How about work demands, recovery, and health? A neuroendocrine field study during and after work
Sluiter, J.K.

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Chapter 1

General Introduction

“Quod caret alterna requie, durabile non est”

(Ovidius, Heroides 4.89)

(Whatever does not recover regularly, will not last)
1 Introduction and motives of this thesis

When children get tired, they generally will stop their activities, lie down, and get some sleep. When children become out of breath while running, they automatically will slow down their speed for a time, or stop.

Thus, in ‘pre-working’ life, people behave ‘automatically’ in ways that get their body and mind ‘back in balance’ and allow them to recover from previously performed exertions. During leisure time, adults show the same behaviours, but what happens to these behaviours during working life? Are work demands and characteristics organised in such a way that actions to meet the workers’ needs to recover are possible and/or accepted? For most people, the time spent in the work place is a major part of their lives. The benefits of the new technologies developed over the last decades are well recognised in terms of increased productivity and reduction of physically hazardous jobs, but the negative side effects of automation and computerisation on both physical and mental health have received less attention (Frankenhaeuser 1994). In the workplace new computer technologies have led to increasing duration of static work postures and mentally demanding tasks in many white-collar jobs. In addition to these effects, productivity demands and work tempos have increased because of the competitiveness between companies, organisational adjustments, and savings in terms of redundancies in many branches. These factors may help explain the rise in occupationally induced mental overload and musculoskeletal problems in many (western) countries. During the last years, almost eighty percent of society’s total costs of work absence and disablement insurance benefits were spent on work-related psychological and musculoskeletal disorders in the Netherlands (Koningsveld & Mossink 1997). Psychological diagnoses alone accounted for one-third of work disability (CBS 1998), and one-third of all workers often report time pressure when performing the job (SCP 1998).

Different terminology is used in the literature to describe the stimuli that are responsible for the ‘stress’ responses they induce. Following Selye (1956), many used the term ‘stressor’ for the stimulus. Ursin & Knardahl (1985) preferred the term ‘load’ for the stimuli producing the stress response, which they referred to as activation. Following Ettema (1973), Frankenhaeuser (1991), Meijman (1993), and Melin & Lundberg (1997), this thesis uses the term ‘demands’ to describe the external stimuli workers are exposed to because of the possibly prejudiced representation of a stimulus showing only negative effects that ‘load’ might give. The term ‘reactivity’ is used to refer to the response.
The possible effects on health caused by the general increase in psychological demands through the aforementioned developments in technology over the last years, is not in correspondence with differences found on job level in the prevalence of psychological overload and burnout. The main demands that work-related tasks and activities put upon people can still be categorised as mental, physical, or a combination of mental and physical demands. Examples of mental demands are found in tasks requiring focused and sustained attention, decision making, and other cognitive processes. Physical demands are found in tasks that put static and/or dynamic biomechanical loads on the body or where, energetically spoken, a high percentage of the maximal oxygen uptake is asked for during longer periods. People are 'tailored' to perform both kinds of tasks, but questions arise as to how long, under what circumstances, and to what extent workers are able to perform these exertions without excessive 'wear and tear' to their bodily systems. Recovery and, therefore, the work-rest ratio or work-leisure relationship could have enormous influence in determining the way people are able to unwind after stressful encounters and activities during work (Meijman & Mulders 1994). Repeated incomplete neuroendocrine recovery from work is thought to be one of the reasons for the development of somatic complaints (Knardahl & Ursin 1985, Meijman et al. 1990). In this thesis, therefore, the main emphasis will be laid on the neuroendocrine reactivity and recovery of adrenaline, noradrenaline, and cortisol during and after work. The three main demands that can be asked for in a job will be referred to as the 'nature of work'. In Figure 1, the assumed relationship is modelled. The work demands and psychosocial work characteristics (i.e., job demands, job control, social demands) a worker is exposed to may lead to short-term effects after the working day. The after-effects of work may be experienced as feelings of physical or mental fatigue, changes in mood, or other short-term complaints. These feelings might occur because (neuro) physiological processes need time to re-balance from work-related exertions. If the duration of these short-term after-effects from work are relatively long in comparison to the work-leisure relationship and occur repetitively, the short-term effects are cumulating and long-term health effects may develop.
“Fatigue” is seen as short-term effect of a working day and, regarding the assumed relationship in figure 1, as an early indicator of mental and physical overload. Fatigue can be expressed in many ways. In this thesis, the concept from the neurophysiological arousal or activation theory as explained by Ursin (1978, 1998) is used to approach, at least in part, the phenomenon of work-related fatigue. Following Ursin’s (1978, 1980, 1993, 1998) explanation, activation theory postulates that activity is the normal physiological response to environmental changes and a part of normal physiology necessary to cope with the environment. To be precise, activation is needed in situations where there is a difference between the set value of a homeostatic variable and the value of that variable which is needed to be able to cope with the situation. Activation will persist until the balance between the two is re-established. If the environment changes repeatedly back and forth, and over time, as could be the case in the work environment, a person’s psychophysiological state changes during and after performance of tasks because mobilisation or continuation of activity is needed to keep up with the situational demands. This will result in psychophysiological costs (Meijman 1991). The mobilisation and continuation of activation can be measured by psychoneuroendocrine techniques during studies of occupational stress. Scandinavian researchers pioneered this kind of research, but several studies of the same kind were performed in The Netherlands as well (Mulders et al. 1982, Meijman 1992 & 1993, Van der Beek 1994). The Scandinavian approach to occupational research in which peripheral neuroendocrine parameters were related to work demands and health outcomes were taken as the starting point for the methods used in this thesis.

Figure 1. The assumed relationship between work demands and work characteristics, short-term effects of a working day in terms of (need for) recovery, and long-term health effects.
An extension of the hypothesis on the cause of work-related psychological overload can be found in the explanation of sustained activation (Knardahl & Ursin 1985). When a person is exposed repeatedly to mild stressors in the workplace without intermittent recovery, a vicious circle might develop in which the homeostatic setpoints of the hormones adrenaline and cortisol change to accommodate the environmental demands, implicating an increase of baseline levels. The non-optimal psychophysiological balance that develops will get worse over time, and the acute occupationally induced fatigue might eventually develop into chronic fatigue (Ursin et al. 1978). In studying patients with chronic fatigue syndrome, contemporary clinical research efforts have documented neuroendocrine disturbances (Demitrack 1997). An analogous hypothesis concerns the development of musculoskeletal disorders (Lundberg 1996).

In this thesis, it is questioned whether workers performing the three different natures of work will recover from neuroendocrine reactivity in the same way, and this might elucidate the relation between the left and middle boxes of Figure 1. From an evolutionary point of view, the neuroendocrine preparatory bodily reactions to stressful situations were aimed mainly at physical reactions. According to Walter B. Cannon (1914), the fight-or-flight response, induced by a perceived threat to control, activates the defence reaction of the sympathetic-adrenal-medullary-system. This causes mobilisation of energy from glucose and fat into the blood circulation, and this is directed towards the muscles in order to prepare the organism for physical activity (Cannon 1914). Although new technologies in the workplace generally have reduced the physical activities of workers, as stated before, stressful situations in the workplace increasingly occur. Therefore, in the light of aforementioned hypothesis regarding the cause of occupationally induced (psycho) somatic complaints, it can also be questioned whether workers showing more (need for) recovery develop more health problems. This question might further elucidate the relation between the middle and right boxes of Figure 1.

2 Objectives of this thesis

The main questions of this thesis are:

1. To what extent are the nature of work (mental, physical, or combined mental/physical demands) and psychosocial work characteristics related to neuroendocrine reactivity and recovery from work?
It is hypothesised that, irrespective of levels in psychosocial work characteristics, a difference exists between the three groups in the levels of neuroendocrine reactivity as well as in recovery from work measured by adrenaline, noradrenaline, and cortisol. A second hypothesis, concerning the psychosocial work characteristics, is that it is expected for job demands to be related to adrenaline reactivity and recovery, while job control is expected to be related to cortisol reactivity and recovery.

2. To what extent is recovery in adrenaline and cortisol related to the workers’ need for recovery and experienced health complaints?

It is hypothesised that, irrespective of level of psychosocial work characteristics, both high neuroendocrine reactivity and incomplete recovery are related to subjective needs for recovery and health complaints. A second hypothesis is that the baseline levels of both adrenaline and cortisol are related to the level of health complaints.

To fulfil these objectives, the two systems of interest where the three hormones originate from are described more extensively at the end of this chapter, and the literature is reviewed to identify what is known about neuroendocrine reactivity and recovery in relation to different work demands. Subsequently, studies in the natural work environment are described. At first, a pilot study was performed to evaluate the chosen method. Following this, three groups of workers (n=60) with different natures of the work were studied in their natural work environment.

3 Outline of the contents

In the remaining part of this chapter, a description of the sympathetic adrenomedullary system and the hypothalamus pituitary adrenocortical system is presented.

Chapter 2 presents a systematic literature review of neuroendocrine studies that measured recovery from different task demands. The occupational and sport studies included in the review (2.1) are ordered by means of a conceptual ‘recovery classification’. This is followed by the protocol for the measurement of adrenaline, noradrenaline, and cortisol used in this thesis (2.2).
For additional insight into the relation between the hormones of the two aforementioned systems, Chapter 3 tests a hypothesis on the possible forward facilitating influence of the HPA system to the SAM system with data from a field study among garbage collectors.

Chapter 4 presents outcomes of a pilot study performed among coach drivers in their natural work environment. In the first part of the chapter (4.1), results of a study on work stress and recovery measured by urinary catecholamines and cortisol in ten long distance coach drivers are presented, providing more insight into the relationship given in the first main question. In the second part of the chapter (4.2), cross-sectional questionnaire data (n=363) are used to evaluate the relationship between subjective indices of need for recovery and health complaints, addressing part of the second main question of this thesis.

In Chapter 5, data from the studies in the natural work environment are presented to address the aforementioned objectives of this thesis. In 5.1, Multi-level analyses are carried out on neuroendocrine reactivity and recovery data of three groups of workers (n=60), differing in the nature of their work. The demands put upon the first group of workers can be labelled as mainly mental, the demands of the second group as mainly physical, and the third group deals with a combination of mental and physical demands. The mental group consisted of (middle) management and supervisors from a flower auction and work foremen from a construction company. The physical group included manual flower transport workers from a flower auction, construction workers, and garbage collectors. The combined mental/physical group included male nurses and drivers working for a municipal ambulance service. Results show the relationship between neuroendocrine reactivity during and recovery from work, nature of work, and work characteristics. The answer to the first main question is formulated in this part. In 5.2, the relationship between neuroendocrine recovery and subjective need for recovery and health complaints is assessed, further addressing the second main question.

Chapter 6 is the epilogue, which presents a general discussion, proposes a cumulative process model and the conclusions of this thesis. Finally, in Chapter 7, recommendations for future research, policy, and work organisations are presented.
4 The sympathetic adrenomedullary system (SAM) and the hypothalamus pituitary adrenocortical system (HPA)

The catecholamines adrenaline and noradrenaline and the adrenal-cortical hormone cortisol are cornerstones in stress research (Frankenhaeuser 1994). Interest in the SAM system (adrenaline and noradrenaline) has its roots in research conducted by Walter B. Cannon (1914) on the emergency function of the adrenal medulla. The HPA system (cortisol) was a central part of Selye's theories on stress and the general adaptation syndrome (Lundberg 1996). This part of the chapter provides some background information on the SAM and HPA system and a summary of the synthesis of the catecholamines and cortisol. All three hormones will be assessed in the studies of this thesis and differences in rhythmicity between the catecholamines and cortisol exist. Therefore, a summary of what is known about the circadian regulation of both aforementioned systems and the relationship between the two systems is outlined next. A short overview of short-term and long-term physiological, pathological, or behavioural effects related to changes in concentrations of the three hormones is then presented.

Biochemical synthesis of the catecholamines and cortisol

Catecholamine biosynthesis begins with uptake of the amino acid tyrosine into the cytoplasm of sympathetic neurons, adrenomedullary cells, possibly para-aortic enterochromaffin cells, and specific centers in the brain. The two hormones are formed by the following synthesis (Goldstein 1995):

\[
\text{Tyrosine + tyrosinehydroxylase} \rightarrow \text{dopa + dopa decarboxylase} \rightarrow \text{dopamine + dopamine-Beta-hydroxylase} \rightarrow \text{noradrenaline + Phenylethanolamine-N-methyltransferase (PNMT)} \rightarrow \text{adrenaline}
\]

Of interest for this thesis is, that both the catecholamines adrenaline and noradrenaline are peripherally released through the SAM system by the adrenal medulla in a ratio of 3:1. Cortisol is released in the cortex of the adrenal. The synthesis of cortisol from cholesterol takes place after several hydroxylations. Once delivered into the bloodstream, 92% circulates in bounded form, and 8% in free form. Only unbounded cortisol reaches the target tissue and elicits glucocorticoid
effects (Kirschbaum & Hellhammer 1994). The HPA system starts in the hypothalamus that contains nuclei like the Nucleus Para Ventricularis (PVN), the Nucleus Supra Opticus (SON), and the Nucleus Supra Chiasmaticus (SCN). From the PVN, Corticotropin Releasing Hormone (CRH) plays a key role in the response of the HPA system by stimulating the release of Adreno Cortico Tropic Hormone (ACTH) from the anterior pituitary gland. ACTH, in turn, stimulates the adrenal cortex to produce cortisol, the main corticosteroid in humans (Hoogendijk 1998). Recently, it has been shown in rats that cortisol levels additionally could be influenced by direct neural activation from SCN to the adrenal cortex independent of ACTH level (Buijs 1997).

Circadian rhythmicity

The SCN in the hypothalamus shows a circadian pattern of activity and, thereby, regulates most circadian rhythms in many of our bodily functions (Buijs 1996). Both the catecholamines and cortisol exhibit a circadian rhythm, albeit in opposite sinuosity. Akerstedt and Levi (1978) gave an extensive description of both rhythms, and most of the knowledge of the circadian characteristics of catecholamines is derived from urine analysis. Under ordinary environmental conditions, the excretion of adrenaline is characterised by very low values during sleep. In the early afternoon, the peak value is found (a quadrupling of the levels). Noradrenaline excretion is characterised by a less pronounced, but equally shaped circadian rhythm as adrenaline. The plasma and urine levels of cortisol are characterised by a nadir with very low excretion in the early night, which is followed by a steep increase and a sharp peak around 05.00-08.00 h and a subsequent decrease towards the evening/night nadir. Thus, the excretion levels of cortisol begin to rise before waking up and often reach their peak during sleeping as well. This morning rise is mainly endogenous and not due to the process of activation. It has been suggested that the cortisol peak may be a part of an arousal mechanism - an endogenous alarm clock (Akerstedt & Levi 1978). The cortisol rhythm persists throughout many days of sleep deprivation under constant environmental conditions, and it shows a considerable inertia in adjusting to changes in environmental synchronisers, e.g. in connection with shift work or travel across time zones (Akerstedt & Levi 1978).
Relation between the SAM and HPA system

Administration of CRH not only increases plasma levels of ACTH, but also evokes large increases in plasma levels of catecholamines, principally adrenaline (Goldstein 1995). Additionally, increases in adrenomedullary activity, as indicated by plasma adrenaline levels, often correlate more closely with increases in pituitary-adrenocortical activity, as indicated by plasma levels of corticotropin (ACTH), than with increases in sympathoneural activity, as indicated by plasma noradrenaline levels. Glucocorticoids, present at high local concentrations due to the corticomedullary direction of blood flow, regulate adrenal PNMT (=Phenylethanolamine-N-MethylTransferase) activity that is necessary in the conversion from noradrenaline to adrenaline (Goldstein 1995).

Short-term effects

An increase in sympathetic activity is normally reflected by an enhanced outflow of adrenaline and noradrenaline, mainly from the adrenal medulla and nerve endings of the sympathetic nervous system, respectively. The catecholamines directly influence hepatic glucose production via stimulation of both glycogenolysis and gluconeogenesis in the liver (Scheurink et al. 1996). Both plasma levels and urinary excretion of free catecholamines are indicators of sympathetic nervous system activity, with urinary excretion seen as the indicator of total catecholamine metabolism and average sympathetic activity during a day (Wallin 1978). Many effects of adrenaline have been described, including anxiety, increased alertness, and trembling. In addition, an energising effect has been described with a decline in muscular and psychological fatigue. Adrenaline increases the intensity of mental concentration and enhances performance of perceptual-motor tasks, despite adrenaline-induced tremor. In addition, adrenaline enhances emotional experiences. The mechanism of the anti-fatigue effect of adrenaline in preparation of skeletal and cardiac muscle (Albanese 1892, Cannon 1914) is actually poorly understood, and research in the last decades seems to have ignored the phenomenon. One possibility is that adrenaline enhances acetylcholine concentrations at cholinergic receptors on skeletal muscle cells, since adrenaline can inhibit acetylcholinesterase (Goldstein 1995). Elevated noradrenaline concentrations are found mainly in situations where physical exertions are needed, although the effects of emotional stress on elevation in noradrenaline also have been reported. In a comprehensive review on the regulation of energy metabolism in rats during exercise, Scheurink et al. (1996) emphasised the reliability of plasma noradrenaline levels as an index for overall sympathetic activation and as a reflection of the
hormonal functions of noradrenaline. In their experiments, exercise caused a significant increase in plasma catecholamine levels. After surgical adrenomedullation, adrenaline levels were undetectable and a reduction in the exercise-induced increase in noradrenaline plasma concentration was found.

Cortisol affects various bodily functions such as gluconeogenesis. It also has an important role in the body’s immune system and is believed to make the cardiovascular system more sensitive to high catecholamine levels (Lundberg 1984). The insulin-antagonistic and gluconeogenic actions of cortisol favour the interpretation that in times of increased metabolic demands such as stress, cortisol is required for energy mobilisation (e.g. higher blood glucose concentrations) to fuel fight or flight reactions. In an experiment in which blood glucose levels were manipulated to study the impact of glucose levels and caloric load on free cortisol levels in acutely stressed adults, glucose load per se did not affect free cortisol levels, but psychosocial stress induced a large cortisol response in glucose-treated subjects. It was concluded that low glucose levels appear to inhibit adrenocortical responsiveness in healthy subjects. The immediate availability of energy seems to be a prerequisite for significant acute stress responses of the HPA axis (Kirschbaum et al. 1997).

Although activation-demanding situations always immediately induce elevation in the level of circulating adrenaline and somewhat later in the levels of noradrenaline and cortisol, the reactivity patterns of the hormones vary with the positive vs. negative emotional evaluation evoked by the situation (Ursin et al. 1978). When demands are experienced as a positive and manageable challenge, the adrenaline output is typically high, whereas the cortisol production is put to rest. When negative feelings and uncertainty dominate, both cortisol and adrenaline levels increase. The three hormones facilitate both mental and physical adjustment to acute environmental demands. In the short term, a rise in stress hormones is, therefore, often beneficial and seldom a threat to health (Frankenhaeuser 1994). The sensitivity of the SAM system to various psychosocial conditions is documented extensively (Lundberg 1995). Simulated under and overload work situations, stressful situations, and real life studies all revealed significantly elevated adrenaline levels. Reactions in the HPA system are driven primarily by emotion: lack of control/uncertainty, anxiety, novelty, unpleasantness, helplessness, and distress are known circumstances in which cortisol levels are elevated (Lundberg 1995). Hence, psychological stress can increase the activity of the HPA axis. Especially in situations
with high ego-involvement, low predictability, low controllability, and novelty, it
was shown that corticotropin releasing hormone (CRH) and ACTH are released with
subsequent rise in cortisol levels (Kirschbaum & Hellhammer 1994).

In a laboratory experiment, Lundberg (1996) examined the influence of
psychological stress and physical loads on short-term muscular tension and
psychophysiological stress responses. In addition to significant increases in blood
pressure, heart rate, and stress hormone secretion, muscular tension was
significantly increased after a stress test. The combination of stress test and physical
load induced a spillover of muscular tension (Lundberg 1996).

**Long-term effects**

Compared to what is known about the short-term effects of changes in hormone
concentrations, there is little ‘hard evidence’ of long-term effects. In the longer
term, a rise in baseline levels of the hormones may cause damaging effects. Ursin
(1980) postulated a psychosomatic theory in which he stated that sustained
activation in the hormones under attention produce somatic pathology. Sustained
activation after a working day is also called ‘spillover’, and it can be seen as
incomplete recovery. In addition, high reactivity may be a risk in all situations with
chronic sustained activation. Kuiper et al. (1998) showed that incomplete recovery
after a working day was significantly related to self-reported psychosomatic health
complaints in truck drivers. Such spillover was interpreted as an indication for
situational overload (Rissler 1979, Frankenhaeuser 1989). Frequent or long-lasting
elevations of hormone levels in the course of daily life may result in structural
changes in the blood vessels which, in turn, may lead to cardiovascular disease.
There is evidence that damage to the myocardium requires the simultaneous
release of adrenaline and cortisol (Frankenhaeuser 1994).

Ockenfels et al. (1995) mentioned some studies that found associations between
prolonged stressor exposure and elevated baseline levels of cortisol, but also
examples from studies (like prolonged combat exposure), that found associations
with chronically lowered cortisol excretion rates. As further example, they mention
a study of employees reporting a high workload who had lower than normal
morning plasma cortisol levels, and did not have the expected decrease in cortisol
from morning to afternoon (Ockenfels et al. 1995).
There are recent findings indicating that psychological stressors play a role in the development of other major health problems, such as musculoskeletal disorders (Bongers et al. 1993). However, more research is needed to make the link between the short-term effects of psychological stress and muscle tension as was found by Lundberg (1996) to a possible relationship between neuroendocrine reactivity and recovery and chronic musculoskeletal disorders.
References


