± 4.1	38.3 ± 4.2	34.0	44.0
10	36.0	31.3	33.0	39.0	40.7	36.0 ± 3.9	36.0 ± 4.5	31.3	40.7
11									
12	43.3	46.7	47.3	42.7	45.3	45.1 ± 2.0	45.5 ± 2.1	42.7	47.3
13	37.7	41.0	40.7	42.0	27.7	37.8 ± 5.9	37.8 ± 6.8	27.7	42.0
14	35.3	33.7	33.7	38.3	27.3	33.7 ± 4.0	33.3 ± 4.5	27.3	38.3
15	70.0	59.3	54.3	55.3	77.0	63.2 ± 9.9	61.5 ± 10.6	54.3	77.0
16	45.3	31.3	31.3	33.0	30.7	34.3 ± 6.2	31.6 ± 1.0	30.7	45.3
17	35.0	39.7	38.0	40.0	31.7	36.9 ± 3.5	37.3 ± 3.9	31.7	40.0
18	44.7	44.3	27.7	36.0	44.3	39.4 ± 7.5	38.1 ± 8.0	27.7	44.7
19		34.5	31.7	24.3	37.0	31.9 ± 5.5	31.9 ± 5.5	24.3	37.0
20	42.0	38.7	35.0	40.3	44.7	40.1 ± 3.6	39.7 ± 4.0	35.0	44.7
Mean	38.9	36.5	34.9	38.1	39.1				
SD	10.2	8.5	7.6	7.4	11.2				
Min	24.0	23.7	20.0	24.3	26.0				
Max	70.0	59.3	54.3	55.3	77.0				

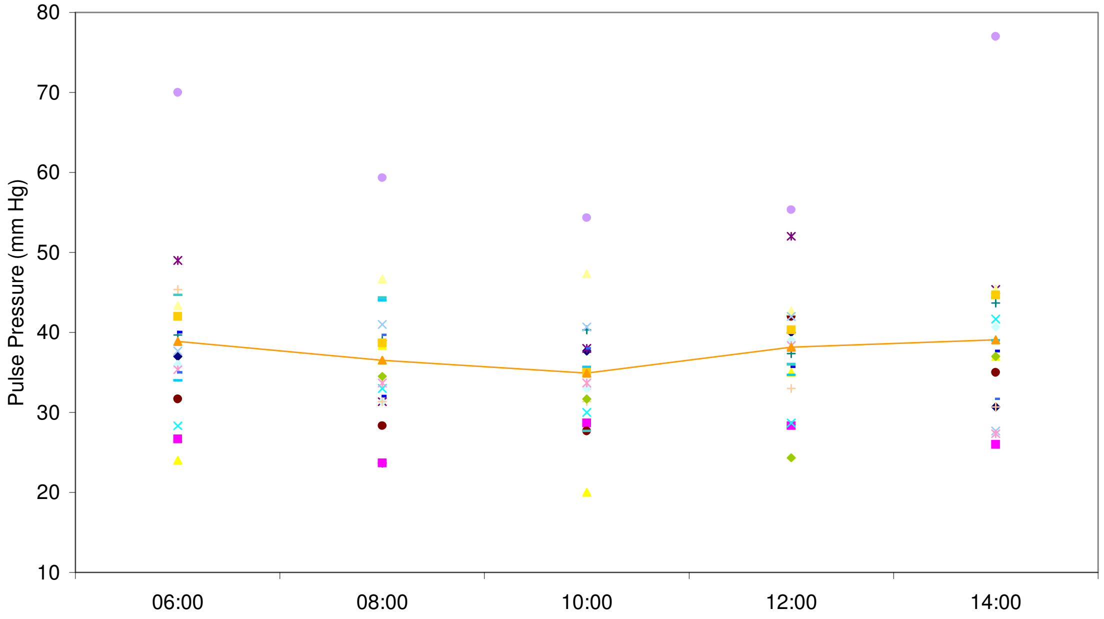

Figure 1.5: Pulse pressure for each individual from 06:00 to 14:00.

Table 1.8: Mean heart rate (measured with the Minimitter) of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of heart rate values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Heart rate (beats.min^{-1})						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 – 14:00	Mean	Min.	Max.
1	79.2	76.2	75.0	75.9	76.6 ± 1.8	75.0	79.2
2	89.1	89.3	86.1	85.5	87.5 ± 2.0	85.5	89.3
3	70.2	67.1	64.2	62.9	66.1 ± 3.2	62.9	70.2
4	89.6	88.1	86.5	88.0	88.1 ± 1.3	86.5	89.6
5		81.8	81.5	81.2	81.5 ± 0.3	81.2	81.8
6	82.4	81.9	80.7	83.5	82.1 ± 1.2	80.7	83.5
7	86.5	81.9	82.0	86.5	84.2 ± 2.6	81.9	86.5
8	87.5	69.4	68.5	71.0	74.1 ± 9.0	68.5	87.5
9	87.7	89.5	88.7	88.2	88.5 ± 0.8	87.7	89.5
10	76.6	77.2	78.4	76.2	77.1 ± 1.0	76.2	78.4
11	80.4	72.3	77.9	80.9	77.9 ± 3.9	72.3	80.9
12	89.2	88.5	90.3	90.9	89.7 ± 1.1	88.5	90.9
13	86.3	82.4	79.1	83.4	82.8 ± 3.0	79.1	86.3
14	86.9	85.5	85.5	83.4	85.3 ± 1.4	83.4	86.9
15	67.0	59.7	64.4	64.1	63.8 ± 3.0	59.7	67.0
16	77.5	70.4	68.9	69.4	71.5 ± 4.1	68.9	77.5
17	80.3	81.7	80.9	80.8	80.9 ± 0.6	80.3	81.7
18	95.2	91.2	96.0	97.6	95.0 ± 2.7	91.2	97.6
19	83.3	80.7	81.5	84.3	82.4 ± 1.7	80.7	84.3
20	75.1	71.8	59.7	63.0	67.4 ± 7.2	59.7	75.1
Mean	82.6	79.3	78.8	79.8			
SD	7.2	8.6	9.5	9.6			
Min	67.0	59.7	59.7	62.9			
Max	95.2	91.2	96.0	97.6			

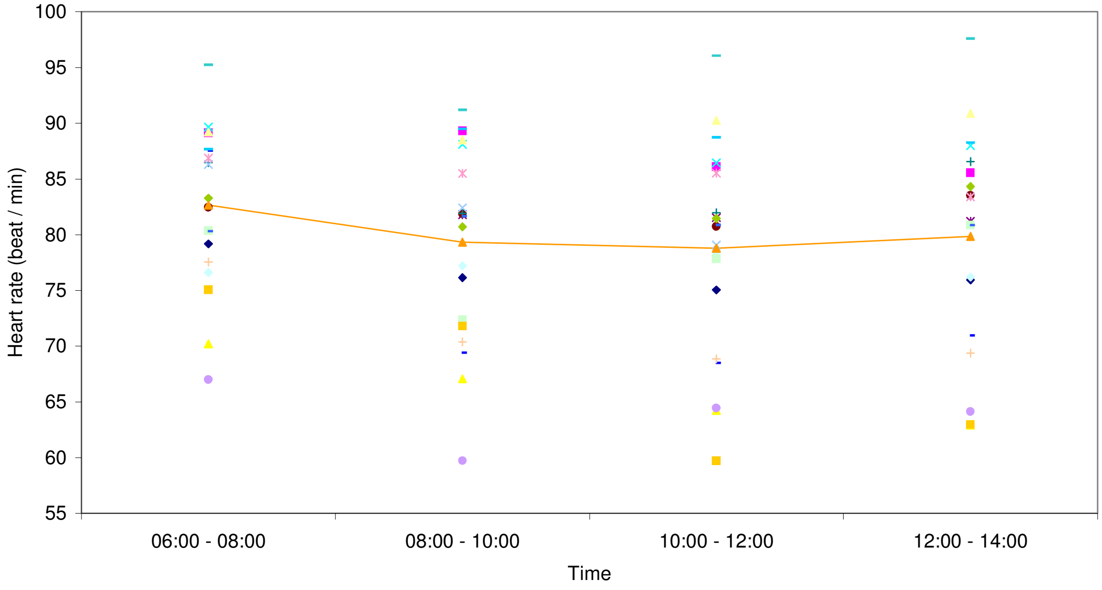

Figure 1.6: Heart rate for each individual from 06:00 to 08:00. (Minimitter)

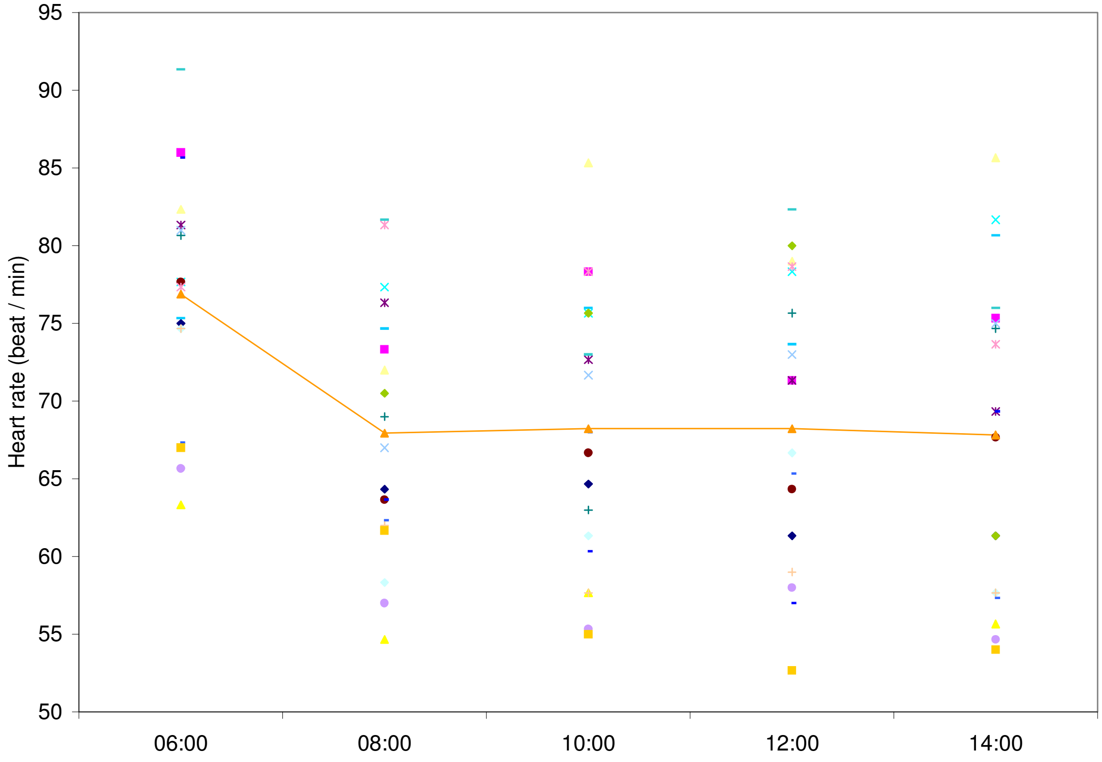

Figure 1.7: Heart rate for each individual from 06:00 to 08:00. (Blood pressure meter).

Table 1.9: Mean RR-intervals of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of RR-interval values for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	RR-interval (ms)						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Mean	Min.	Max.
1	766.5 ± 52.1	796.3 ± 54.5	808.1 ± 57.7	797.8 ± 55.8	792.2 ± 17.9	766.5	808.1
2	677.3 ± 35.8	677.5 ± 37.7	703.6 ± 40.1	708.9 ± 45.1	691.8 ± 16.8	677.3	708.9
3	875.4 ± 70.4	909.7 ± 82.4	949.2 ± 87.0	972.8 ± 87.3	926.8 ± 43.0	875.4	972.8
4	670.7 ± 16.7	682.8 ± 17.3	696.3 ± 19.1	684.6 ± 22.2	683.6 ± 10.5	670.7	696.3
5		738.6 ± 38.1	741.9 ± 36.9	745.6 ± 40.5	742.0 ± 3.5	738.6	745.6
6	738.5 ± 47.1	744.4 ± 46.6	758.2 ± 51.2	727.3 ± 43.0	742.1 ± 12.9	727.3	758.2
7	701.5 ± 37.2	742.4 ± 47.1	748.6 ± 48.7	699.9 ± 39.0	723.1 ± 26.0	699.9	748.6
8	691.5 ± 31.3	871.1 ± 46.5	882.0 ± 46.4	857.1 ± 44.4	825.4 ± 89.9	691.5	882.0
9	689.5 ± 35.9	675.5 ± 37.0	681.2 ± 37.4	684.3 ± 33.1	682.6 ± 5.8	675.5	689.5
10	791.3 ± 45.1	786.0 ± 50.2	774.0 ± 52.9	797.2 ± 60.3	787.1 ± 9.9	774.0	797.2
11	757.5 ± 32.2	836.9 ± 39.9	789.4 ± 38.6	754.9 ± 32.6	784.7 ± 38.2	754.9	836.9
12	677.4 ± 37.2	683.1 ± 38.0	670.0 ± 41.1	665.5 ± 40.8	674.0 ± 7.8	665.5	683.1
13	698.6 ± 29.1	733.6 ± 38.2	765.9 ± 35.0	723.1 ± 32.6	730.3 ± 27.9	698.6	765.9
14	694.2 ± 36.9	705.6 ± 29.3	705.7 ± 28.3	723.2 ± 29.8	707.2 ± 11.9	694.2	723.2
15	900.0 ± 18.5	1009.3 ± 24.1	935.9 ± 21.1	938.8 ± 20.6	946.0 ± 45.8	900.0	1009.3
16	779.8 ± 30.6	857.4 ± 33.3	879.2 ± 36.6	871.9 ± 37.9	847.1 ± 45.8	779.8	879.2
17	757.5 ± 64.3	745.8 ± 65.4	751.7 ± 62.9	750.9 ± 60.6	751.5 ± 4.8	745.8	757.5
18	633.8 ± 29.2	665.2 ± 30.5	628.9 ± 30.3	618.4 ± 25.1	636.6 ± 20.1	618.4	665.2
19	729.0 ± 49.3	751.5 ± 44.4	744.9 ± 48.4	719.0 ± 46.3	736.1 ± 14.8	719.0	751.5
20	809.6 ± 35.8	844.3 ± 40.6	1015.3 ± 51.8	963.3 ± 48.5	908.1 ± 97.2	809.6	1015.3
Mean	738.9	772.8	781.5	770.2			
SD	70.1	91.1	102.0	101.0			
Min	633.8	665.2	628.9	618.4			
Max	900.0	1009.3	1015.3	972.8			

Table 1.10: Mean low frequency values of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of low frequency derived from Fast Fourier analysis for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	LF (ms^2)						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Mean	Min.	Max.
1	1173.8	1163.9	1380.2	1331.7	1262.4 ± 109.9	1163.9	1380.2
2	332.0	421.1	426.8	540.0	430.0 ± 85.2	332.0	540.0
3	1679.2	2377.9	2573.9	2552.9	2296.0 ± 420.4	1679.2	2573.9
4	107.6	112.0	136.6	207.2	140.9 ± 46.0	107.6	207.2
5		563.5	559.9	669.1	597.5 ± 62.0	559.9	669.1
6	780.3	723.4	820.3	587.6	727.9 ± 101.6	587.6	820.3
7	427.4	657.1	737.6	513.8	583.9 ± 139.5	427.4	737.6
8	408.8	727.0	767.5	690.0	648.3 ± 162.8	408.8	767.5
9	434.6	519.7	564.6	397.7	479.1 ± 76.5	397.7	564.6
10	773.8	895.9	1054.3	1397.8	1030.4 ± 270.5	773.8	1397.8
11	327.1	524.2	573.4	401.7	456.6 ± 112.5	327.1	573.4
12	508.8	503.5	657.9	669.4	584.9 ± 91.1	503.5	669.4
13	242.3	403.5	338.5	264.9	312.3 ± 73.4	242.3	403.5
14	645.6	364.6	327.4	378.7	429.1 ± 146.0	327.4	645.6
15	75.1	111.0	88.7	98.1	93.2 ± 15.2	75.1	111.0
16	310.7	357.4	434.4	453.2	388.9 ± 66.6	310.7	453.2
17	1261.5	1238.9	1043.5	1127.0	1167.7 ± 101.6	1043.5	1261.5
18	362.2	382.8	414.8	252.9	353.2 ± 70.3	252.9	414.8
19	835.0	698.3	792.7	733.2	764.8 ± 60.9	698.3	835.0
20	371.6	476.7	669.3	571.5	522.3 ± 127.6	371.6	669.3
Mean	582.0	661.1	718.1	691.9			
SD	417.1	496.9	537.2	558.7			
Min	75.1	111.0	88.7	98.1			
Max	1679.2	2377.9	2573.9	2552.9			

Table 1.11, the LF to HF ratios in Table 1.12, the RMSSD value in Table 1.13 and the graphical presentations for each individual, over 15 minute intervals, over the total work session in Figures1.8 to 1.12.

Table 1.11: Mean high frequency values of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of high frequency derived from Fast Fourier analysis for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	HF (ms^2)						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Mean	Min.	Max.
1	93.6	128.6	130.8	118.7	117.9 ± 17.0	93.6	130.8
2	143.9	183.6	252.9	296.5	219.2 ± 68.4	143.9	296.5
3	592.8	786.0	746.4	918.2	760.9 ± 134.0	592.8	918.2
4	16.4	19.7	25.1	36.1	24.3 ± 8.6	16.4	36.1
5		100.3	69.5	76.1	82.0 ± 16.2	69.5	100.3
6	201.3	209.9	249.5	211.9	218.2 ± 21.4	201.3	249.5
7	154.6	309.9	320.7	140.7	231.5 ± 97.1	140.7	320.7
8	85.4	221.3	184.4	189.0	170.0 ± 58.8	85.4	221.3
9	176.0	159.4	115.4	127.8	144.6 ± 27.9	115.4	176.0
10	200.7	286.4	341.3	383.0	302.8 ± 78.8	200.7	383.0
11	91.7	165.3	102.5	53.8	103.3 ± 46.3	53.8	165.3
12	129.5	134.0	114.4	111.9	122.5 ± 11.0	111.9	134.0
13	111.8	237.2	171.9	162.9	170.9 ± 51.5	111.8	237.2
14	26.3	21.7	25.9	26.6	25.1 ± 2.3	21.7	26.6
15	49.5	98.6	58.8	51.5	64.6 ± 23.0	49.5	98.6
16	58.9	80.9	96.5	125.8	90.5 ± 28.1	58.9	125.8
17	693.3	711.9	746.2	735.1	721.6 ± 23.7	693.3	746.2
18	32.0	45.0	38.3	26.1	35.3 ± 8.1	26.1	45.0
19	356.3	237.4	310.3	227.5	282.9 ± 61.3	227.5	356.3
20	146.9	215.3	445.5	387.7	298.8 ± 140.8	146.9	445.5
Mean	176.9	217.6	227.3	220.4			
SD	183.2	199.7	212.6	235.0			
Min	16.4	19.7	25.1	26.1			
Max	693.3	786.0	746.4	918.2			

Table 1.12: Mean Total (low plus high) frequency values of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of total frequency derived from Fast Fourier analysis for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Total (ms^2)						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Mean	Min.	Max.
1	1267.5	1292.5	1510.9	1450.5	1380.3 ± 118.9	1267.5	1510.9
2	475.9	604.7	679.6	836.5	649.2 ± 150.6	475.9	836.5
3	2272.0	3163.9	3320.2	3471.1	3056.8 ± 538.0	2272.0	3471.1
4	124.0	131.7	161.7	243.3	165.2 ± 54.5	124.0	243.3
5		663.8	629.4	745.2	509.6 ± 343.2	0.0	745.2
6	981.6	933.3	1069.8	799.6	946.1 ± 112.8	799.6	1069.8
7	581.9	967.0	1058.2	654.4	815.4 ± 232.6	581.9	1058.2
8	494.2	948.2	951.9	879.0	818.4 ± 218.7	494.2	951.9
9	610.6	679.1	680.0	525.5	623.8 ± 73.2	525.5	680.0
10	974.5	1182.3	1395.6	1780.8	1333.3 ± 344.3	974.5	1780.8
11	418.9	689.4	675.9	455.5	559.9 ± 142.6	418.9	689.4
12	638.4	637.5	772.3	781.3	707.4 ± 80.3	637.5	781.3
13	354.1	640.7	510.4	427.8	483.3 ± 122.9	354.1	640.7
14	671.9	386.3	353.3	405.3	454.2 ± 146.7	353.3	671.9
15	124.6	209.6	147.4	149.6	157.8 ± 36.4	124.6	209.6
16	369.6	438.3	530.9	579.0	479.5 ± 93.6	369.6	579.0
17	1954.7	1950.8	1789.7	1862.1	1889.3 ± 79.0	1789.7	1954.7
18	394.2	427.7	453.1	279.0	388.5 ± 76.9	279.0	453.1
19	1191.3	935.7	1103.0	960.7	1047.7 ± 120.8	935.7	1191.3
20	518.5	692.0	1114.8	959.2	821.1 ± 266.8	518.5	1114.8
Mean	720.9	878.7	945.4	912.3			
SD	583.1	674.6	707.3	761.6			
Min	0.0	131.7	147.4	149.6			
Max	2272.0	3163.9	3320.2	3471.1			

Table 1.13: Mean Ratio (LF/HF) values of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of Ratio (LF/HF) derived from Fast Fourier analysis for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Ratio (LF/HF)						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 – 14:00	Mean	Min.	Max.
1	12.5	9.1	10.6	11.2	10.8 ± 1.4	9.1	12.5
2	2.3	2.3	1.7	1.8	2.0 ± 0.3	1.7	2.3
3	2.8	3.0	3.4	2.8	3.0 ± 0.3	2.8	3.4
4	6.6	5.7	5.4	5.7	5.9 ± 0.5	5.4	6.6
5		5.6	8.1	8.8	7.5 ± 1.7	5.6	8.8
6	3.9	3.4	3.3	2.8	3.3 ± 0.5	2.8	3.9
7	2.8	2.1	2.3	3.7	2.7 ± 0.7	2.1	3.7
8	4.8	3.3	4.2	3.7	4.0 ± 0.7	3.3	4.8
9	2.5	3.3	4.9	3.1	3.4 ± 1.0	2.5	4.9
10	3.9	3.1	3.1	3.6	3.4 ± 0.4	3.1	3.9
11	3.6	3.2	5.6	7.5	5.0 ± 2.0	3.2	7.5
12	3.9	3.8	5.8	6.0	4.9 ± 1.2	3.8	6.0
13	2.2	1.7	2.0	1.6	1.9 ± 0.2	1.6	2.2
14	24.5	16.8	12.6	14.2	17.1 ± 5.3	12.6	24.5
15	1.5	1.1	1.5	1.9	1.5 ± 0.3	1.1	1.9
16	5.3	4.4	4.5	3.6	4.4 ± 0.7	3.6	5.3
17	1.8	1.7	1.4	1.5	1.6 ± 0.2	1.4	1.8
18	11.3	8.5	10.8	9.7	10.1 ± 1.3	8.5	11.3
19	2.3	2.9	2.6	3.2	2.8 ± 0.4	2.3	3.2
20	2.5	2.2	1.5	1.5	1.9 ± 0.5	1.5	2.5
Mean	5.3	4.4	4.8	4.9			
SD	5.5	3.6	3.4	3.6			
Min	1.5	1.1	1.4	1.5			
Max	24.5	16.8	12.6	14.2			

Table 1.14: Mean RMSSD values of TCOs over an eight hour shift at the workstations selected by Spoornet for the MWL-index validation. Mean and standard deviation of RMSSD derived from Fast Fourier analysis for each TCO was calculated over the whole eight hour shift and from 08:00-14:00. Minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	RMSSD						
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Mean	Min.	Max.
1	25.9	29.8	31.9	30.1	29.4 ± 2.5	25.9	31.9
2	32.2	30.1	36.6	41.2	35.0 ± 4.9	30.1	41.2
3	60.2	70.7	72.5	79.4	70.7 ± 7.9	60.2	79.4
4	10.0	10.2	11.9	13.5	11.4 ± 1.6	10.0	13.5
5		22.8	20.6	22.7	22.0 ± 1.3	20.6	22.8
6	34.6	33.6	38.4	33.3	35.0 ± 2.3	33.3	38.4
7	31.6	43.0	44.0	31.2	37.5 ± 7.0	31.2	44.0
8	20.0	37.4	35.5	34.5	31.8 ± 8.0	20.0	37.4
9	25.3	24.0	22.3	22.6	23.6 ± 1.4	22.3	25.3
10	32.0	38.5	39.8	43.6	38.5 ± 4.8	32.0	43.6
11	24.4	32.1	26.2	20.7	25.8 ± 4.8	20.7	32.1
12	23.6	24.5	23.6	23.1	23.7 ± 0.6	23.1	24.5
13	30.3	40.8	36.7	34.2	35.5 ± 4.4	30.3	40.8
14	14.8	12.8	13.6	13.7	13.7 ± 0.8	12.8	14.8
15	20.5	27.7	23.5	21.8	23.4 ± 3.1	20.5	27.7
16	19.4	23.7	25.9	28.6	24.4 ± 3.9	19.4	28.6
17	60.0	60.3	58.3	53.0	57.9 ± 3.4	53.0	60.3
18	12.1	15.5	12.6	10.8	12.7 ± 2.0	10.8	15.5
19	42.5	35.4	40.1	34.6	38.1 ± 3.8	34.6	42.5
20	28.9	34.7	52.4	48.9	41.2 ± 11.2	28.9	52.4
Mean	28.9	32.4	33.3	32.1			
SD	13.6	14.5	15.6	16.0			
Min	10.0	10.2	11.9	10.8			
Max	60.2	70.7	72.5	79.4			

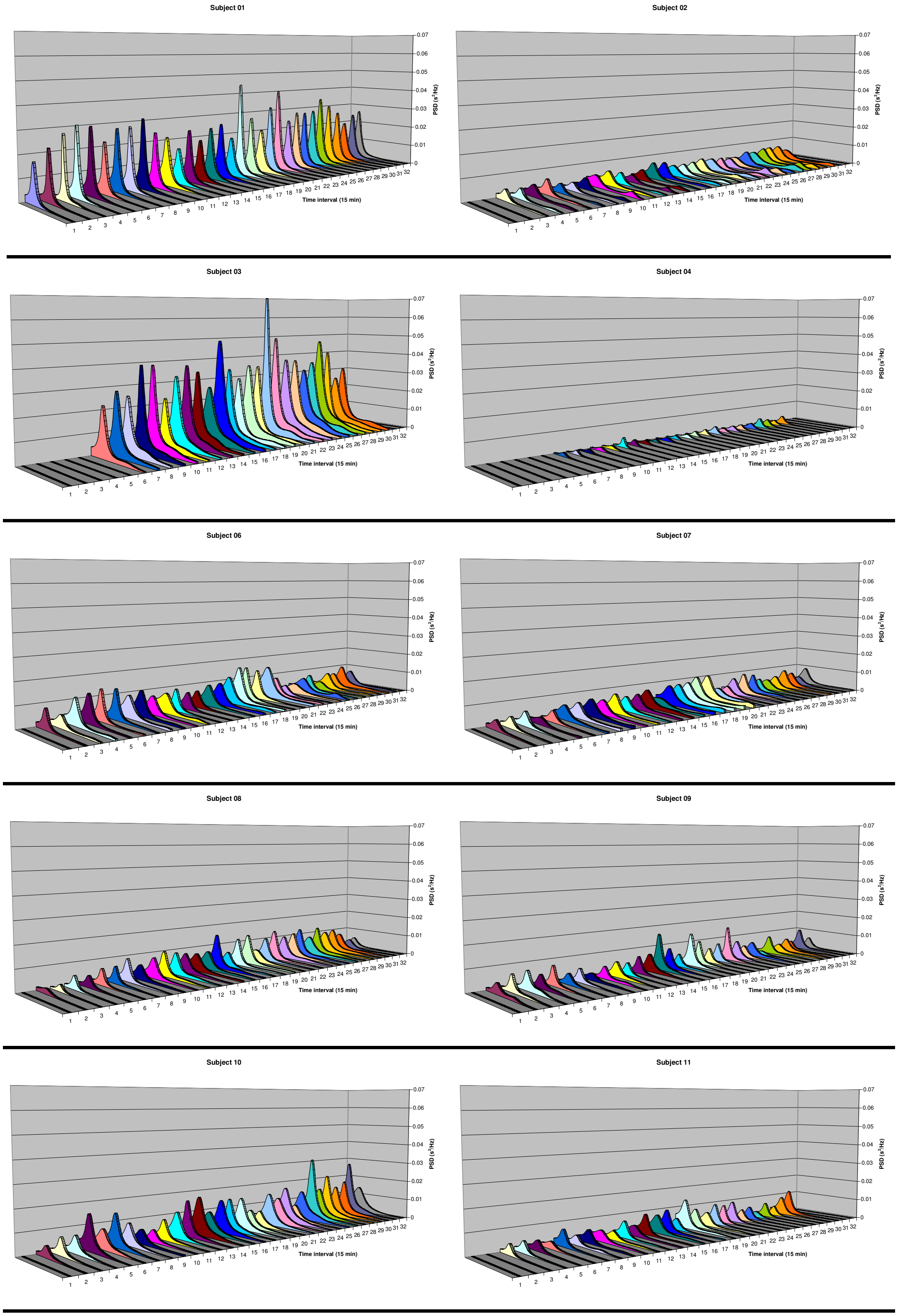

Figure 1.8: Autoregressive analysis of heart rate variability at 15 minute intervals for S1 – S11 from 06:00 to 14:00.

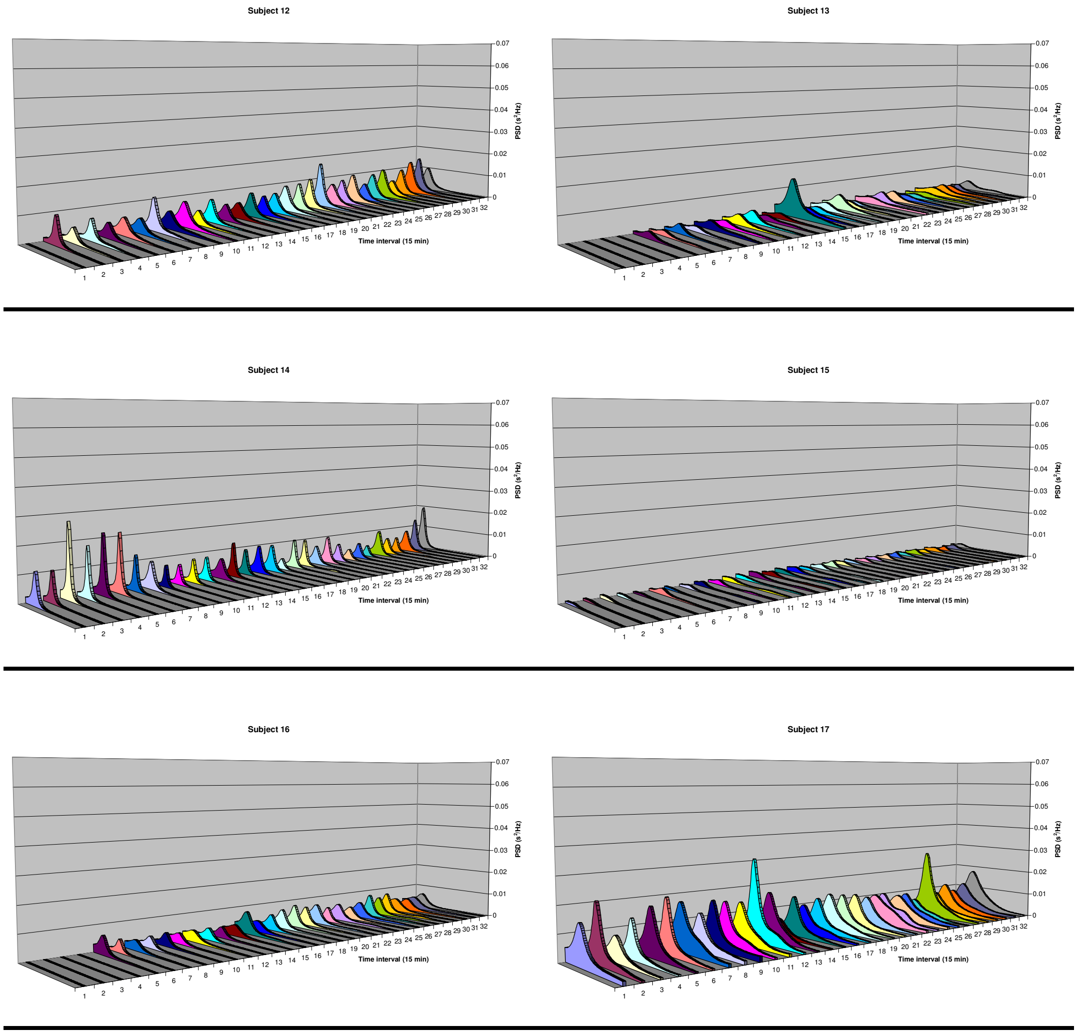

Figure 1.9: Autoregressive analysis of heart rate variability at 15 minute intervals for S12 – S17 from 06:00 to 14:00.

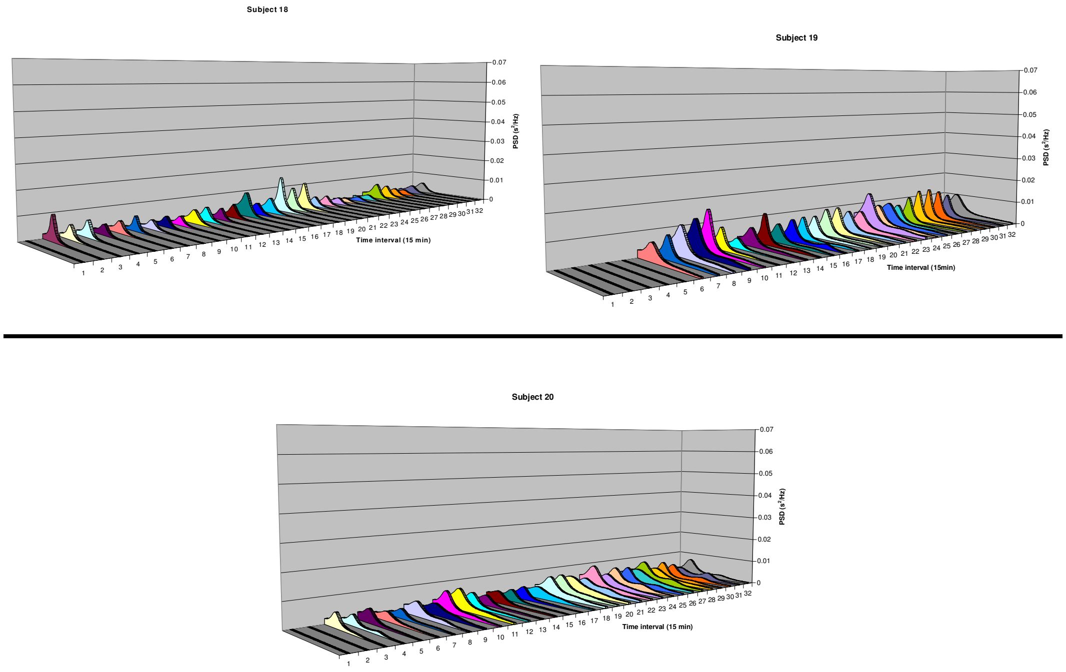

Figure 1.10: Autoregressive analysis of heart rate variability at 15 minute intervals for S18 – S20 from 06:00 to 14:00.

Online time analyses over the work shift can be seen from Tables 1.15 to Table 1.19 with Table 1.15 giving the number of radio communications, Table 1.16 the number of telephonic communications, Table 1.17 the number of times updating the train diagram (schedules), Table 1.18 the number of trains and Figure 1.19 the number of authorizations.

Table 1.15: Number of radio communications at the workstations selected by Spoornet for the MWL-index validation. Total and standard deviation of the number of radio communications over the whole eight hour shift and from 08:00-14:00 and minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Number of radio communications							
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 – 14:00	Total	Stdev	Min.	Max.
1	21	37	24	32	114	7.3	21	37
2	6	17	14	4	41	6.2	4	17
3	11	17	11	5	44	4.9	5	17
4	5	15	20	18	58	6.7	5	20
5	30	46	62	92	230	26.5	30	92
6	2	10	8	23	43	8.8	2	23
7	21	22	2	35	80	13.6	2	35
8	17	13	25	38	93	11.0	13	38
9	55	18	0	0	73	25.9	0	55
10	47	47	39	37	170	5.3	37	47
11	54	42	27	31	154	12.1	27	54
12	30	40	39	12	121	13.0	12	40
13	3	6	3	3	15	1.5	3	6
14	36	35	36	57	164	10.7	35	57
15	19	19	28	19	85	4.5	19	28
16	5	9	16	11	41	4.6	5	16
17	32	56	49	48	185	10.1	32	56
18	93	68	75	61	297	13.7	61	93
19	40	53	10	48	151	19.3	10	53
20	34	26	34	30	124	3.8	26	34
Mean	28.1	29.8	26.1	30.2				
SD	22.6	18.0	20.0	23.2				
Min	2	6	0	0				
Max	93	68	75	92				

Table 1.16: Number of telephonic communications at the workstations selected by Spoornet for the MWL-index validation. Total and standard deviation of the number of telephonic communications over the whole eight hour shift and from 08:00-14:00 and minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Number of telephonic communications							
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Total	Stdev	Min.	Max.
1	4	8	11	13	36	3.9	4	13
2	2	6	2	3	13	1.9	2	6
3	4	21	14	14	53	7.0	4	21
4	10	10	11	6	37	2.2	6	11
5	22	19	18	18	77	1.9	18	22
6	4	7	1	8	20	3.2	1	8
7	2	2	8	7	19	3.2	2	8
8	8	9	4	6	27	2.2	4	9
9	11	7	1	2	21	4.6	1	11
10	13	11	13	10	47	1.5	10	13
11	23	20	24	14	81	4.5	14	24
12	18	11	7	2	38	6.8	2	18
13	8	9	8	10	35	1.0	8	10
14	5	6	9	6	26	1.7	5	9
15	9	10	8	11	38	1.3	8	11
16	0	4	2	1	7	1.7	0	4
17	17	16	11	23	67	4.9	11	23
18	9	8	14	7	38	3.1	7	14
19	6	10	14	6	36	3.8	6	14
20	11	12	8	12	43	1.9	8	12
Mean	9.3	10.3	9.4	9.0				
SD	6.5	5.1	5.9	5.6				
Min	0	2	1	1				
Max	23	21	24	23				

Table 1.17: Number of schedules (updating the train diagram) at the workstations selected by Spoornet for the MWL-index validation. Total and standard deviation of the number of schedules over the whole eight hour shift and from 08:00-14:00 and minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Number of schedules							
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Total	Stdev	Min.	Max.
1	16	18	15	16	65	1.3	15	18
2	3	6	8	2	19	2.8	2	8
3	4	9	2	2	17	3.3	2	9
4	4	6	5	6	21	1.0	4	6
5	10	13	17	19	59	4.0	10	19
6	1	2	3	4	10	1.3	1	4
7	7	9	1	13	30	5.0	1	13
8	7	7	10	15	39	3.8	7	15
9	25	14	0	0	39	12.1	0	25
10	17	18	17	21	73	1.9	17	21
11	20	20	15	14	69	3.2	14	20
12	22	25	25	11	83	6.7	11	25
13	2	5	2	2	11	1.5	2	5
14	23	21	25	29	98	3.4	21	29
15	8	5	11	7	31	2.5	5	11
16	3	4	8	5	20	2.2	3	8
17	12	28	27	27	94	7.7	12	28
18	37	27	33	16	113	9.1	16	37
19	14	17	4	13	48	5.6	4	17
20	14	15	14	13	56	0.8	13	15
Mean	12.5	13.5	12.1	11.8				
SD	9.5	8.1	9.7	8.3				
Min	1	2	0	0				
Max	37	28	33	29				

Table 1.18: Number of trains at the workstations selected by Spoornet for the MWL-index validation. Total and standard deviation of the number of trains over the whole eight hour shift and from 08:00-14:00 and minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Number of trains							
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Total	Stdev	Min.	Max.
1	4	5	5	4	18	0.6	4	5
2	1	2	2	1	6	0.6	1	2
3	1	2	0	2	5	1.0	0	2
4	0	2	3	1	6	1.3	0	3
5	4	3	6	5	18	1.3	3	6
6	1	0	1	1	3	0.5	0	1
7	4	0	0	6	10	3.0	0	6
8	2	2	2	6	12	2.0	2	6
9	7	4	0	0	11	3.4	0	7
10	7	7	6	6	26	0.6	6	7
11	8	7	5	3	23	2.2	3	8
12	17	16	16	12	61	2.2	12	17
13	2	2	1	2	7	0.5	1	2
14	4	4	5	7	20	1.4	4	7
15	3	4	6	4	17	1.3	3	6
16	1	2	2	1	6	0.6	1	2
17	8	11	10	8	37	1.5	8	11
18	21	22	20	20	83	1.0	20	22
19	11	3	2	4	20	4.1	2	11
20	6	5	6	5	22	0.6	5	6
Mean	5.6	5.2	4.9	4.9				
SD	5.5	5.5	5.2	4.6				
Min	0	0	0	0				
Max	21	22	20	20				

Table 1.19: Number of authorisations at the workstations selected by Spoornet for the MWL-index validation. Total and standard deviation of the number of authorisations over the whole eight hour shift and from 08:00-14:00 and minimum and maximum values for each TCO are also reported. Mean, standard deviation, minimum and maximum values for every 2 hours from 06:00 – 14:00 are also reported for all the TCOs.

	Number of authorisations							
Subject	06:00 - 08:00	08:00 - 10:00	10:00 - 12:00	12:00 - 14:00	Total	Stdev	Min.	Max.
1	5	8	4	5	22	1.7	4	8
2	1	2	2	1	6	0.6	1	2
3	1	2	0	2	5	1.0	0	2
4	0	2	3	1	6	1.3	0	3
5	4	3	6	9	22	2.6	3	9
6	1	2	1	1	5	0.5	1	2
7	4	0	0	6	10	3.0	0	6
8	4	2	2	9	17	3.3	2	9
9	12	4	0	0	16	5.7	0	12
10	8	7	9	7	31	1.0	7	9
11	11	8	7	3	29	3.3	3	11
12	19	11	8	4	42	6.4	4	19
13	2	2	1	2	7	0.5	1	2
14	7	4	6	12	29	3.4	4	12
15	2	1	1	2	6	0.6	1	2
16	1	1	1	1	4	0.0	1	1
17	3	7	7	8	25	2.2	3	8
18	2	2	0	3	7	1.3	0	3
19	20	8	3	7	38	7.3	3	20
20	6	5	6	5	22	0.6	5	6
Mean	5.7	4.1	3.4	4.4				
SD	5.8	3.1	3.0	3.4				
Min	0	0	0	0				
Max	20	11	9	12				

3.2 Comparisons Between Spoornet Models of Workload at the Different Venues and the Physiological Indicators of Individuals Working at the Respective Venues (Validation of the MWL-index)

In this section the MWL-index as received from Spoornet was tested to see whether it reflects the load as calculated by the physiological stress indicators of the individuals. In other words, it investigated whether a correlation exists between division of the different venues into high and low work stress venues by using the MWL-index on the one hand, and the reflection of the workload as reflected by values of the physiological stress indicators tested in the study on the other.

The developed MWL-index as received from Spoornet (using data collected in 2003), hence referred to as Model 1, is seen in Table 2.1, showing the number of SIMS/ETD, the number of authorisations, weighted number of authorisations, number of telephone and radio communications, number of weighted communications, total number of actions, total number of actions, moderators, the final workload index of this model and the original Spoornet rating according to this model and the workstation system.

Table 2.1: Spoornet MWL-index (using data collected in 2003, i.e., Model 1)

Id	SIMS	ETA/ETD	No of data transactions (SIMS + ETA/ETD)	No of auth	Weighted no of auth	No of other tel/radio comms	Weighted no of comms	Total no of actions (weighted)	Mental work-load Index (Model 1)	Spoornet rating (Model 1)	System
1	5	0	5	34	510	204	1020	1535	2629	High	TWS 2
2	0	0	0	9	135	50	250	385	553	Low	TWS 1
3	3	13	16	15	225	100	500	741	1155	Low	RTO 1
4	0	0	0	9	135	9	45	180	281	Low	RTO 2
5	4	0	4	38	570	271	1355	1929	3320	High	TWS 2
6	3	0	3	20	300	130	650	953	1476	Medium	TWS 1
7	0	0	0	35	525	146	730	1255	2228	Low	RTO 1
8	4	12	16	97	1455	345	1725	3196	5789	High	RTO 1
9	4	20	24	39	585	297	1485	2094	3722	High	TWS 1
10	6	12	18	19	285	366	1830	2133	3666	Medium	TWS 3
11	7	0	7	45	675	325	1625	2307	5174	High	RTO 1
12	5	0	5	13	195	264	1320	1520	2214	Low	RTO 1
13	0	0	0	6	90	8	40	130	171	Low	RTO 1
14	0	0	0	42	630	327	1635	2265	4399	High	TWS 1
15	0	10	10	8	120	23	115	245	374	Low	RTO 4
16	0	20	20	31	465	261	1305	1790	3086	Low	RTO 1
17	5	4	9	8	120	88	440	569	866	Low	RTO 1
18	0	0	0	8	120	91	455	575	863	Low	RTO 1
19	2	0	2	46	690	222	1110	1802	3443	High	TWS 1
20	0	0	0	71	1065	82	410	1475	2828	High	TWS 2

SIMS = Spoornet information management system; ETA = Estimated time of arrival; ETD = Estimated time of departure

The above model (Model 1) was of a historical nature and represented workload information not necessary appropriate for the individual presently involved in working at each specific workstation. A revised Spoornet MWL-index (Model 2) was calculated based on real time activities (activities recorded at the time of the physiological measurements). This revised MWL-index (Model 2) is seen in Table 2.2. Table 2.2 shows the calculated MWL-index for Model 1 and Model 2.

Table 2.2: Model 1 (historical data) and Model 2 (real time data recorded at time of physiological measurements). Comparison between Model 1 and Model 2 values indicate no significant differences between the two groups ($p = 0.6753$). A significant correlation exists between Model 1 and Model 2 values ($r = 0.5224$; $p = 0.0181$)

Id	SIMS	ETA/ETD	No of data transactions (SIMS + ETA/ETD)	No of auth	Weighted no of auth	No of other tel/radio comms	Weighted no of comms	Total no of actions (weighted)	Mental work-load Index (Model 2)	50 – 50 Split (Model 2)	Mental work-load Index (Model 1)	Spoornet rating (Model 1)	System
1	0	0	0	22	330	150	750	1080	1797	Low	2629	Medium	TWS 1
2	0	0	0	6	90	56	279	369	561	Low	553	Low	TWS 1
3	1	0	1	6	86	115	575	662	1032	Low	1155	Low	RTO 1
4	0	0	0	6	90	109	543	633	902	Low	281	Low	RTO 2
5	1	0	1	22	330	307	1535	1866	3789	High	3320	High	TWS 2
6	0	0	0	5	75	63	315	390	575	Low	1476	Medium	TWS 1
7	1	0	1	10	150	99	495	646	1147	Low	2228	Low	RTO 1
8	0	0	0	17	255	120	600	855	1724	Low	5789	High	RTO 1
9	0	4	4	32	480	188	940	1424	2458	High	3722	High	TWS 1
10	1	8	9	31	465	217	1085	1559	2601	High	3666	Medium	TWS 3
11	0	0	0	29	435	243	1213	1648	3696	High	5174	High	RTO 1
12	0	0	0	42	630	159	795	1425	2075	High	2214	Low	RTO 1
13	2	0	2	8	120	57	286	408	569	Low	171	Low	RTO 1
14	0	0	0	29	435	190	950	1385	2348	High	4399	High	TWS 1
15	1	7	8	6	90	123	615	713	1028	Low	374	Low	RTO 4
16	0	0	0	5	69	55	274	343	677	Low	3086	Low	RTO 1
17	1	0	1	25	375	252	1260	1636	2773	High	866	Low	RTO 1
18	0	0	0	7	105	335	1675	1780	2671	High	863	Low	RTO 1
19	0	0	0	38	570	214	1069	1639	3587	High	3443	High	TWS 1
20	0	0	0	22	330	167	835	1165	2559	High	2828	High	TWS 2

It was subsequently tested whether statistical significant differences could be found between individuals grouped into high and low MWL-indices when the classification was based on the revised MWL-index (Model 2). Comparisons were made for age, mass, height, BMI, SA, blood pressure heart rate variability variables, smoking or not, length of previous shift, length of test shift, years experience at particular station, shift preferences and time line analyses of the shift when the physiological recordings were made. The results (means of the results over the workshifts and statistical analyses) can be seen in Table 2.3, and the blood pressure arrival values for subjects in Table 2.4.

The experimental data of individuals from the six highest and from the six lowest workload stations, according to the MWL-index (Model 2), were subsequently compared and statistical tests performed to see if they differed significantly. The results can be seen in Table 2.5.

Hereafter the high and low MWL-index groups, according to Model 2 were compared in terms of the way they react to the workload over the total workshifts. The results can be seen in Table 2.6.

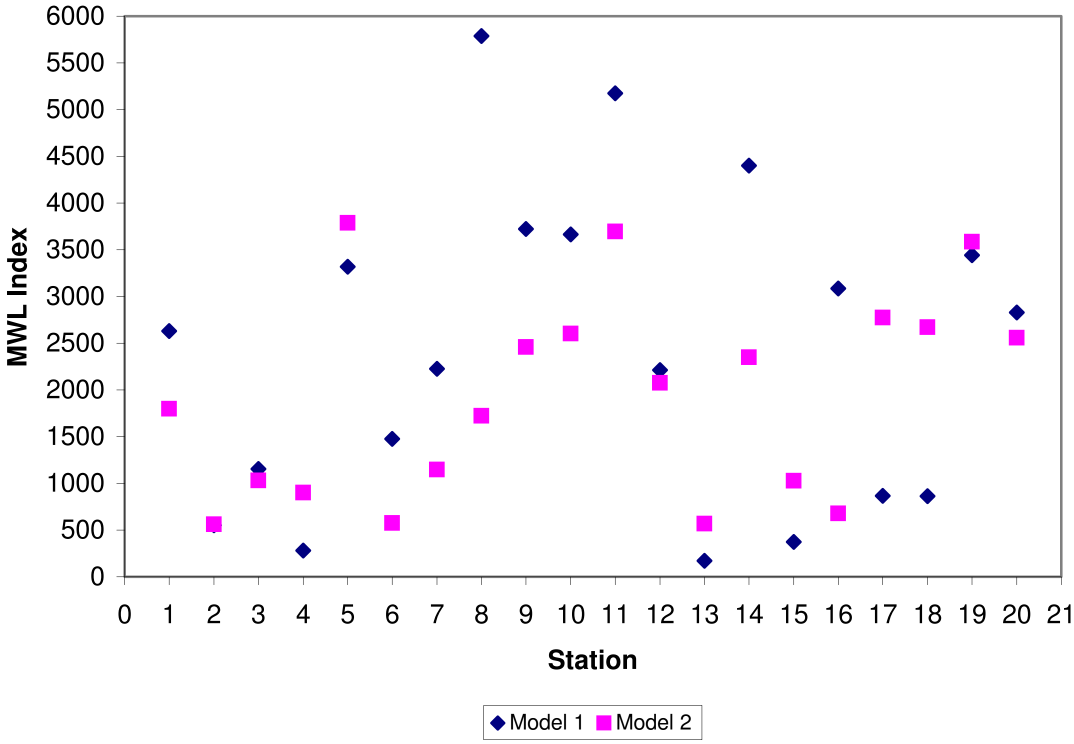

Figure 2.1: Comparison between Model 1 (historical data) and Model 2 (real time data) MWL-index values.

Table 2.3: Mean values over a six hour period (08:00 – 14:00) for subjects divided into high and low stress groups according to Model 2 MWL-index.

Variable	HS	LS	p value
Age	36.7 ± 6.3	43.7 ± 11.5	0.1125
Mass	90.7 ± 29.7	89.7 ± 19.1	0.9325
Height	1.718 ± 0.112	1.738 ± 0.080	0.6441
Body mass index	30.1± 7.4	29.5 ± 5.2	0.8263
Surface area	2.08 ± 0.40	2.09 ± 0.26	0.9533
Cohens	18.7 ± 5.5	20.9 ± 6.4	0.4227
Diastolic blood pressure	83.9 ± 11.7	85.4 ± 9.0	0.7598
Systolic blood pressure	122.1 ± 14.3	122.1 ± 14.1	0.9928
Mean arterial pressure	96.6 ± 12.5	97.6 ± 9.9	0.8472
Pulse pressure	38.2 ± 4.2	36.8 ± 10.0	0.6888
Heart rate (blood pressure monitor)	72.0 ± 8.2	67.8 ± 7.6	0.2665
Cortisol	3.8 ± 1.5	4.2 ± 1.2	0.5643
Heart rate (MiniMitter)	82.6 ± 7.7	77.7 ± 8.6	0.1983
SD of heart rate	5.3 ± 0.9	4.9 ± 1.6	0.5252
RR	741.0 ± 76.0	790.8 ± 93.6	0.2076
SD of RR	41.6 ± 10.4	41.7 ± 17.9	0.9899
RMSSD	29.7 ± 14.0	33.4 ± 15.3	0.5821
SD1	21.3 ± 9.9	23.9 ± 10.9	0.5788
SD2	89.7 ± 19.2	93.4 ± 31.0	0.7511
LF	638.6 ± 269.0	688.4 ± 656.6	0.8280
HF	211.9 ± 207.6	206.8 ± 206.9	0.9567
Ratio (LF/HF)	5.6 ± 4.8	3.9 ± 2.7	0.3244
Total power	850.5 ± 460.4	895.2 ± 843.4	0.8851
Smoking	0.4 ± 0.5	0.5 ± 0.5	0.6733
Length of previous shift	11.6 ± 1.3	10.1 ± 1.9	0.0487
Length of test shift	12.0 ± 0.0	10.5 ± 1.8	No value
Years experience at particular station	4.6 ± 3.3	7.5 ± 7.4	0.2806
Shift preference	1.1 ± 1.0	0.8 ± 0.8	0.4645
Radio communications	166.9 ± 61.9	61.4 ± 30.4	0.0003
Telephone communications	47.4 ± 20.7	28.5 ± 13.9	0.0276
Scheduling	73.2 ± 23.7	26.3 ± 16.3	0.0001
Number of Trains	32.1 ± 22.6	9.0 ± 5.1	0.0105
Number of Authorisations	26.1 ± 10.2	8.8 ± 6.0	0.0002

BMI = Body Mass Index (kg / m^2); SA = Surface Area (Mass$^{0.425}$ x Height$^{0.725}$ x 71.84)

Table 2.4: Mean values at 06:00 for subjects divided into high and low stress group according to Model 2 MWL-index.

Variable	HS	LS	p value
Diastolic	85.9 ± 10.4	89.6 ± 11.2	0.4645
Systolic	125.8 ± 13.5	127.6 ± 16.8	0.2872
MAP	99.2 ± 11.2	102.2 ± 11.8	0.5832
Pulse pressure	39.9 ± 5.6	38.0 ± 13.1	0.6881
Heart rate (blood pressure monitor)	77.1 ± 8.1	76.7 ± 7.5	0.9947
Cortisol	7.7 ± 2.6	7.9 ± 4.2	0.8830

Table 2.5: Selection of the six highest and six lowest MWL-index stations according to the Model 2 MWL-index. Means represent values of subjects grouped into high and low stress groups according to the Model 2 MWL-index. Values represent means over a six hour period (08:00 – 14:00).

Variable	HS	LS	p value
Age	37.3 ± 6.5	44.3 ± 11.1	0.2135
Mass	93.8 ± 34.5	86.2 ± 22.7	0.6612
Height	1.7 ± 0.1	1.7 ± 0.1	0.9521
Body mass index	31.3 ± 8.9	29.3 ± 6.3	0.6599
Surface area	2.11 ± 0.46	2.03 ± 0.31	0.7244
Cohens	18.8 ± 7.0	19.7 ± 8.2	0.8542
Diastolic blood pressure	85.5 ± 9.8	83.9 ± 11.5	0.8188
Systolic blood pressure	122.9 ± 13.8	117.9 ± 14.5	0.5768
Mean arterial pressure	97.9 ± 11.1	95.2 ± 12.4	0.7166
Pulse pressure	37.5 ± 4.2	34.0 ± 4.7	0.2328
Heart rate (blood pressure monitor)	70.9 ± 7.2	71.9 ± 5.9	0.8176
Cortisol	4.1 ± 1.7	4.0 ± 1.3	0.9061
Heart rate (MiniMitter)	82.5 ± 6.5	82.7 ± 6.0	0.9485
SD of heart rate	5.5 ± 1.0	4.9 ± 1.4	0.3605
RR	739.7 ± 54.9	736.3 ± 58.8	0.9214
SD of RR	44.3 ± 12.5	36.1 ± 9.9	0.2376
RMSSD	32.5 ± 15.9	29.8 ± 10.1	0.7307
SD1	23.3 ± 11.2	21.3 ± 7.2	0.7280
SD2	95.8 ± 18.4	82.6 ± 22.1	0.2897
LF	728.4 ± 321.7	430.7 ± 205.7	0.0852
HF	254.7 ± 253.8	159.1 ± 84.1	0.4145
Ratio (LF/HF)	4.9 ± 3.2	3.3 ± 1.5	0.2858
Total power	983.0 ± 560.9	589.8 ± 277.6	0.1547
Smoking	0.5 ± 0.5	0.5 ± 0.5	1.000
Length of previous shift	12.0 ± 0.0	9.0 ± 1.5	
Length of test shift	12.0 ± 0.0	9.7 ± 1.9	
Years experience at particular station	3.4 ± 3.2	9.3 ± 9.1	0.1876
Shift preference	1.2 ± 1.0	1.0 ± 0.9	0.7650
Radio communications	197.8 ± 56.4	46.3 ± 21.5	0.0007
Telephone communications	57.7 ± 19.9	21.8 ± 11.9	0.0036
Scheduling	76.0 ± 23.8	18.5 ± 7.3	0.0013
Number of Trains	34.5 ± 24.7	6.3 ± 2.3	0.0380
Number of Authorisations	25.3 ± 10.5	6.3 ± 2.1	0.0063

Table 2.6: Repeated measures evaluation between the two stress groups (Model 2 MWL-index), change over time for the whole group under investigation and group time interaction for physiological and time line analysis variables.

Variable	Group	Time	Group*Time
Cortisol	0.5643	0.0642	0.4521
Systolic blood pressure	0.0742	0.4159	0.5047
Diastolic blood pressure	0.5784	0.2770	0.7522
Mean arterial pressure	0.2684	0.4305	0.5530
Pulse pressure	0.0122	0.1549	0.9011
Heart rate*	0.2138	0.0001	0.3612
RR*	0.2213	0.0001	0.5683
sdHR*	0.5196	0.0504	0.6269
sdRR*	0.9934	0.0006	0.4212
Body mass index			
Total*	0.8781	0.0060	0.5319
LF power*	0.8260	0.0226	0.5525
LFn	0.4210	0.0703	0.8785
LF peak*	0.2435	0.8383	0.0707
HF power*	0.9762	0.0056	0.4778
HFn	0.4210	0.0703	0.8785
HF peak*	0.1601	0.4830	0.0536
Ratio (LF/HF)*	0.2863	0.0866	0.8189
RMSSD*	0.5784	0.0017	0.5659
SD1*	0.5753	0.0017	0.5619
SD1n*	0.7424	0.0078	0.5472
SD2*	0.8046	0.0017	0.4962
SD2n*	0.7253	0.1413	0.7272
Number of authorisations*	0.0002	0.2093	0.2001
Radio communications*	0.0001	0.4620	0.5608
Scheduling*	0.0001	0.4975	0.4418
Telephone communications*	0.0350	0.1424	0.1442
Number of trains*	0.0064	0.5394	0.0453

* = Hour intervals

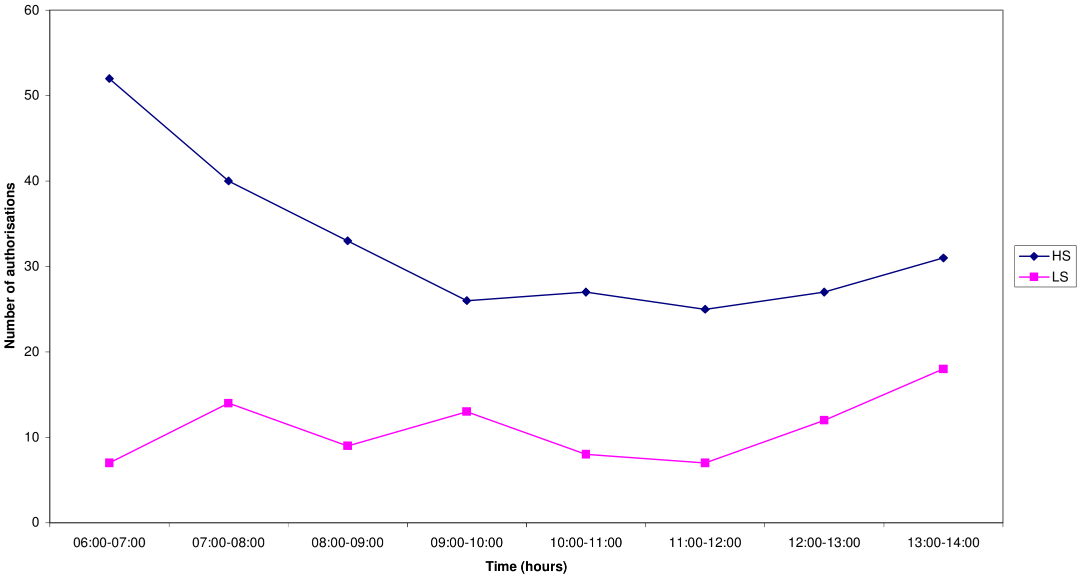

Figure 2.2: Mean total number of authorizations for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

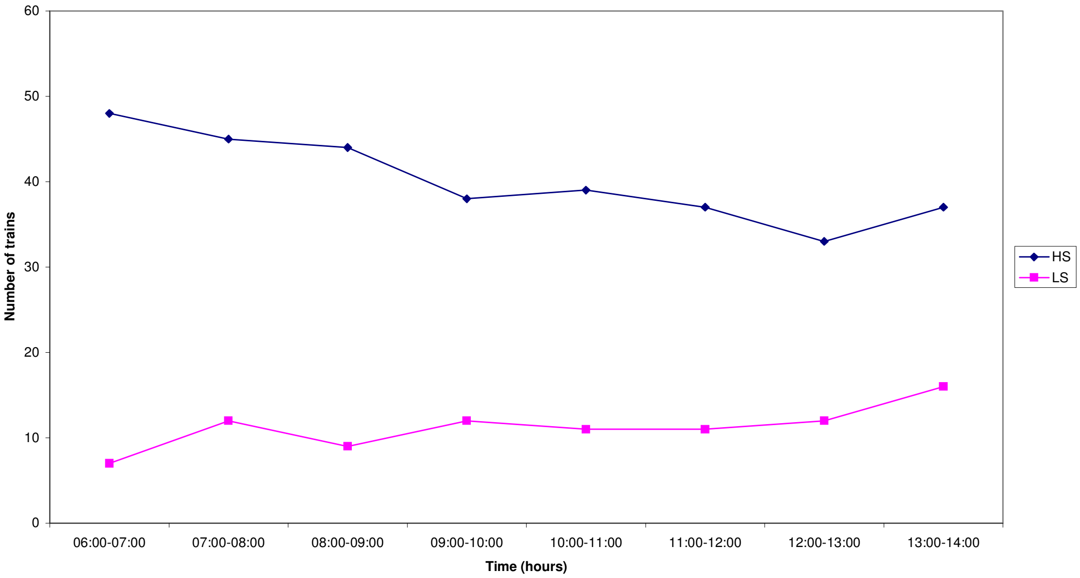

Figure 2.3: Mean total number of trains for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

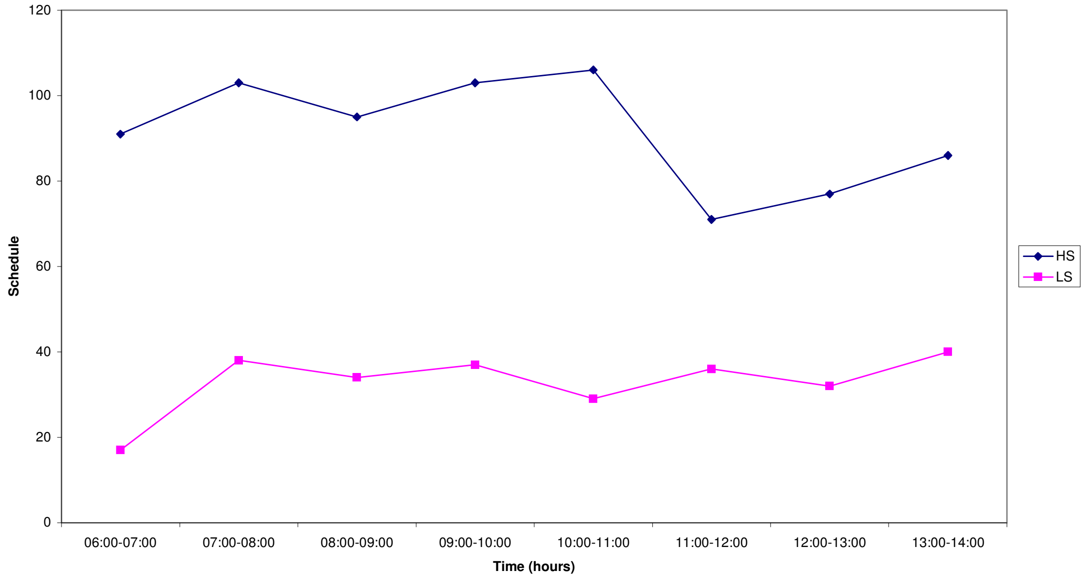

Figure 2.4: Mean total number of schedule transactions for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

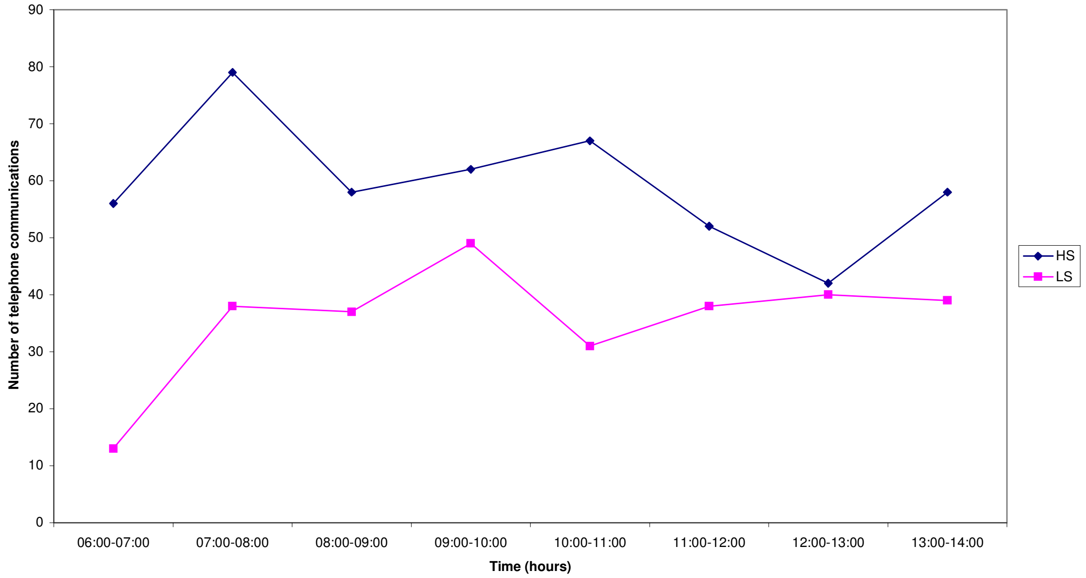

Figure 2.5: Mean total number of telephone communications for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

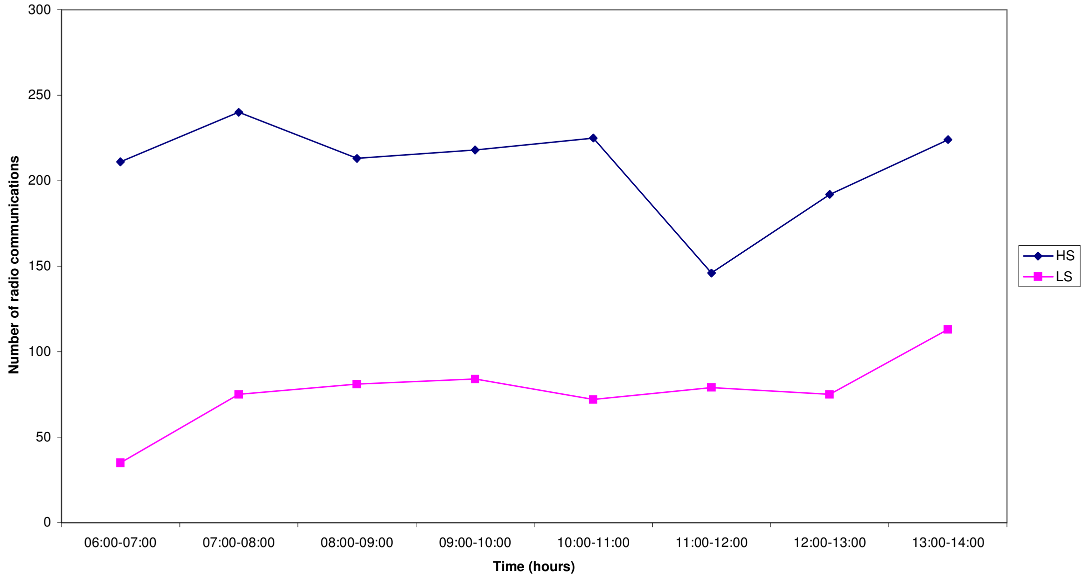

Figure 2.6: Mean total number of radio communications for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

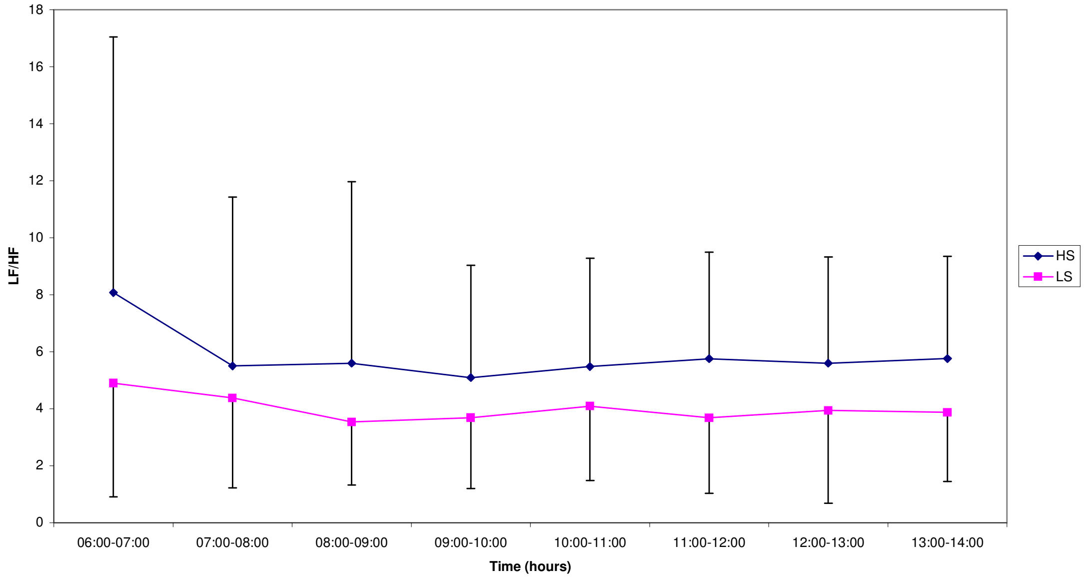

Figure 2.7: Mean ratio (LF/HF) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

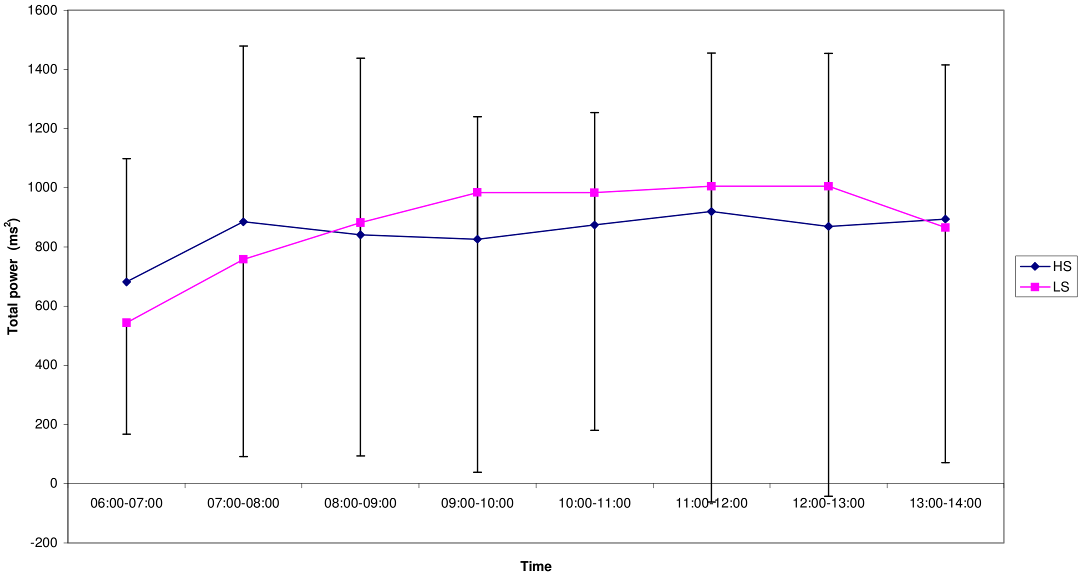

Figure 2.8: Mean total power for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

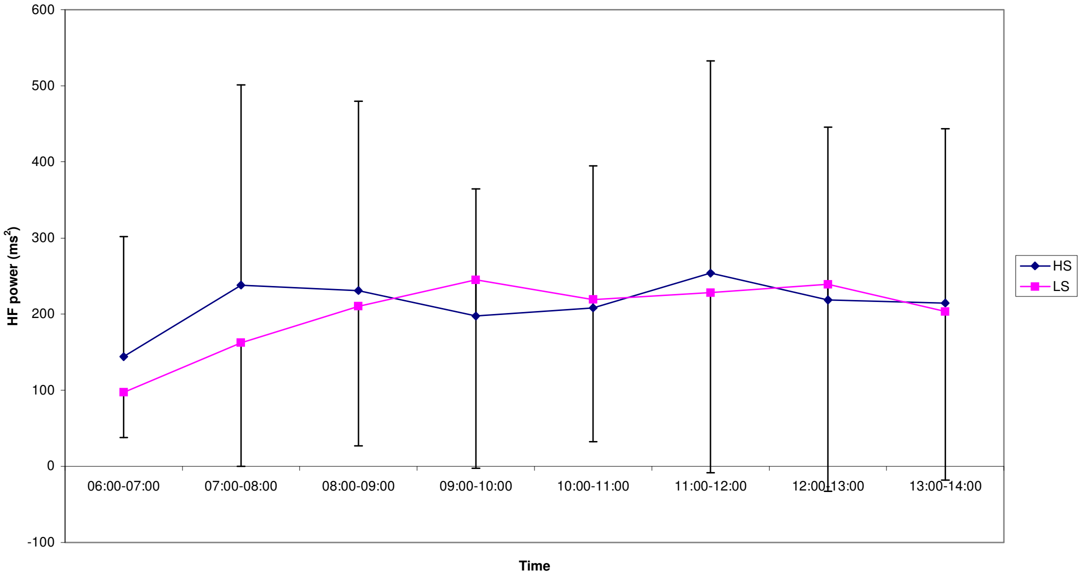

Figure 2.9: Mean high frequency (HF) power for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

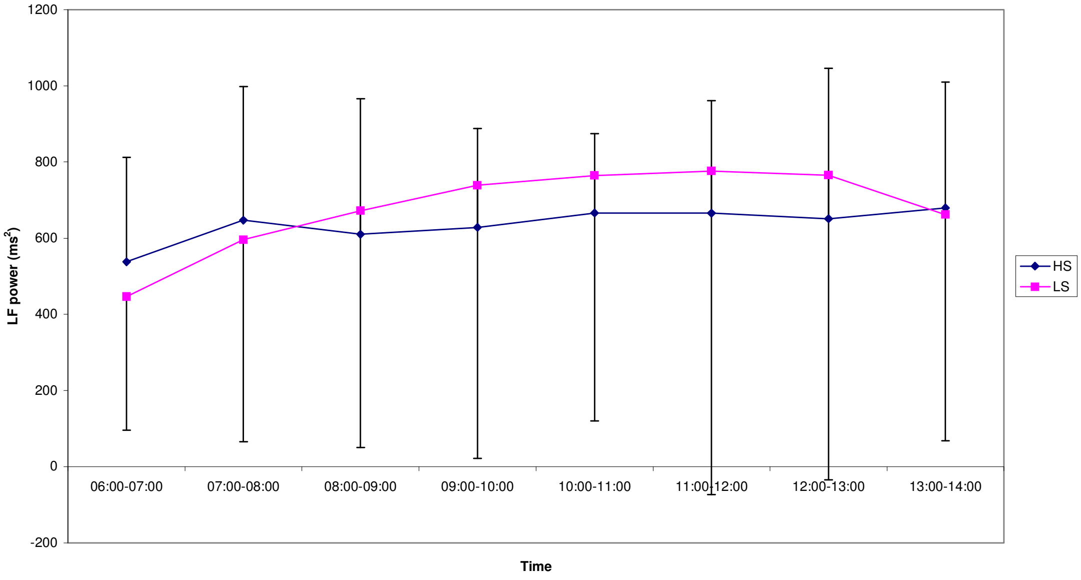

Figure 2.10: Mean low frequency power (LF) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

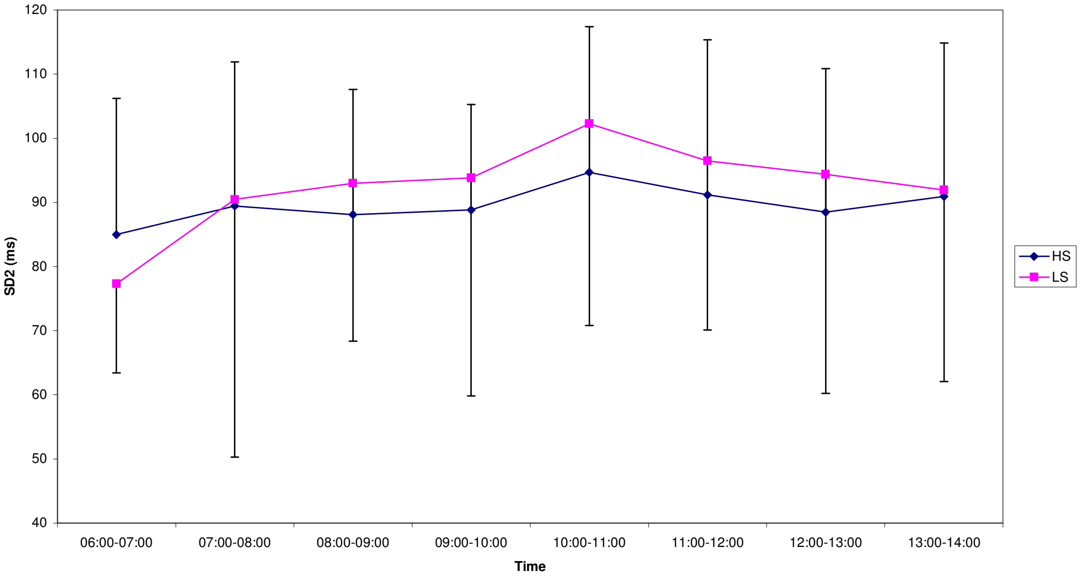

Figure 2.11: Mean SD2 for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

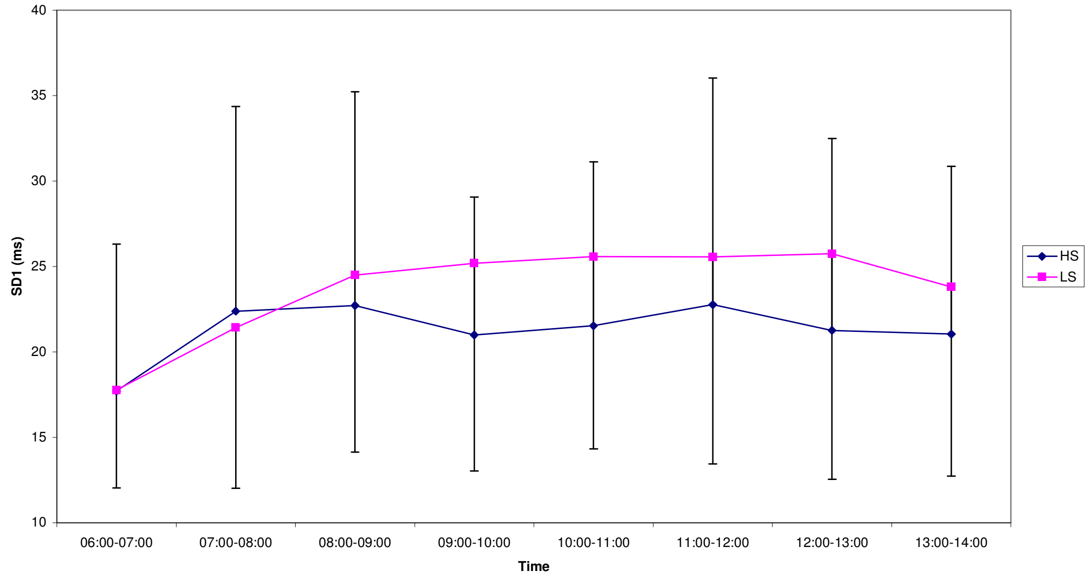

Figure 2.12: Mean SD1 for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

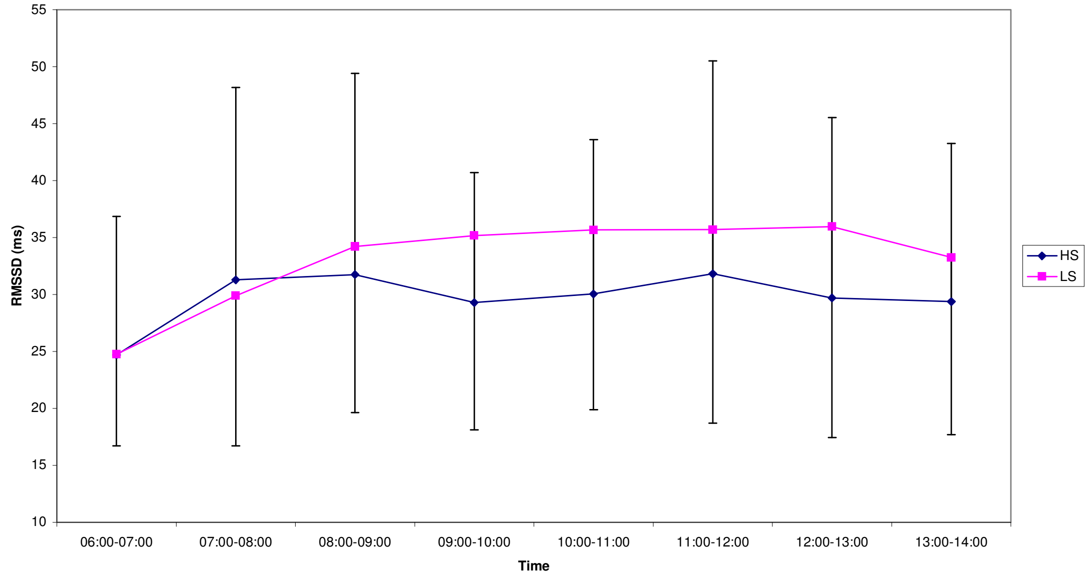

Figure 2.13: Mean RMSSD for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

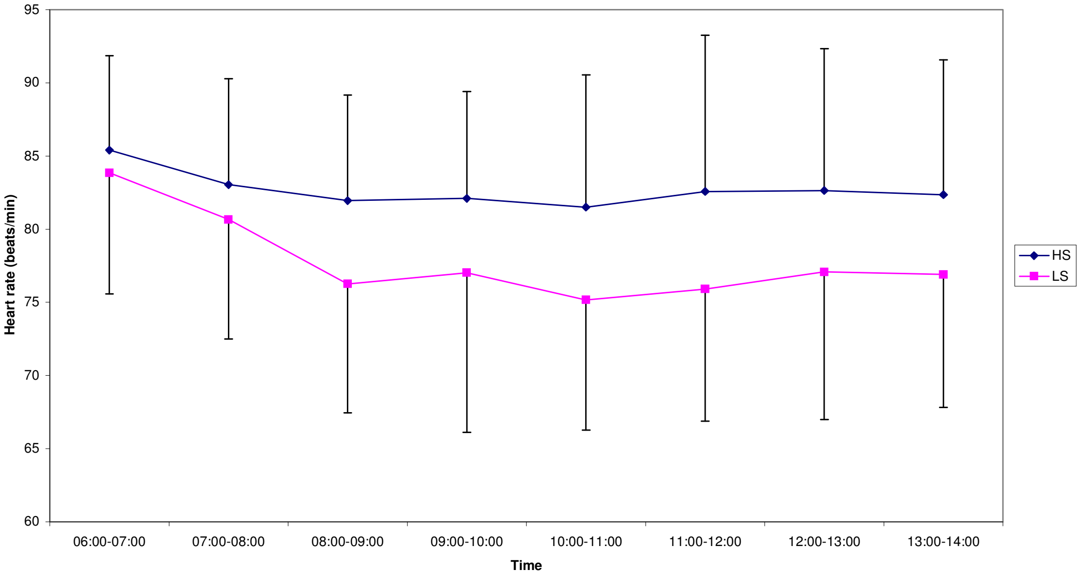

Figure 2.14: Mean heart rate (Minimitter) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

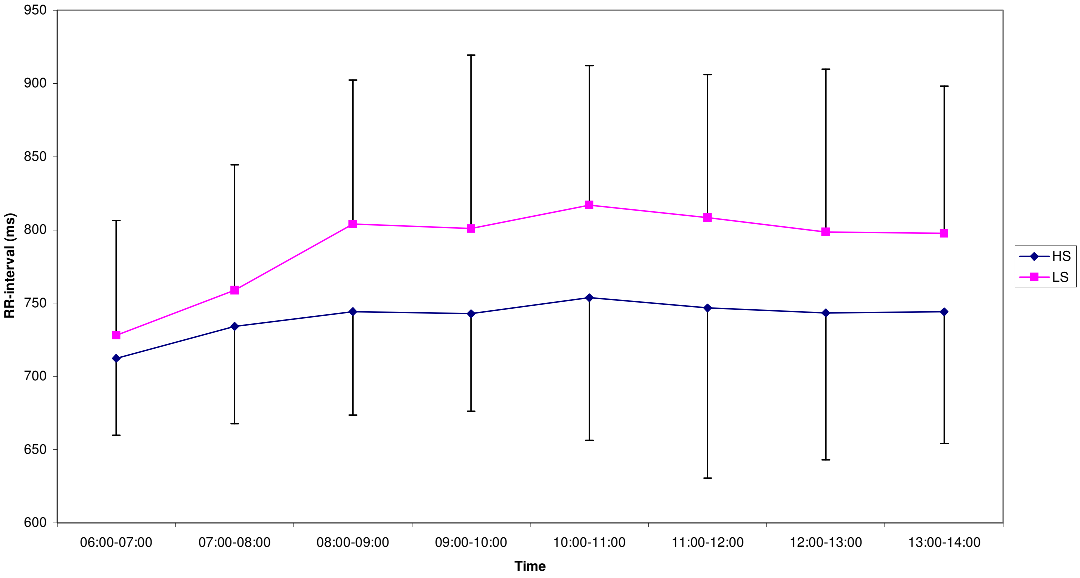

Figure 2.15: Mean RR-interval for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

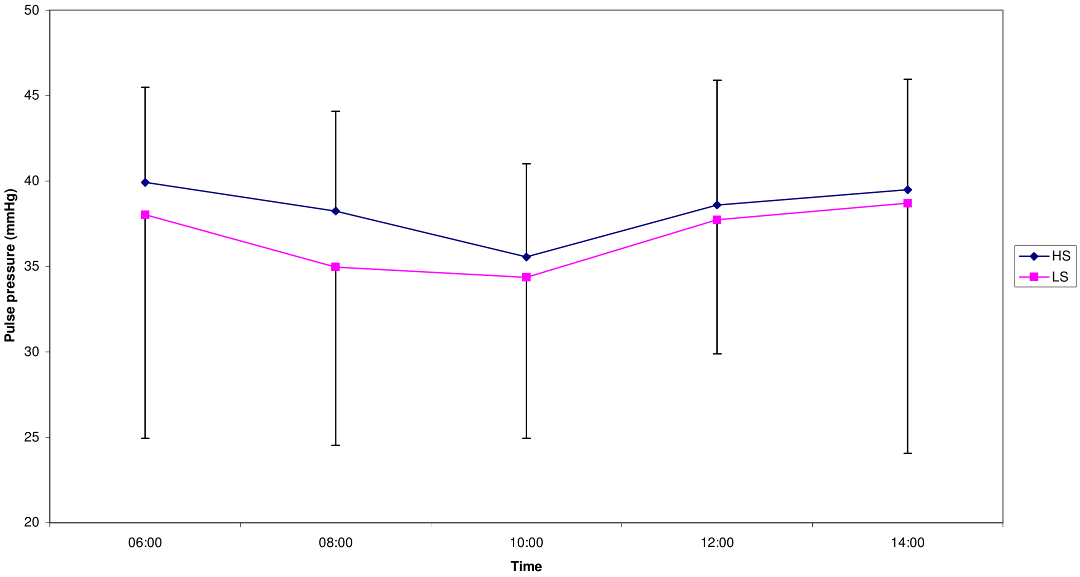

Figure 2.16: Mean pulse pressure for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

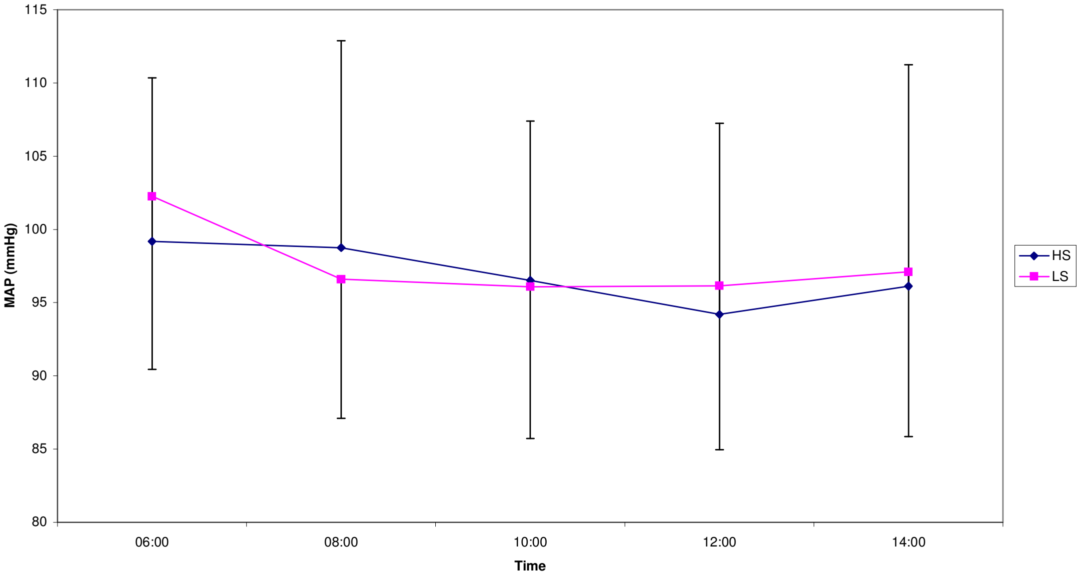

Figure 2.17: Mean arterial pulse pressure (MAP) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

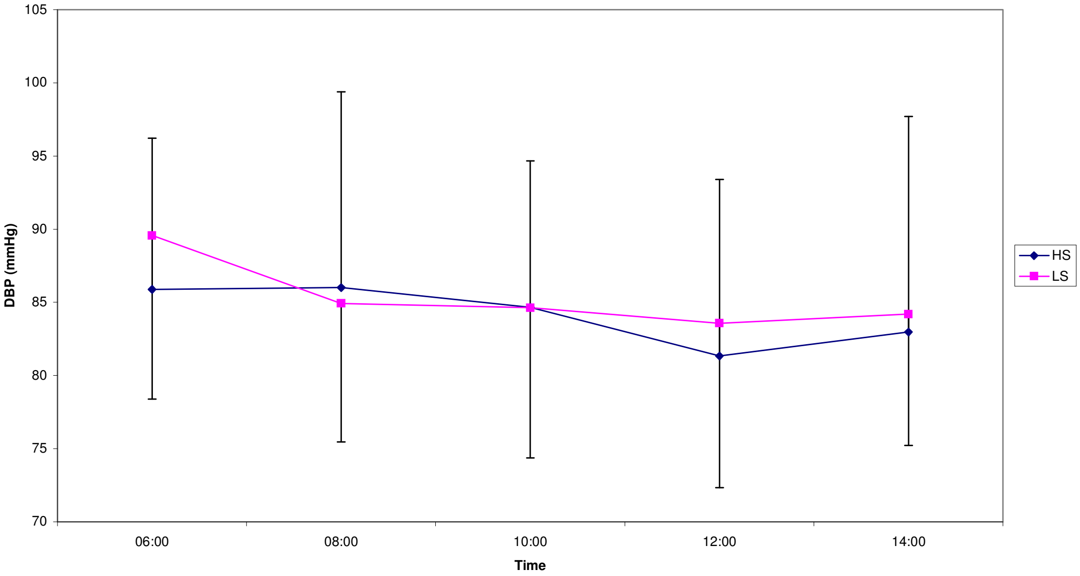

Figure 2.18: Mean diastolic blood pressure (DBP) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

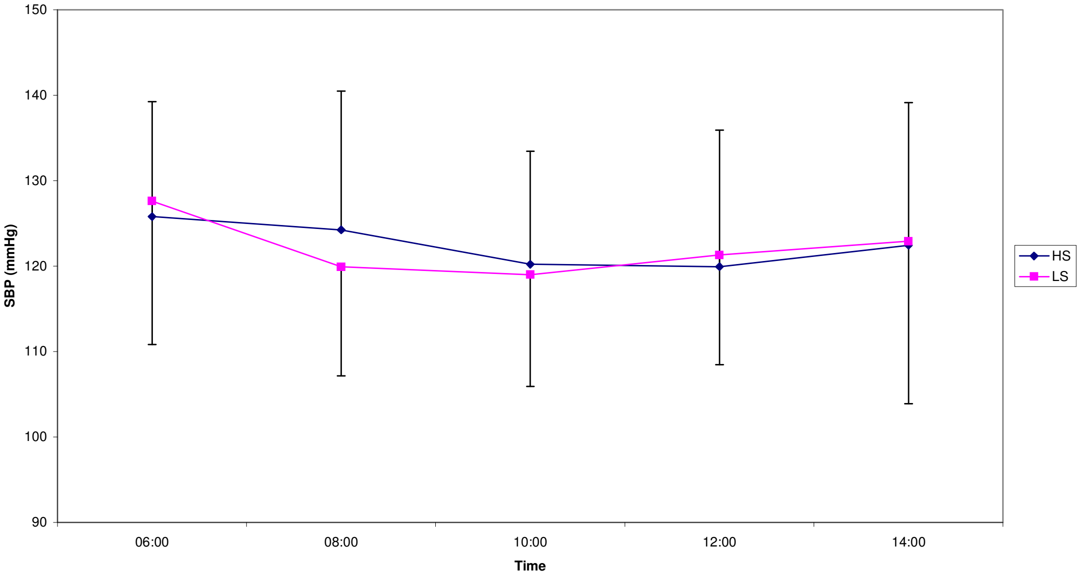

Figure 2.19: Mean systolic blood pressure (SBP) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

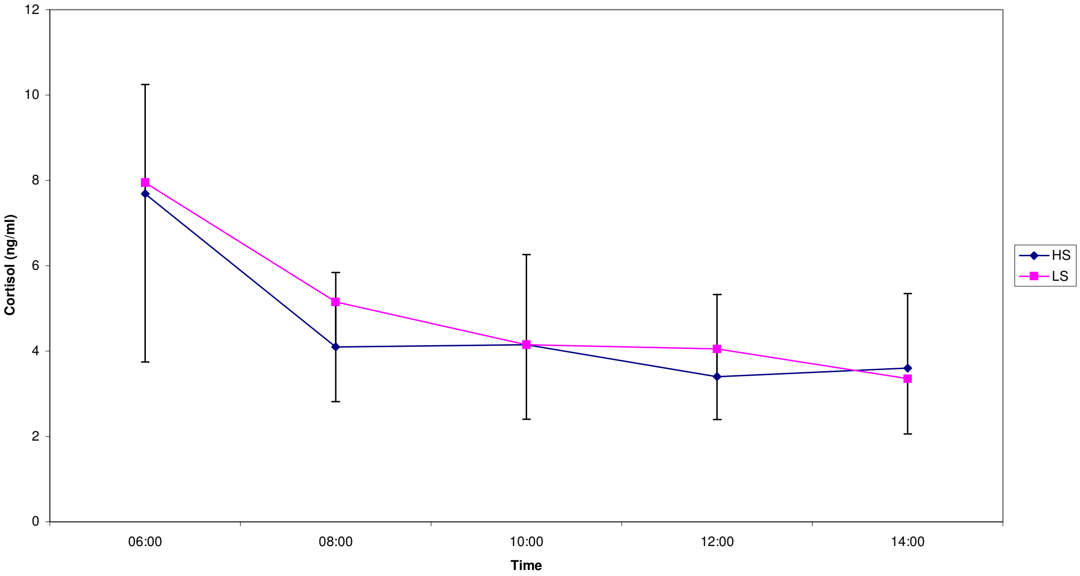

Figure 2.20: Mean cortisol for TCOs designated to fall into the high (HS) or low (LS) stress group according to the MWL-index (Model 2).

3.3 Physiological Parameters: Separation of Work Stations Into High and Low Stress as Extrapolated from the Stress Levels of the Individuals at the Work Stations

The analyses here was performed in terms of an adapted allostatic load measurement, only those parameters that could be measured within the possibilities of the study could be included. Those measurements that required venipuncture could not be performed. The data used in the calculation of the numerical value for each individual factor or parameter of the allostatic load were derived from the mean of the values obtained over the work shift. The reason for this was that baseline values in this group could not really be seen as base line, as all of them appeared to arrive with values higher than any reached during the experimental procedure. The fact that the stressor, in this case is not a once off stressor, but that the TCOs live with this level of stress axes activity for the major part of everyday, supports the decision to use the mean values over the work shift. The values of the following parameters were included: salivary cortisol and BMI as an indices of hypothalamo-pituitary-adrenocortical axis activity, systolic and diastolic pressure as measure, of cardiovascular activity - largely reflecting sympatho-adrenomedullary axis activation, heart rate as an indicator of sympatho-adrenomedullary activation and heart rate variability variables as indicators of autonomic activity. The values of each individual for each of the 5 indicators were classified according to the 50th percentile. Allostatic load was then calculated by summing up the number of parameters for which the subject fell into the highest risk, i.e., above the 50 percentile. Subjects were subsequently ranked according to their total hits.

Table 3.1 shows combinations of factors used to calculate the adapted allostatic load and classifications into high and low groups according to the values of different combinations of physiological stress indicators. The decision whether an individual was classified with a high or low allostatic load depended on whether the sum was greater or equal to 3 (high) or not (low). Three models, i.e., A, B and C were developed – depending on the combination of factors included. The significance of the statistical differences for the three models, i.e., the three combinations of factors can be seen in Tables 3.2, 3.3 and 3.4.

The physiological rating of the three models can be seen in Tables 3.5, 3.6 and 3.7. Graphical presentations of the time line variables and the physiological measures can be seen in Figures 3.1 to 3.19.

Table 3.1 Calculation of allostatic load index

	Physiological variables measure that are associated with allostatic load						50th Percentile						Allostatic load index			Allostatic group		
Id	BMI	Cortisol	Systolic	Diastolic	HR	LF	BMI	Cortisol	Systolic	Diastolic	HR	LF	A,B,C,D,E,F (A)	A,B,C,D,E (B)	B,C,D,E (C)	A,B,C,D,E,F (A)	A,B,C,D,E (B)	B,C,D,E (C)
	A	B	C	D	E	F	28.4	3.4	119.3	84.1	81.8	553.1						
1	27.7	3.6	118.9	85.9	76.6	1262.4		1		1			2	2	2	Low	Low	Low
2	20.7	2.5	93.1	66.4	87.5	430.0					1	1	2	1	1	Low	Low	Low
3	27.8	3.3	119.3	86.7	66.1	2296.0				1			1	1	1	Low	Low	Low
4	40.2	3.3	130.6	97.3	88.1	140.9	1		1	1	1	1	5	4	3	High	High	High
5	36.1	3.0	137.8	96.2	81.5	597.5	1		1	1			3	3	2	High	High	Low
6	28.1	3.4	116.8	83.5	82.1	727.9					1		1	1	1	Low	Low	Low
7	28.5	4.0	134.2	94.1	84.2	583.9	1	1	1	1	1		5	5	4	High	High	High
8	28.4	5.0	124.5	89.9	74.1	648.3	1	1	1	1			4	4	3	High	High	High
9	30.2	3.3	119.8	81.5	88.5	479.1	1		1		1	1	4	3	2	High	High	Low
10	28.5	5.0	114.3	78.3	77.1	1030.4	1	1					2	2	1	Low	Low	Low
11	46.8	7.1	*	*	77.9	456.6	1	1	1	1		1	5	4	3	High	High	High
12	34.1	1.9	143.8	98.3	89.7	584.9	1		1	1	1		4	4	3	High	High	High
13	27.3	4.8	113.6	75.8	82.8	312.3		1			1	1	3	2	2	High	Low	Low
14	26.8	5.3	117.4	84.2	85.3	429.1		1		1	1	1	4	3	3	High	High	High
15	35.1	5.9	143.8	82.3	63.8	93.2	1	1	1			1	4	3	2	High	High	Low
16	31.0	6.1	113.1	81.5	71.5	388.9	1	1				1	3	2	1	High	Low	Low
17	28.3	2.9	121.4	84.1	80.9	1167.7			1				1	1	1	Low	Low	Low
18	26.6	3.1	134.3	96.2	95.0	353.2			1	1	1	1	4	3	3	High	High	High
19	21.5	3.5	105.8	73.9	82.4	764.8		1			1		2	2	2	Low	Low	Low
20	22.1	3.1	100.8	61.1	67.4	522.3						1	1	0	0	Low	Low	Low
							10	10	10	10	10	10						

* - it was assumed that this subject had high blood pressure

Table 3.2: Mean values over a six hour period (08:00 – 14:00) for subjects divided into high and low stress groups according to Model A of allostatic load.

Variable	HS	LS	p value
Age	45.3 ± 8.0	32.5 ± 6.5	0.0013
Mass	100.0 ± 22.8	75.5 ± 19.5	0.0225
Height	1.7 ± 0.1	1.7 ± 0.1	0.3639
Body mass index	32.6 ± 6.2	25.6 ± 3.5	0.0047
Surface area	2.21 ± 0.28	1.90 ± 0.32	0.0291
Cohens	20.3 ± 5.9	19.1 ± 6.4	0.6899
Diastolic blood pressure	89.5 ± 7.3	78.0 ± 9.8	0.0091
Systolic blood pressure	129.7 ± 10.8	111.6 ± 10.3	0.0019
Mean arterial pressure	102.9 ± 7.6	89.2 ± 9.8	0.0031
Pulse pressure	40.2 ± 8.6	33.6 ± 4.1	0.0431
Heart rate (blood pressure monitor)	72.9 ± 7.5	65.5 ± 6.8	0.0415
Cortisol	4.4 ± 1.6	3.4 ± 0.7	0.0766
Heart rate (MiniMitter)	81.9 ± 8.8	77.5 ± 7.5	0.2655
SD of heart rate	4.5 ± 1.1	6.1 ± 0.9	0.0024
RR	748.5 ± 88.1	792.0 ± 83.6	0.2851
SD of RR	33.6 ± 7.6	53.8 ± 13.4	0.0031
RMSSD	23.8 ± 8.4	43.2 ± 13.9	0.0010
SD1	17.1 ± 5.9	30.9 ± 9.9	0.0010
SD2	79.1 ± 17.5	110.1 ± 24.2	0.0037
LF	422.3 ± 176.9	1025.2 ± 592.2	0.0238
HF	105.4 ± 65.1	365.3 ± 239.9	0.0181
Ratio (LF/HF)	5.5 ± 4.3	3.6 ± 3.0	0.2752
Total power	527.7 ± 219.5	1390.5 ± 776.2	0.0161
Smoking	0.4 ± 0.5	0.5 ± 0.5	0.7309
Length of previous shift	10.8 ± 1.7	10.9 ± 1.8	0.9595
Length of test shift	11.5 ± 1.2	10.9 ± 1.8	0.3577
Years experience at particular station	6.8 ± 6.6	4.8 ± 4.5	0.4689
Shift preference	0.9 ± 0.9	1.0 ± 0.9	0.8433
Radio communications	117.6 ± 81.6	109.0 ± 59.4	0.8018
Telephone communications	37.0 ± 21.8	39.4 ± 17.4	0.7998
Scheduling	51.1 ± 33.1	47.8 ± 30.1	0.8219
Number of Trains	22.8 ± 24.1	17.1 ± 11.8	0.4912
Number of Authorisations	16.3 ± 12.0	19.2 ± 12.6	0.5989

Table 3.3: Mean values over a six hour period (08:00 – 14:00) for subjects divided into high and low stress groups according to Model B of allostatic load.

Variable	HS	LS	p value
Age	43.8 ± 7.8	36.6 ± 10.4	0.0970
Mass	102.0 ± 24.6	78.5 ± 18.3	0.0261
Height	1.7 ± 0.1	1.7 ± 0.1	0.04896
Body mass index	33.3 ± 6.5	26.3 ± 3.5	0.0102
Surface area	2.23 ± 0.31	1.94 ± 0.29	0.0423
Cohens	21.5 ± 5.5	18.1 ± 6.2	0.2092
Diastolic blood pressure	91.5 ± 6.5	78.6 ± 8.9	0.0023
Systolic blood pressure	132.6 ± 9.8	112.7 ± 9.3	0.0003
Mean arterial pressure	105.2 ± 6.4	89.9 ± 8.8	0.0005
Pulse pressure	41.1 ± 9.3	34.1 ± 3.9	0.0608
Heart rate (blood pressure monitor)	74.0 ± 7.3	66.0 ± 6.7	0.0230
Cortisol	4.2 ± 1.6	3.8 ± 1.1	0.05643
Heart rate (MiniMitter)	82.8 ± 9.0	77.5 ± 7.1	0.1566
SD of heart rate	4.5 ± 1.2	5.7 ± 1.2	0.0365
RR	740.5 ± 91.0	791.3 ± 78.7	0.1987
SD of RR	33.4 ± 8.4	49.8 ± 14.4	0.0061
RMSSD	22.6 ± 8.3	40.6 ± 13.7	0.0023
SD1	16.2 ± 5.9	29.0 ± 9.7	0.0022
SD2	78.9 ± 18.9	104.1 ± 25.1	0.0208
LF	436.7 ± 191.2	890.3 ± 595.0	0.0427
HF	100.3 ± 68.1	318.4 ± 234.3	0.0172
Ratio (LF/HF)	6.0 ± 4.6	3.5 ± 2.7	0.1419
Total power	537.0 ± 241.5	1208.7 ± 784.6	0.0258
Smoking	0.4 ± 0.5	0.5 ± 0.5	0.6733
Length of previous shift	10.8 ± 1.9	10.9 ± 1.6	0.9010
Length of test shift	11.6 ± 1.3	10.9 ± 1.6	0.2912
Years experience at particular station	5.7 ± 3.8	6.4 ± 7.5	0.7961
Shift preference	0.9 ± 0.9	1.0 ± 0.9	0.8086
Radio communications	135.5 ± 77.3	92.8 ± 62.9	0.1919
Telephone communications	40.2 ± 21.7	35.7 ± 18.4	0.6230
Scheduling	58.2 ± 31.6	41.3 ± 29.9	0.2349
Number of Trains	26.1 ± 25.3	15.0 ± 11.3	0.2280
Number of Authorisations	18.4 ± 12.1	16.5 ± 12.6	0.7344

Table 3.4: Mean values over a six hour period (08:00 – 14:00) for subjects divided into high and low stress groups according to Model C of allostatic load.

Variable	HS	LS	p value
Age	43.4 ± 6.0	38.5 ± 11.0	0.2857
Mass	100.3 ± 27.9	84.8 ± 21.3	0.1800
Height	1.7 ± 0.1	1.7 ± 0.1	0.8335
Body mass index	33.1 ± 7.8	28.0 ± 4.6	0.0849
Surface area	2.21 ± 0.34	2.02 ± 0.32	0.2417
Cohens	22.1 ± 5.8	18.5 ± 5.8	0.2039
Diastolic blood pressure	93.7 ± 5.4	80.5 ± 9.0	0.0044
Systolic blood pressure	131.4 ± 8.7	117.8 ± 13.8	0.0429
Mean arterial pressure	106.3 ± 6.3	93.0 ± 10.0	0.0087
Pulse pressure	37.7 ± 4.7	37.3 ± 8.8	0.09240
Heart rate (blood pressure monitor)	76.3 ± 5.4	66.8 ± 7.2	0.0108
Cortisol	4.2 ± 1.7	3.9 ± 1.2	0.5781
Heart rate (MiniMitter)	84.9 ± 7.1	77.6 ± 8.1	0.0590
SD of heart rate	4.7 ± 1.0	5.3 ± 1.4	0.3086
RR	719.2 ± 65.7	791.1 ± 88.5	0.0767
SD of RR	34.1 ± 8.6	45.7 ± 15.3	0.0834
RMSSD	22.4 ± 10.2	36.5 ± 14.2	0.0320
SD1	16.1 ± 7.2	26.1 ± 10.1	0.0320
SD2	79.5 ± 22.6	98.0 ± 24.9	0.1183
LF	456.7 ± 173.5	774.8 ± 570.3	0.0822
HF	101.7 ± 79.8	267.3 ± 225.6	0.0295
Ratio (LF/HF)	6.9 ± 5.1	3.6 ± 2.6	0.1442
Total power	558.4 ± 241.6	1042.1 ± 758.6	0.0512
Smoking	0.6 ± 0.5	0.4 ± 0.5	0.4499
Length of previous shift	10.3 ± 2.1	11.2 ± 1.5	0.2953
Length of test shift	11.4 ± 1.5	11.2 ± 1.5	0.6967
Years experience at particular station	5.6 ± 4.2	6.2 ± 6.7	0.8155
Shift preference	0.6 ± 0.8	1.2 ± 0.9	0.1672
Radio communications	138.1 ± 79.9	101.2 ± 67.0	0.2858
Telephone communications	38.0 ± 20.3	37.9 ± 20.2	0.9936
Scheduling	64.7 ± 35.5	41.7 ± 26.6	0.1173
Number of Trains	30.7 ± 29.5	15.1 ± 9.9	0.2169
Number of Authorisations	20.0 ± 13.7	16.1 ± 11.4	0.5020

Table 3.5 Physiological rating, Model A: Cortisol, systolic blood pressure, diastolic blood pressure, heart rate, LF power and BMI

Variable	Group	Time	Group*Time
Cortisol	0.3879	0.1357	0.4345
Systolic blood pressure	0.0320	0.6155	0.9046
Diastolic blood pressure	0.4240	0.2186	0.4327
Mean arterial pressure	0.0296	0.4726	0.5975
Pulse pressure	0.4000	0.1775	0.8002
Heart rate*	0.2193	0.0002	0.2067
RR*	0.1743	0.0002	0.1564
sdHR*	0.9401	0.0592	0.4809
sdRR*	0.4943	0.0003	0.0521
Body mass index			
Total*	0.6556	0.0010	0.0278
LF power*	0.7133	0.0110	0.2162
LFn	0.9104	0.0299	0.0008
LF peak*	0.5627	0.6572	0.1180
HF power*	0.5980	0.0001	0.0003
HFn	0.9104	0.0299	0.0008
HF peak*	0.9682	0.5256	0.3921
Ratio (LF/HF)*	0.9907	0.0910	0.8633
RMSSD*	0.7347	0.0002	0.0046
SD1*	0.7310	0.0002	0.0047
SD1n*	0.8134	0.0015	0.0058
SD2*	0.2146	0.0041	0.0987
SD2n*	0.4607	0.2223	0.3031
Number of authorisations*	0.4821	0.2192	0.8366
Radio communications*	0.3090	0.4045	0.2866
Scheduling*	0.3314	0.4724	0.3623
Telephone communications*	0.7846	0.0145	0.1530
Number of trains*	0.6477	0.4917	0.9929

* = Hour intervals

Table 3.6 Physiological rating, Model B: Cortisol, systolic blood pressure, diastolic blood pressure, heart rate and BMI

Variable	Group	Time	Group*Time
Cortisol	0.5643	0.0691	0.7287
Systolic blood pressure	0.0104	0.3500	0.1504
Diastolic blood pressure	0.4544	0.3248	0.2275
Mean arterial pressure	0.1123	0.4758	0.1613
Pulse pressure	0.0057	0.1210	0.3002
Heart rate*	0.1711	0.0001	0.2525
RR*	0.2131	0.0002	0.1923
sdHR*	0.0422	0.0410	0.4505
sdRR*	0.0067	0.0004	0.1138
Body mass index			
Total*	0.0209	0.0026	0.0852
LF power*	0.0368	0.0183	0.3780
LFn	0.1018	0.0153	0.0001
LF peak*	0.4949	0.8378	0.1677
HF power*	0.0144	0.0006	0.0018
HFn	0.1018	0.0153	0.0001
HF peak*	0.9073	0.4853	0.4328
Ratio (LF/HF)*	0.1251	0.0837	0.8213
RMSSD*	0.0027	0.0006	0.0164
SD1*	0.0026	0.0006	0.0170
SD1n*	0.0026	0.0036	0.0245
SD2*	0.0204	0.0030	0.3261
SD2n*	0.0328	0.0911	0.6028
Number of authorisations*	0.7920	0.1578	0.7340
Radio communications*	0.1926	0.4240	0.1506
Scheduling*	0.2347	0.4533	0.1058
Telephone communications*	0.6673	0.1389	0.1672
Number of trains*	0.2401	0.4861	0.9473

* = Hour intervals

Table 3.7: Physiological rating, Model C: Cortisol, systolic blood pressure, diastolic blood pressure and heart rate

Variable	Group	Time	Group*Time
Cortisol	0.3498	0.1352	0.5378
Systolic blood pressure	0.1667	0.5201	0.8207
Diastolic blood pressure	0.1059	0.7820	0.1343
Mean arterial pressure	0.1116	0.8103	0.2841
Pulse pressure	0.6299	0.2645	0.7071
Heart rate*	0.1178	0.0001	0.2759
RR*	0.2059	0.0002	0.5233
sdHR*	0.6746	0.0596	0.8012
sdRR*	0.2260	0.0011	0.4261
Body mass index			
Total*	0.2983	0.0146	0.4374
LF power*	0.3212	0.0489	0.7297
LFn	0.2893	0.0359	0.1760
LF peak*	0.3055	0.9320	0.1667
HF power*	0.3234	0.0100	0.1199
HFn	0.2893	0.0359	0.1760
HF peak*	0.9900	0.5953	0.8676
Ratio (LF/HF)*	0.1695	0.0149	0.2808
RMSSD*	0.1659	0.0019	0.1538
SD1*	0.1663	0.0019	0.1549
SD1n*	0.1848	0.0085	0.1667
SD2*	0.2360	0.0014	0.4467
SD2n*	0.3766	0.1078	0.5326
Number of authorisations*	0.1690	0.1190	0.9517
Radio communications*	0.2241	0.3864	0.2522
Scheduling*	0.3541	0.3858	0.3335
Telephone communications*	0.7592	0.1702	0.1385
Number of trains*	0.0451	0.6096	0.7609

* = Hour intervals

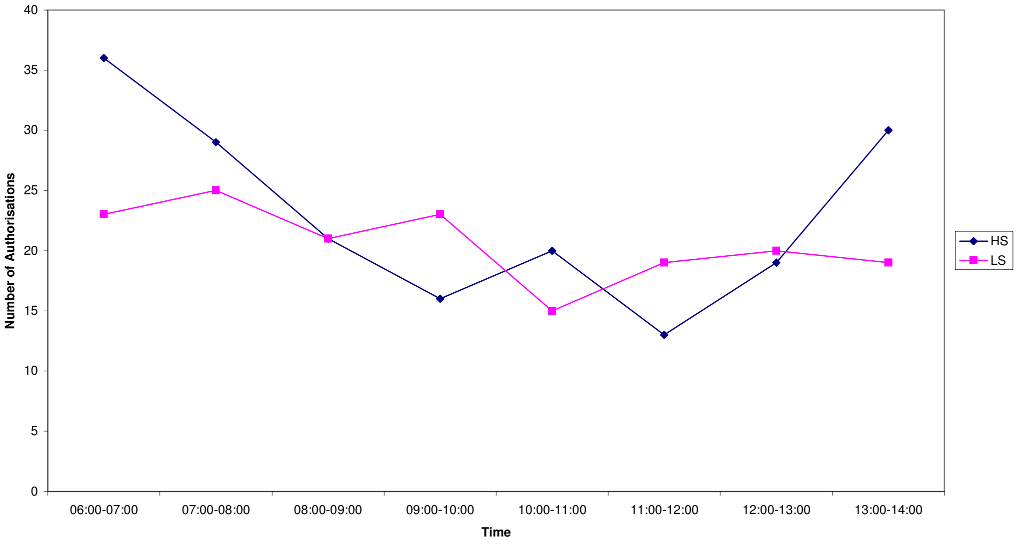

Figure 3.1: Mean total number of authorizations for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

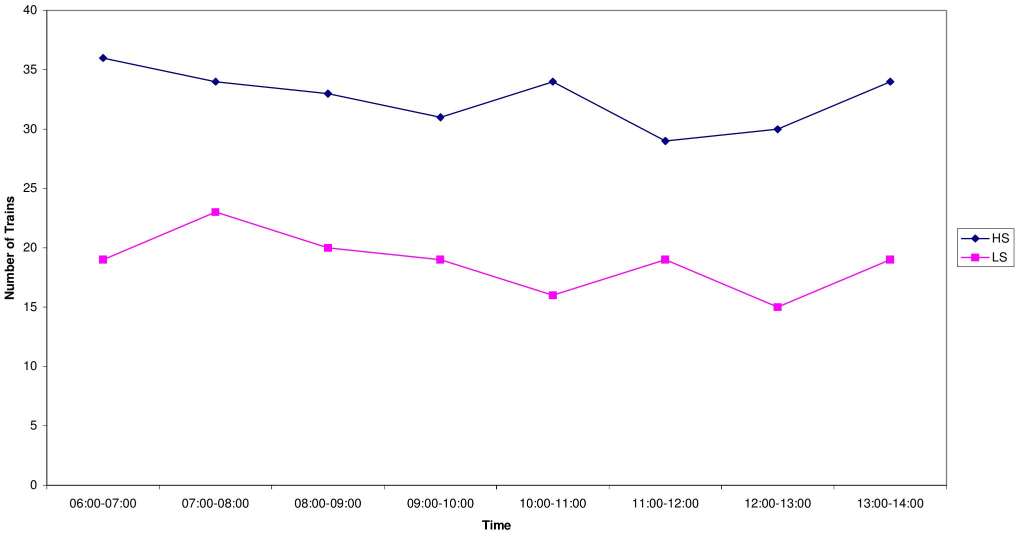

Figure 3.2: Mean total number of trains for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

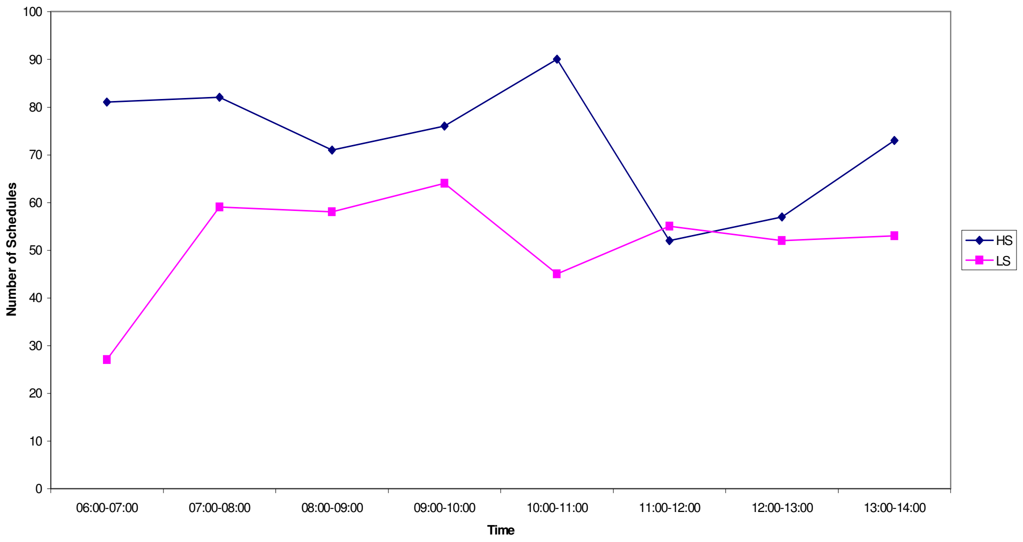

Figure 3.3: Mean total number of schedule transactions for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

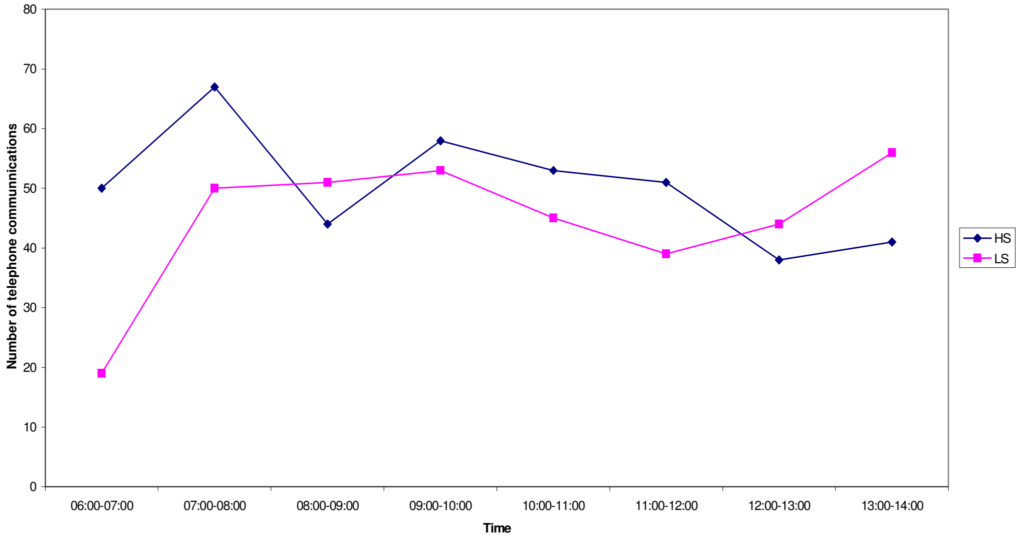

Figure 3.4: Mean total number of telephone communications for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

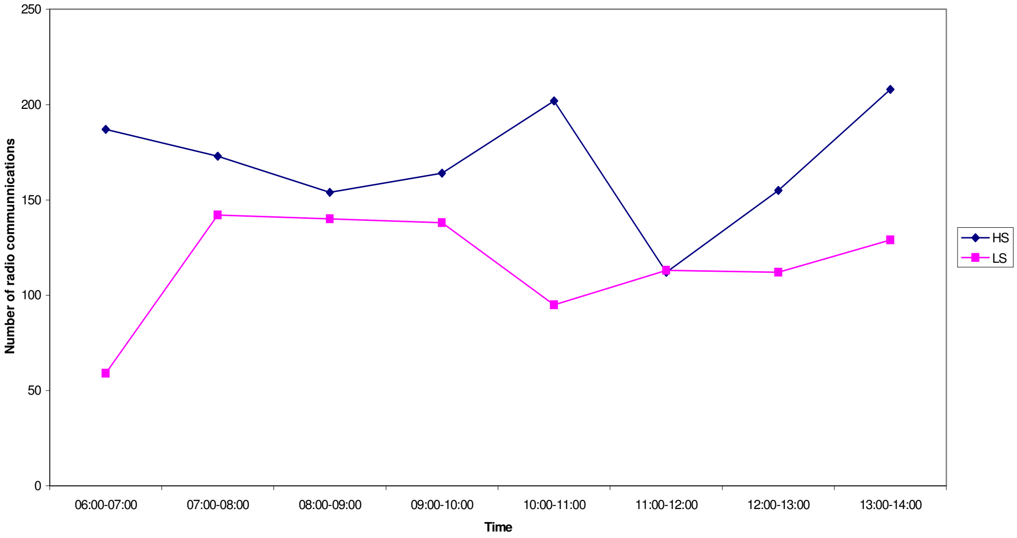

Figure 3.5: Mean total number of radio communications for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

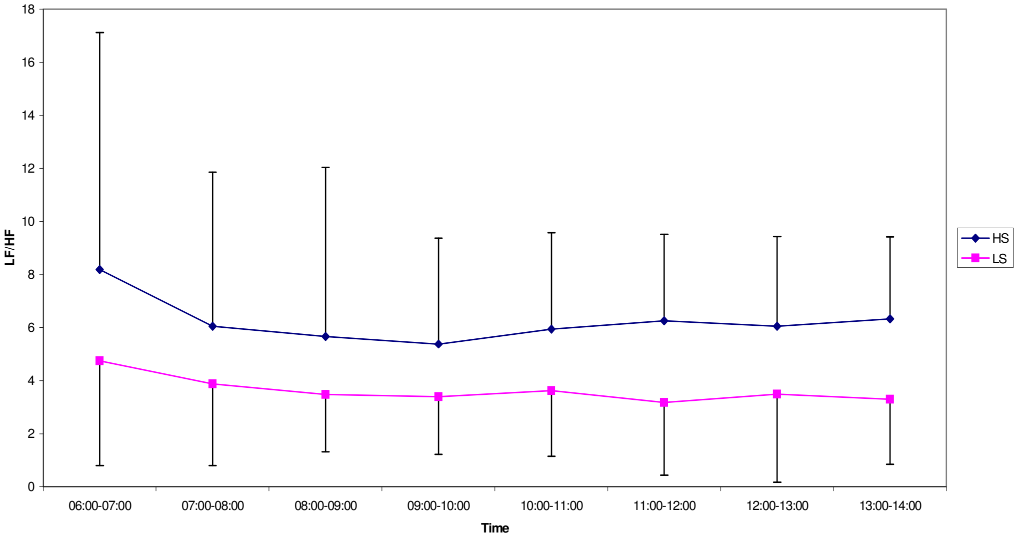

Figure 3.6: Mean ratio (LF/HF) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

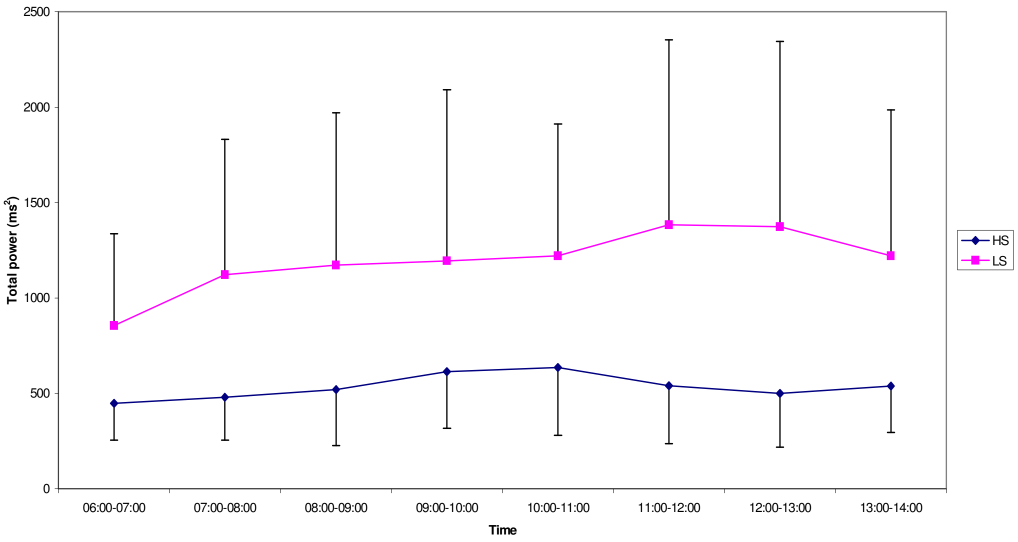

Figure 3.7: Mean total power for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

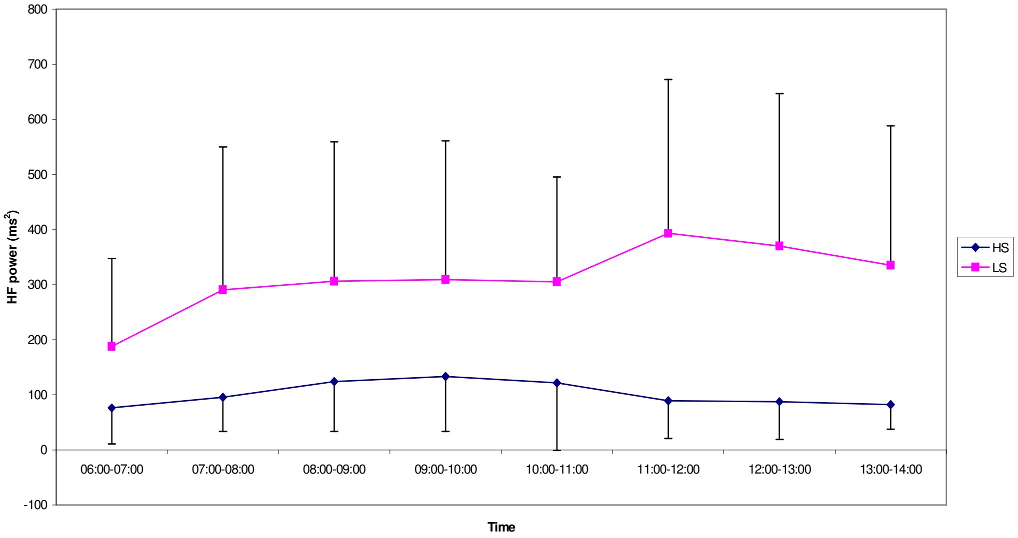

Figure 3.8: Mean high frequency (HF) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

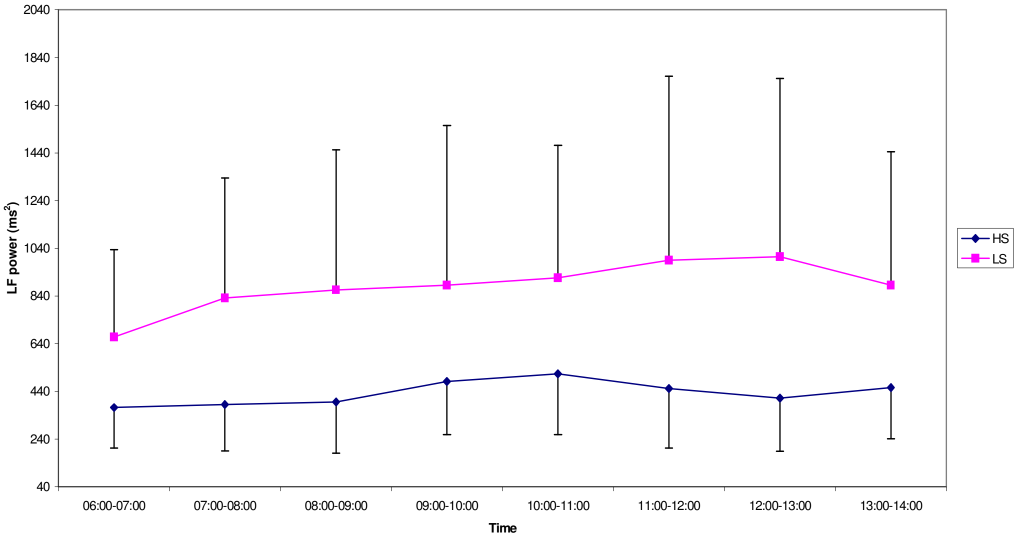

Figure 3.9: Mean low frequency (LF) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

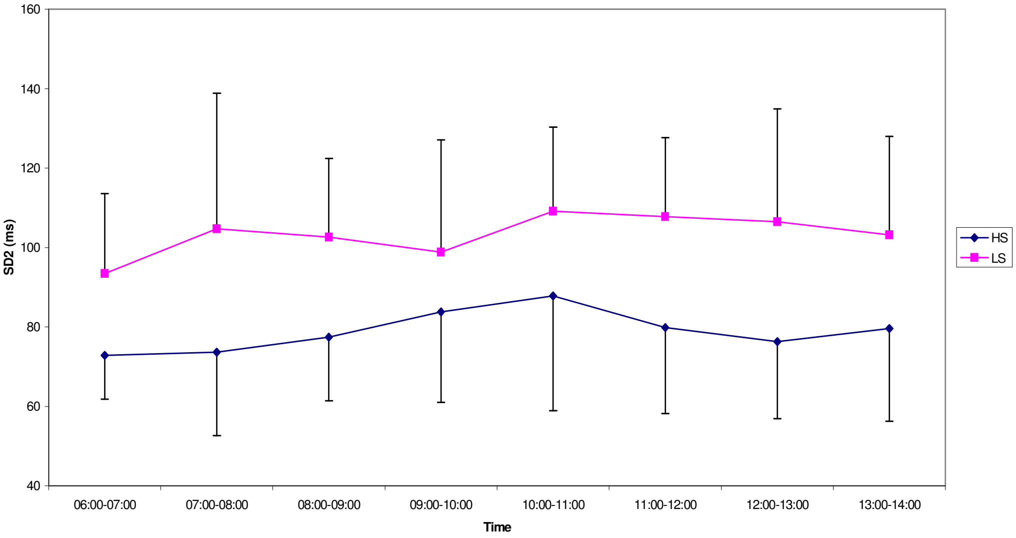

Figure 3.10: Mean SD2 for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

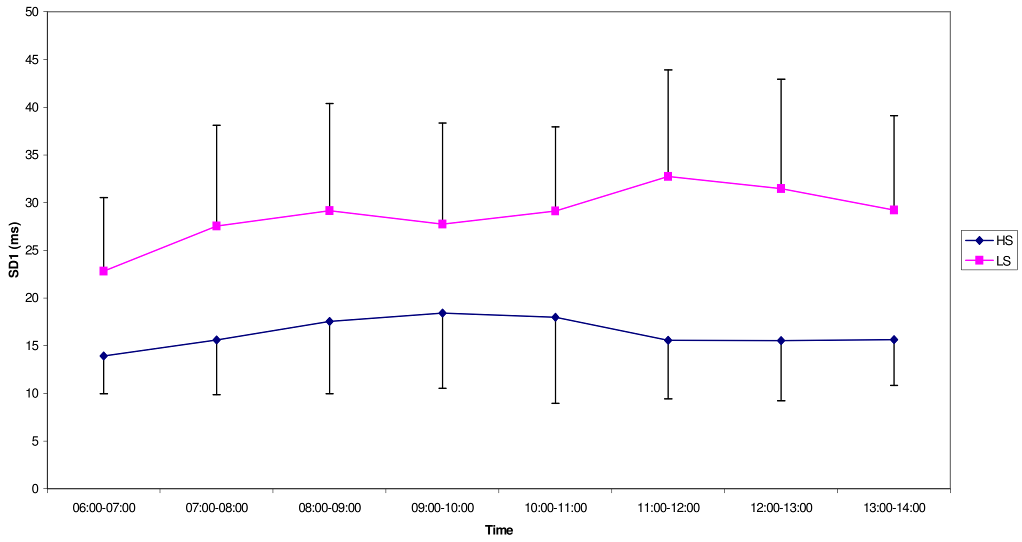

Figure 3.11: Mean SD1 for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

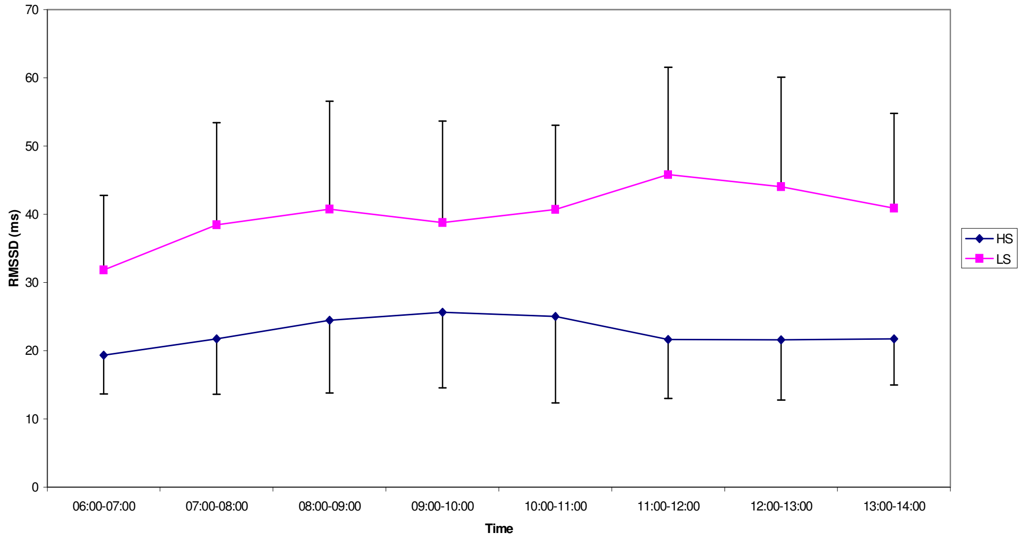

Figure 3.12: Mean RMSSD for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

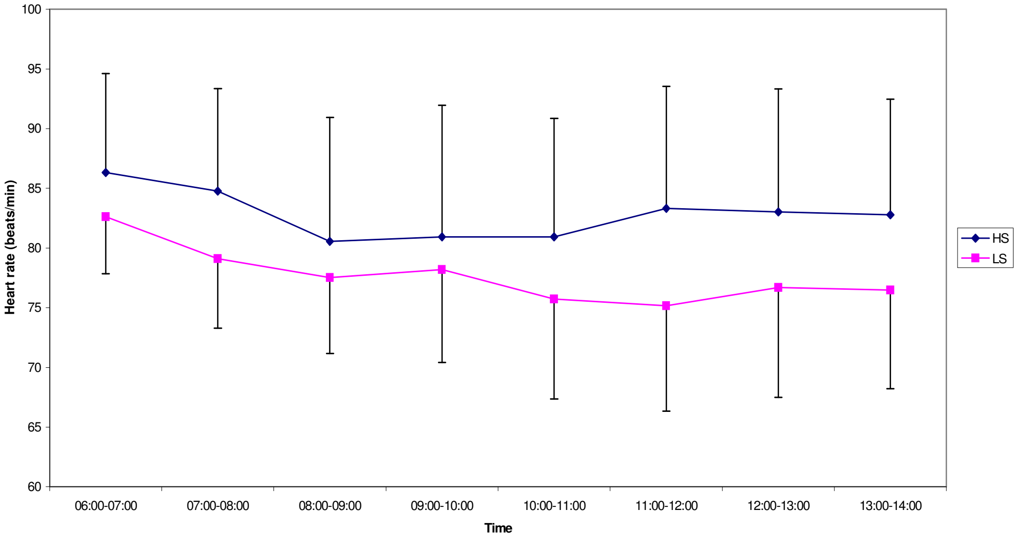

Figure 3.13: Mean heart rate (Minimitter) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

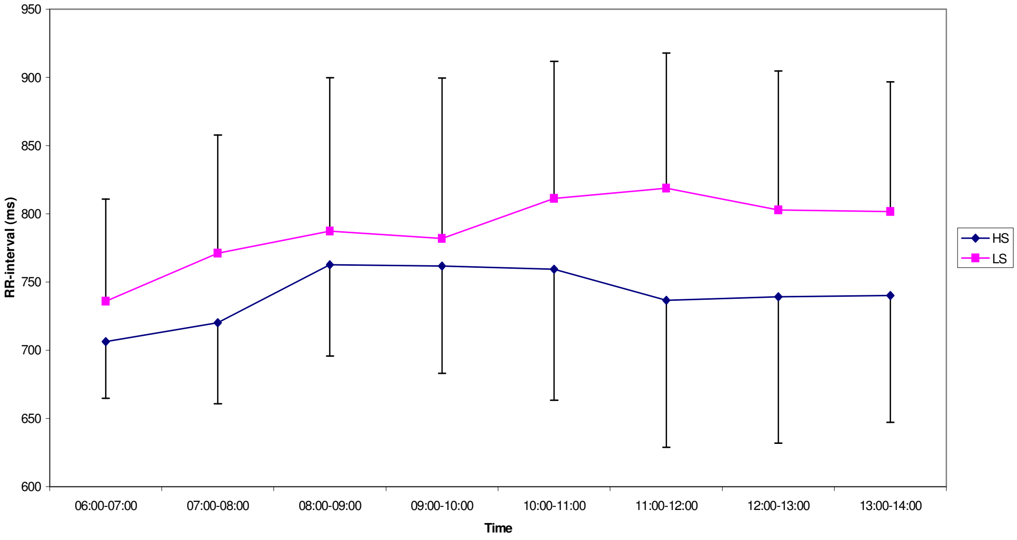

Figure 3.14: Mean RR-interval for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

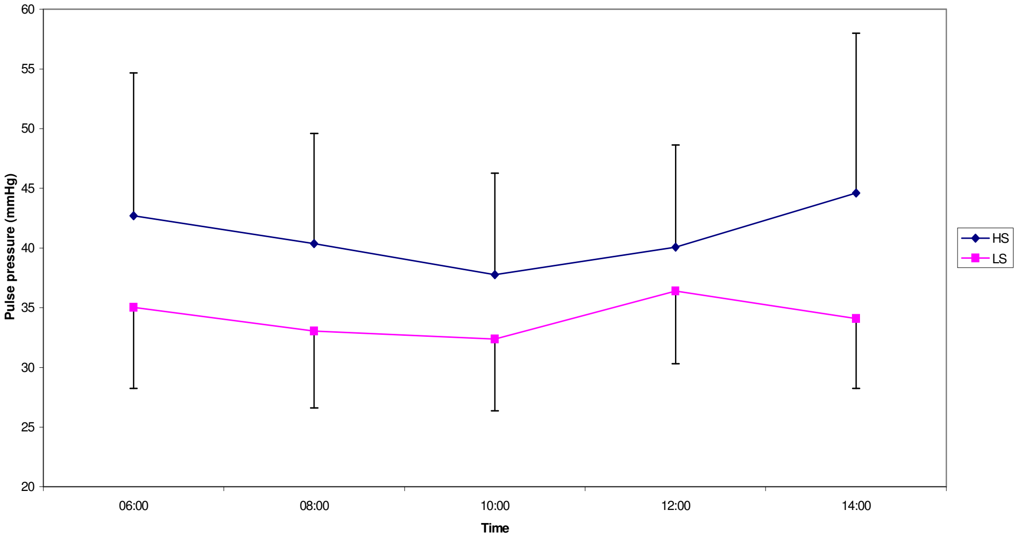

Figure 3.15: Mean pulse pressure for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

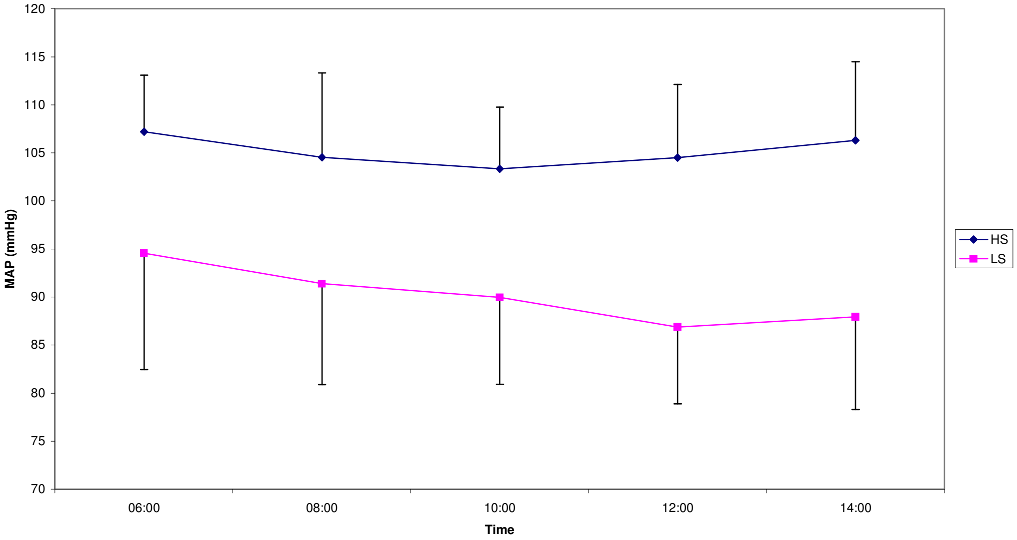

Figure 3.16: Mean arterial pulse pressure (MAP) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

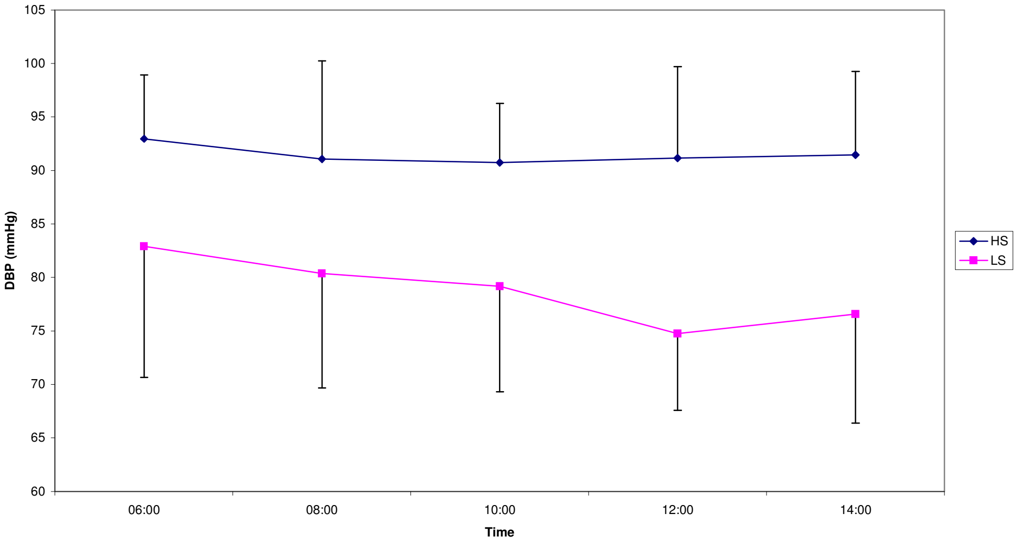

Figure 3.17: Mean diastolic blood pressure (DBP) total number of authorizations for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

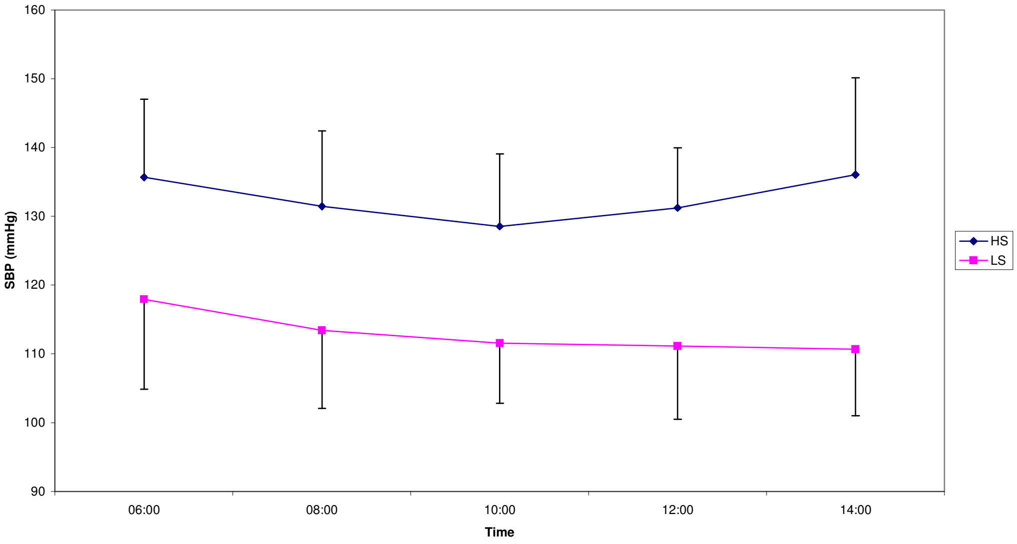

Figure 3.18: Mean systolic blood pressure (SBP) for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

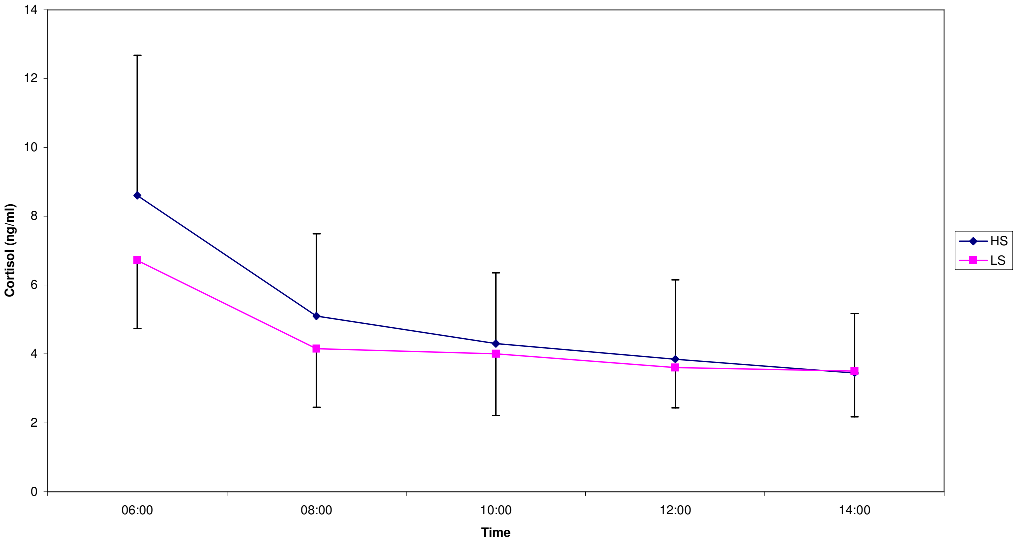

Figure 3.19: Mean cortisol for TCOs designated to fall into the high (HS) or low (LS) stress group according to the Allostatic load index (Model B).

3.4 Integration of MWL-index (Model 2) and Combinations of Experimental Test Parameters and Online Time Analysis

Table 4.1 shows a comparison between the values of the six work stations with the highest and that of the six lowest MWL-indices where the experimental means for the individuals at the six low and six high workstations are calculated form the experimental values over the total work shift.

The evaluation of Models 1 and 2 against combinations of physiological stress parameters (allostatic factors) and against online perception of observer can be seen in Table 2.

Table 4.1: Selection of the six highest and six lowest tables according to the MWL-index (Model 2). Means represent values of subjects grouped into high and low stress groups according to the Physiological Allostatic load index. Values represent means over a six hour period (08:00 – 14:00).

Variable	HS	LS	p value
Age	43.2 ± 5.4	39.1 ± 11.6	0.4893
Mass	106.6 ± 31.5	78.2 ± 19.9	0.0832
Height	1.7 ± 0.1	1.7 ± 0.1	0.8032
Body mass index	35.6 ± 8.3	26.5 ± 3.8	0.0689
Surface area	2.27 ± 0.39	1.93 ± 0.32	0.1317
Cohens	22.6 ± 7.5	16.9 ± 6.7	0.1923
Diastolic blood pressure	95.9 ± 1.7	78.2 ± 6.4	0.0002
Systolic blood pressure	134.6 ± 3.3	112.0 ± 9.6	0.0015
Mean arterial pressure	108.8 ± 1.0	89.4 ± 7.4	0.0004
Pulse pressure	38.7 ± 4.6	33.8 ± 3.8	0.0843
Heart rate (blood pressure monitor)	76.5 ± 3.8	68.6 ± 5.6	0.0357
Cortisol	4.1 ± 1.7	4.0 ± 1.3	0.9270
Heart rate (MiniMitter)	85.3 ± 6.6	80.6 ± 5.0	0.1908
SD of heart rate	4.6 ± 1.1	5.6 ± 1.1	0.1482
RR	714.0 ± 56.5	755.1 ± 49.4	0.2093
SD of RR	33.0 ± 9.4	45.4 ± 10.5	0.0622
RMSSD	21.9 ± 10.6	37.8 ± 10.0	0.0247
SD1	15.7 ± 7.6	27.0 ± 7.1	0.0246
SD2	81.5 ± 26.4	94.6 ± 15.1	0.2987
LF	426.4 ± 188.3	688.9 ± 329.7	0.1427
HF	95.3 ± 82.8	286.6 ± 204.4	0.0544
Ratio (LF/HF)	6.0 ± 2.8	2.7 ± 1.0	0.0597
Total power	521.7 ± 253.7	975.5 ± 510.6	0.0995
Smoking	0.4 ± 0.5	0.6 ± 0.5	0.5995
Length of previous shift	10.4 ± 2.2	10.6 ± 1.8	0.8850
Length of test shift	11.2 ± 1.8	10.6 ± 1.8	0.5648
Years experience at particular station	4.9 ± 4.6	7.4 ± 8.8	0.5840
Shift preference	1.2 ± 0.8	1.0 ± 1.0	0.7234
Radio communications	163.8 ± 100.5	92.3 ± 72.7	0.1811
Telephone communications	50.4 ± 27.2	32.1 ± 20.8	0.2158
Scheduling	58.4 ± 36.4	39.3 ± 33.3	0.3672
Number of Trains	28.0 ± 31.5	15.0 ± 12.9	0.4228
Number of Authorisations	14.8 ± 10.2	16.6 ± 14.3	0.8185

Table 4.2: Evaluation of MWL-index (Model 2) against physiological stress indicators and against online stress perceptions of observer with observer blind to MWL-index classification.

Id	Place	MWL index (Model 2)	Spoornet expert rating	Observer rating	Allostatic index			Agreement				Remarks	Contribution to increased stress	Medication
					BMI, cortisol, sys, dia, hr, lf (A)	BMI, cortisol, sys, dia, hr (B)	cortisol, sys, dia, hr (C)	Observer	Model A	Model B	Model C			
1	[redacted]	Low	Medium	High	Low	Low	Low		1	1	1	Confident, Experience, take no nonsence	Attitude of drivers, radio communication	None
2	[redacted]	Low	Low	Low	Low	Low	Low	1	1	1	1	Nothing to do at all, quiet place	Radio communication	None
3	[redacted]	Low	Low	Low	Low	Low	Low	1	1	1	1	Joked with colleagues, Pleasant atmosphere	Radio communication	None
4	[redacted]	Low	Low	Low	High	High	High	1				Lost temper during shift, highly strung		None
5	[redacted]	High	High	High	High	High	Low	1	1	1		Etopic beats HRV data bad	RIMAS, train problems	None
6	[redacted]	Low	Medium	Low	Low	Low	Low	1	1	1	1	Apprehensive worried about outcome of test		None
7	[redacted]	Low	Low	Low	High	High	High	1				Power failure, Top management NOSA present		None
8	[redacted]	Low	High	Low	High	High	High	1				Cool cat, Open minded / no hang-ups		None
9	[redacted]	High	High	High	High	High	Low	1	1	1		Stop testing at 10 o'clock	Attitude of drivers	None
10	[redacted]	High	Medium	Low	Low	Low	Low						Radio communication	None
11	[redacted]	High	High	High	High	High*	High*	1	1	1	1		Drives all want to talk simultaneously	Blood pressure medication
12	[redacted]	High	Low	High	High	High	High	1	1	1	1	Busy	Drives all want to talk simultaneously, drivers don't wait	Asthma pump
13	[redacted]	Low	Low	Low	High	Low	Low	1		1	1	Chat a lot, no real work relaxed atmosphere	Experience of the people he works with	None
14	[redacted]	High	High	High	High	High	High	1	1	1	1	Fell asleep, relaxed, cool customer	Drivers not co-operative, locomotives to old - when they break the hold up everything	None
15	[redacted]	Low	Low	Low	High	High	Low	1			1	Dubble by pass (1999) high blood pressure medication		Blood pressure medication
16	[redacted]	Low	Low	Low	High	Low	Low	1		1	1	Quiet	Drivers are in a hurry and want authorisations straight away	Blood pressure medication, rheumatism
17	[redacted]	High	Low	High	Low	Low	Low	1				CTC doing TCO work	Broken locomotives, accidents, and radio communication	None
18	[redacted]	High	Low	High	High	High	High	1	1	1	1	Nervous, highly strung, on the edge	Number or trains and work teams, broken locomotives, occupations on line	Blood pressure medication
19	[redacted]	High	High	High	Low	Low	Low	1				Lady, low blood pressure, after 7 very busy, sort out business with section manager	Drivers who don't communicate properly	None
20	[redacted]	High	High	High	Low	Low	Low	1				Lady, low blood pressure, Dolly visited	Radio communication	None
	Low	10		10	8	10	13							
	High	10		10	12	10	7							
	Accuracy (%)							90	50	60	55			

Table 4.3: Pearson correlation of MWL-index (Model 2) with time line analysis variables

Variable	MWL-index (Model 2)	
	r	P
Trains + Authorisations	0.7986	0.0001
Telephone + Radio + Scheduling	0.9110	0.0001
Trains	0.6401	0.0024
Authorisations	0.7286	0.0003
Telephone	0.6306	0.0029
Radio	0.8813	0.0001
Scheduling	0.8342	0.0001

4. DISCUSSION

The brief for this project was to investigate whether the MWL-index, developed by Spoornet, is supported by the values of physiological stress indicators. This was done in terms of changes over the work shifts and in terms of indicators of physiological wear and tear (allostatic load) as a result of long-term exposure to high workloads.

The mental workload index, as developed by Spoornet, consisted of three weighted task factors and eleven weighted moderators. The moderators were factors that carry certain weights (as percentages) as previously decided by a panel of user experts. Tasks factors of the MWL-index were a) the number of data transactions captured by the TCO (weight = 1), b) the number of authorisations (weight = 15) and the number of radio and telephone communications (weight = 5). The moderating factors included a) shift type (shifted work weight = 12%), b) experience as a TCO on the particular system (experience in years on RTO/TWS = 18%), c) planning complexity (interface complexity = 5%, running times between crossing places = 7%, types of crossing places = 5%, location of platforms = 3%, authorisations per shift versus number of crossing places = 10%, d) inherent difficulty (type/mix of trains = 7%, presence of locomotive depots = 9%, presence of shunting yards/activities = 14%, topography = 4%).

In evaluating the MWL-index (Model 1) it became clear that the subdivisions into low and high workload stations, as indicated by this model (Model 1), could not summarily be used as received. The calculations, and therefore the classification of workstations, were based on historical data not reflecting the present workloads at the different venues. A revised classification into work intensity venues was subsequently compiled based on real time data. When comparing the historical classification (based on Model 1), to the real time classification (based on Model 2) there was a difference in the spreading of the various venues over the work intensity spectrum, i.e., the subdivision into high and low centres (Table 2.2). The next step was to compare the subdivisions of workstations as done by the MWL-index to the subdivisions based on stress levels and reactivity in the individuals working at the various stations. In the introduction a background to the rational for measuring the specific stress indicators in individuals was given and it will therefore not be discussed at this point. The mean experimental (physiological) values over the work shifts for sub groupings according to Model 2 were compared (see Table 2.3) to see whether physiological differences could be found between individuals grouped into high and low MWL-indices. The parameters which were included in this comparison comprised factors which could either reflect the stress reactivity in individuals, or the wear and tear as a result of chronic exposure to stressors, or factors that could influence the afore mentioned two types of indicators. Comparisons were made for age, mass, height, body mass index (BMI), surface area (SA), systolic blood pressure, diastolic blood pressure, mean arterial pressure, pulse pressure, heart rate variability variables, smoking or not, length of previous shift, length of test shift, number of years experience a particular station, shift preferences and time line analyses of the shifts when the physiological recordings were made. Very few parameters showed any significant difference between the high and low stress groups. In fact, only the time line analysis, which is anyhow built into the MWL-index, showed, as would be expected, statistical differences between the high and low workload groups throughout (radio communications p = 0.0003; telephone communications p = 0.0276; scheduling p = 0.0001; number of trains p = 0.0105; number of authorisations p = 0.0002). The influence of the duration of previous shifts differed significantly (p = 0.0487) between the two stress groups with longer duration of the previous shifts correlating with the higher stress group. In short, the values of the physiological stress parameters did not mirror the MWL-index model. To see whether exposure to high workloads caused higher expectation stress in workers, the arrival values (before the workload could have had any effect) between the two groups were compared for those parameters measured at arrival. No significant difference could again be found between high and low stress groups (Table 2.4).

In order to sharpen the division between high and low workloads, as calculated by the MWL-index (Model 2), the values of only those individuals at the six highest and six lowest ranked workload stations were compared. These results were seen in Table 2.5. The statistical analyses of this data once again showed that physiological stress values did not mirror the activity intensity as described by the MWL-index. Very significant correlations were again seen between time line analyses and experimental values. These correlations between the time line analysis factors and the early morning value was most probably only a reflection of the fact that time line analyses were built into the MWL-index. It nevertheless confirmed the fact that the MWL-index gives a good reflection of activities at the specific workstations.

The next step was to look at the reactivity over the duration of shifts. When the high and low MWL-index groups, according to MWL-index Model 2, were compared in terms of the way they physiologically reacted to the workload over the total work shifts, hardly any correlations were seen between the workload and reactivity. The results of these repeated measure evaluation between the two groups, change over working time for the whole group, and the group time interaction for the physiological parameters and the time line analysis variables were seen in Table 2.6. Many factors probably contributed to the fact that the results of the MWL-index were not mirrored by the stress levels of the workers. The most likely contributing factors are probably background differences such as age, health status, years of experience and gender. This was discussed under 1.4.4. of the introduction. The populations at the various stations differed significantly with regard to such aspects, and with the experimental group size of this project, such differences could nullify any significant differences. An additional confounding factor is the fact that only three of the twenty workers were female. As discussed in the introduction there are indications that females are perhaps more stress responsive than males. This, however, is contradictory as there are certain factors that protect females against the negative effects of high stress system activation. In this work the females had lower stress levels but were also younger than the average TCO – a fact that could very well underlie their low allostatic loads.

There are several other reasons why workloads of stations would not necessarily be reflected by the physiological values of workers and by changes in response to workload at the specific stations. In the introduction, under adrenal medulla (1.3.3), it was discussed how habituation to known stressors may occur with repeated exposure to the same stressor and how TCOs may therefore adjust to high work loads if subjected to it over extended periods of time. It is only when novel stressors such as dramatic changes to the normal routine, are introduced into the work environment that sensitisation and the effect of high allostatic loads with subsequent influences on their skills, as well as their mental and physical health might be noticed. It speaks for itself that changes in infrastructure and policies may resort under such novel environmental stressors. A similar phenomenon was also discussed in the introduction under HPA-axis (1.3.4 and 1.4.3). To quote “although acute stress can cause an increase in the basal-to-peak difference of cortisol the amplitude of the rhythm decreases in conditions of chronic stress as a result of the increase in baseline levels. As in the case of the SAM-axis, bouts of heterotypic acute stressor application during periods of chronic stress alter the response. It would seem that acute stress superimposed on chronic stress is dependent on the familiarity with the type of stressor. As in the case of the SAM-axis, it appears that the response to an acute stressor in the chronically stressed would be less than expected if the stressor is homotypic (a repetition of what caused the chronic stress response). In contrast, if a heterotypic stressor is applied to a chronically stressed individual, the response would be bigger. It is however possible that cross-tolerance to stressors may develop – especially stressors that involve the same neurological pathways. This once again can in theory be extrapolated to the working situation where high cortisol levels would then not be as significantly increased by increased levels of homeotypic stressors such as increases in the amount of work to which the individual is accustomed. In contrast, the response can be exacerbated when stressors other than the typical work stressors to which the individual is accustomed to are encountered. The implication that can be deduced from the previously mentioned fact (i.e., that the amplitude of the stressor-induced increase in cortisol levels, as well as the circadian amplitude difference to additional homeotypic stressors may be lower during chronic high stress) would be that those individuals with chronic high cortisol levels will not show the expected increase from basal trough values when stress levels increase and that this could be ascribed to the fact that the trough values are higher than normal”. To extrapolate this to the TCOs, one could expect that habituation to their respective workloads could rule out the development of significant stress differences between the different work intensity groups and that the magnitude of the stress reactions from baselines to stimulated responses could be negated by above normal baseline values. The latter part of the last statement would apply to stressor-induced changes over shifts.

The next step was to identify high and low stress groups on the grounds of physiological variables. After the comparison between the values of the Spoornet index of workloads at the various stations on the one hand, and the physiological indicators of stress in the workers at the different stations/tables on the other, the possibility of separating the workers at the different stations into high and low stress groups on grounds of the values of their physiological parameters was investigated. The analyses, as previously mentioned, were performed in terms of an adapted allostatic load measurement where the data used in the calculation of the numerical value for each individual factor or parameter of the allostatic load were derived from the mean of the values obtained over the work shift. The reason for this was that baseline values in this group could not really be seen as baseline as all of them appeared to arrive with values higher than any reached during the experimental procedure. Many factors could have contributed to this type of observation, not least of all the fact that the arrival time coincided with a steeper part of the circadian rhythm of factors such as cortisol, while subsequent measurements were performed at times when the circadian values were already lower. Expectation or anticipation of the work stress before initiation of the work shift could further have contributed. Anticipation as a stressor and the orienting reflex were discussed in the introduction under 1.6.2 and 1.6.3. In addition, it is known that individuals in high stress jobs seldom recover to baseline value over the time off. This has been shown by various studies such as that of Steptoe, et al 1999, (32). In the study on job strain of Steptoe et al, blood pressure, heart rate and electrodermal responses were determined to externally paced (uncontrollable) and self-paced (controllable) tasks. The results of the above study showed that blood pressure reactions to uncontrollable tasks were greater in high than low job-strain groups, but the same differences were not seen with controllable tasks. Systolic and diastolic pressures did not differ between their groups over the day but decreased more over the evening with low job strain. The authors concluded, and rightfully so, that the failure of high strain job subjects to reduce their blood pressure over the evening may be a manifestation of high allostatic loads. There can be no doubt that the stressors in the case of TCOs should be considered uncontrollable as the number of trains and other activities required are predetermined by the job at hand and is not under their own control. The fact that the stressor, in this case, is not a once off stressor but that TCOs exist with these levels of stress axes activity for the major part of every day supports the decision to use the mean value over the work shift.

As previously mentioned, in the process of subdividing workers at various stations/tables into high and low stress groups, based on physiological values, the values of the following parameters were included: salivary cortisol and BMI as indices of hypothalamo-pituitary-adrenocortical axis activity, systolic and diastolic pressure as measure, of cardiovascular activity – largely reflecting sympatho-adrenomedullary axis activation, heart rate as an indicator of sympatho-adrenomedullary activation and heart rate variability variables as indicators of autonomic activity. The values of each individual for each of the 5 indicators were classified according to the 50^{th} percentile. Allostatic load was then calculated by summing up the number of parameters for which the subjects fell into the highest risk, i.e., above the 50 percentile. Subjects were subsequently ranked according to their total hits, as previously discussed. Three models, Model A (including the values of cortisol, systolic blood pressure, diastolic blood pressure, heart rate, low frequency and BMI), Model B (cortisol, systolic, diastolic, heart rate and BMI) and Model C (cortisol systolic, diastolic and heart rate) were developed and tested and the TCOs subdivided into high or low stress groups. When the TCOs were subdivided into high and low stress groups and the differences for all physiological parameters (not only those included in the three models, respectively were tested for significant differences between the groups of individuals subdivided into high and into low according to Model A, B and C, it was seen that Model B was superior to Model A and C. This was supported by the fact that for Model A 10 out of 17, for Model C 8 out of 17, and for Model B 12 out of 17, physiological variables differed significantly ($p < 0.05$) between the high stress groups and low stress groups (two sample T-test). The significances were further generally higher for Model B than for the other 2. Model B also divided the 20 TCOs directly into a 50-50 split. The superiority of model B was also borne out by the results of the Two-way AOV where heart rate variability variables confirmed significant differences between the two stress groups in terms of statistical, frequency domain and geometric methods of analyses (total power, low frequency power, root means square of successive differences, standard deviation of RR, standard deviation of HR, etc).

In the final analysis, subdivisions of workstations on the basis of the MWL-index, were compared to subdivisions of the individuals at those stations, and to online perceptions of the observer about the stressor value of the workstation. A 90% agreement was seen between the MWL-index and online observer perception (this was subjective perception and not based on the sum of the activity as determined by time line analyses) and a 60% agreement between the subdivisions into high and low stations by MWL-index on the one hand, and subdivisions based on Model B on the other.

Time line analysis is built into the MWL-index and one would therefore expect to find some kind of correlation between time line analysis and MWL-index. In an attempt to investigate the strength of the correlation and to see whether the MWL-index has a significant advantage over simple time line analysis, correlations was tested between the MWL-index on the one hand and the individual factors in time line analysis, as well as two combinations of time line analysis factors (Table 4.3). The correlations between the MWL-index and the two combinations of factors were $r = 0.7986$; $p = 0.0001$ (trains and authorizations) and $r = 0.9110$; $p = 0.0001$ (radio, telephone, schedules) and all individuals factors also showed significant correlations. It would therefore appear that the time line analysis very much gives the same information as that derived from calculating the model.

5. SUMMARY

The original subdivisions of stations into high and low workload, was based on historical data (Model 1). A revised MWL index (Model 2) was created to incorporate real time data (time line analysis) recorded during physiological testing. In using the revised MWL-index it was shown that it is imperative to incorporate results of the latest time line analysis, and not historical data, in the estimation of the workload at the various stations. The workloads, at the various stations, as predicted by the MWL-index (Model 2), were not reflected by either the adapted allostatic load (including all measured parameters of the individuals working at those stations), or by changes in stress levels over work shifts. However, in developing three models, consisting of different combinations of allostatic load indicators, there was a 60% correspondence between subdividing workstations into low and high workloads according to the MWL-index, and subdivision of workers at the corresponding stations into high and low stress according to Model B. Model B was based on the means of the values taken over the shift for cortisol, systolic pressure, diastolic pressure, heart rate and BMI. It can thus be said that the combination of physiological parameters used in Model B supports the validity of the MWL-index as indicator of work stress at the various stations. In the final analysis it is necessary to ask whether either the development of a Mental Workload Index or the use of physiological parameters of the workers at the various stations gave significantly better estimates of the stress levels at the stations than the mere use of simple time line analysis. At this stage the answer will have to be in the negative. Although the MWL-index is a good reflection of the activities at the stations, and Model B supports the use of the index, neither would appear to have an advantage over simple time line analysis over the work shift. Another question, in view of the high correspondence between the MWL-index and subjective perception by an observer, is whether the workload cannot simply be estimated through observance without either time line analysis, physiological measurements or calculation of the MWL-index. Once again the answer should be in the negative as it could, depending on the observer, change with the ability and commitment of the observer as well as her or his objectivity.

6. CONCLUSIONS AND FINAL REMARKS

- The MWL-index as received from Spoornet (Model 1) used historical data (2003) instead of real time data. The model was corrected for real time data and the corrected version (Model 2) thereafter used as the MWL-index.
- The total spectrum of physiological stress indicators did not support the workload as predicted by the corrected MWL-index. However a combination of physiological stress indicators (referred to as Model B) did support (60% correspondence) the classification into high and low workstations as predicted by the MWL-index.
- Although the MWL index (Model 2) gave a relatively good reflection of the activities at the stations, and the allostatic load index (Model B) supports the use of the MWL index, neither appears to have an advantage over simple time line analysis over the shift.
- Factors such as habituation and sensitisation influence physiological responses to work stress and could have attenuated the correlations between the workloads and the physiological responses. Habituation (decrease physiological responses to work stress) may be disturbed by marked changes in the work environment or company policies and may once again lead to overt stress responses in the face of high workloads.

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