
AN INVESTIGATION OF RAIL CREW FATIGUE AND WELL-BEING

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SUMMARY

Occupational fatigue is a severe problem in the rail industry, potentially jeopardising train crew health and train safety. The aim of this thesis was to investigate fatigue, its risk factors, and the associations between fatigue, well-being outcomes, and performance among staff members in the rail industry by conducting a series of studies. It also aimed to develop a usable online fatigue measure to examine fatigue in a real-life setting.

A large-scale questionnaire survey was conducted to examine the prevalence of fatigue, identify the risk factors related to fatigue, and investigate the associations between fatigue and well-being outcomes among railway staff in general. An online experiment was then run to investigate the effects of time of day and workload on fatigue and the association between subjective fatigue and objective performance, with a student sample. Finally, a questionnaire exploring the potential risk factors and greater details for fatigue among railway staff was conducted, followed by a diary study investigating the effects of workload and other risk factors in the prediction of fatigue, and the impact of fatigue on objective performance in work life, with a railway staff sample.

The results of this thesis suggested that job demands, especially mental workload and overtime work were the main predictors of different types of fatigue among train crew, although the risk factors for fatigue appeared to differ between job roles. Job demands, shift-work and other negative work characteristics were shown to increase fatigue, while positive work and individual characteristics were shown to play a buffering role against it. The results also demonstrated that increased subjective fatigue contributed to sub-standard performance and poor well-being. In particular, fatigue was found to mediate the effects of risk factors on well-being outcomes. The study provided empirical support for potential organisational interventions to combat fatigue and improve staff members' well-being.

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DECLARATION

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any degree or other award.

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STATEMENT 1

This thesis is being submitted in partial fulfillment of the requirements for the degree of PhD.

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This thesis is the result of my own independent work/investigation, except where otherwise stated, and the thesis has not been edited by a third party beyond what is permitted by Cardiff University's Policy on the Use of Third Party Editors by Research Degree Students. Other sources are acknowledged by explicit references. The views expressed are my own.

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PEER-REVIEWED PUBLICATIONS RESULTING FROM THIS THESIS

At the time of final submission (4th September, 2018), sections of this PhD thesis had been published in the following peer-reviewed journal articles.

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Fan, J. & Smith, A. P. (2018b). The Mediating Effect of Fatigue on Work-life Balance Positive Well-being in Railway Staff. *Open Journal of Social Sciences*. 6, 1-10. doi: 10.4236/jss.2018.66001

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CHAPTER 1: INTRODUCTION

This chapter is a brief introduction to the thesis which states the main background problem and objectives of the research and outlines why current research is considered useful in managing occupational fatigue.

1.1 THE PROBLEM BEHIND THIS RESEARCH

Fatigue is a severe problem in the rail industry, potentially jeopardising train crew health and train safety. Train crew usually have heavy workloads and irregular work hours. The jobs in the rail industry were designed to operate on a 24/7 basis, and often have an irregular shift schedule. For example, in freight operations, there is a high proportion of night shifts and early morning shifts. Due to the nature of this industry, the majority of workers do shift work (e.g., early-morning shifts that start before 6:00 a.m. or night shifts that end after 4:00 a.m.), and they are often exposed to noise or fumes at work. These job characteristics may result in fatigue, with a related reduction in performance, and may damage workers' well-being, both at work and outside of work. Understanding fatigue, managing it, and improving well-being among train staff not only benefits their health, but also reduces the risk of train safety problems. It is hoped that the research in this thesis can contribute to a better understanding of fatigue, its risk factors and outcomes, and develop a tool to detect fatigue in an occupational setting, and to counteract the effects of unhealthy work experience and work environments on train safety and personal well-being.

1.2 OBJECTIVES OF THIS THESIS

The aim of the thesis is to investigate fatigue among train crew, based on the following objectives:

1) To review the general literature on occupational fatigue, its risk factors and general outcomes and to review the specific literature on train crew fatigue.
2) To examine the prevalence of fatigue and identify the risk factors related to fatigue among railway staff in general.
3) To develop an online measure of fatigue to examine the effects of time of day and workload on fatigue, and to establish the relationship between subjective fatigue and objective performance.
4) To further explore the potential risk factors for fatigue among railway staff.
5) To test the Demands, Resources, and Individual Effects (DRIVE) model.
6) To investigate the effects of workload and other risk factors in the prediction of fatigue, and the impact of fatigue on impairing performance in the work life of railway staff.

1.3 OUTLINE OF THIS THESIS

This dissertation begins with a literature review in Chapter 2, which gives a brief introduction to the history of fatigue research and summarises the literature related to the definition of occupational fatigue, its causes and effects on working performance, and related physiological problems. It also reviews fatigue prevention and management in the workplace and fatigue problems in different transport sectors.

Chapter 3 presents a systematic review of fatigue in the rail industry. It assesses the progress of research on railway fatigue, including research on the main risk factors for railway fatigue, the association between fatigue and railway incidents, and strategies for managing fatigue in the railway industry.

A fatigue survey is then described in Chapter 4. This large-scale survey first considers associations between occupational risk factors and perceived fatigue by examining the prevalence of fatigue and identifying its potential risk factors in the UK railway industry. Based on the DRIVE model, this study builds a detailed picture of the relationships between workplace stressors, individual differences, fatigue, and well-being outcomes, covering all job roles in the railway industry.

Chapter 5 presents two experiments which were carried out to examine the effects of fatigue, workload, and time of day on performance using a student sample. The first investigated the effect of time of day and the second studied the effect of workload.

Chapter 6 presents an online survey exploring potential risk factors for fatigue among rail staff. It investigated the causes of three different dimensions of fatigue, namely physical fatigue, mental fatigue and emotional fatigue.

Chapter 7 presents an experiment using online measures on a rail staff sample. It was an online study using diary and cognitive performance tests in the workplace, before and after actual work.

In the final chapter, Chapter 8, all the work described in previous sections is summarised, and the methodological strengths and weaknesses of the present studies are discussed, with a view to future research.

CHAPTER 2: LITERATURE REVIEW OF OCCUPATIONAL FATIGUE

2.1 CHAPTER INTRODUCTION

This chapter reviews the literature on the general area of occupational fatigue. It gives a brief introduction to the history of fatigue research and summarises the literature related to the definition of occupational fatigue, its causes and effects on working performance and physiological problems. It also reviews fatigue prevention and management in the workplace, and fatigue problems in the transport sectors.

2.2 HISTORICAL BACKGROUND

Fatigue is one of the core constructs for theory and research in modern psychology, and it has been researched for over 100 years. In the 1890s, early studies of fatigue were conducted in Germany and the United States, which focused on the question of how long the school day or the work day could be without fatigue-related decrements in learning and performance. Shortly after that, Mosso (1906) developed the ergograph to measure physical fatigue. This instrument measured the amount of muscular contraction, usually in experiments on work and fatigue. Subsequently, objective assessments of some aspects of physical fatigue became possible. The ergograph, primarily an instrument for measuring muscle exertion, was also seen as a window into mental activity. Mosso noticed that, even in a state of muscular fatigue, numerous mental or cognitive factors resulted in changes in patterns of fatigue, indicating mental fatigue also existed. Although there was no agreement on its definition (Dodge, 1917), mental fatigue (or cognitive fatigue) was an issue of critical importance in the both the psychological laboratory, and the workplace.

Over the past 100 years, the research on mental fatigue reached an early peak in the 1940s, when it became an essential issue in military and industrial contexts. Although there was much valuable research from that period, the data were collected largely during or shortly after World War II, before the cognitive revolution occurred in the 1950s and 1960s. In the 1980s, new interest in fatigue increased, with the rise of new models and theories of cognitive processing and the availability of new strategies and tools for empirical inquiry. As a result of this, there was nearly a 10-fold increase in the number of articles on fatigue that have appeared in the following 40 years. Adopting these new techniques, researchers attempted to understand task and personal characteristics which lead to fatigue in both the laboratory and the field.

Recently, there has been a substantial increase in the number of applications related to fatigue, including both military and civilian applications (Ackerman, 2011). Military applications of fatigue have remained a central concern for fatigue research over the past few decades. Further, fatigue in civilian occupations, such as aviation, driving, shift work, healthcare, and so on, have become the essential topics of fatigue research and application.

2.3 DEFINITION OF OCCUPATIONAL FATIGUE

Fatigue refers to the effects or after-effects of diverse activities, such as spending a busy day at work, driving on a long journey, or even concentrating for a short duration of time on highly demanding physical exercises. It can be the result of either the sustained stress of work or doing something enjoyable (e.g., playing tennis or playing chess). There are different stages of fatigue, including acute fatigue and chronic fatigue. For example, fatigue that occurs during or after work is known as *acute fatigue*, while the carried-forward fatigue is known as *chronic fatigue*. According to the Oxford Dictionary 2013, fatigue in humans is “extreme tiredness arising from mental or physical effort”. The subjective feelings of fatigue include descriptors such as tired, lacking energy, sleepy, or exhausted (Shen, Barbera, & Shapiro, 2006; Job & Dalziel, 2001). Generally, fatigue results in the deterioration of attention, perception, decision-making, and skilled performance (Cercarelli & Ryan, 1996), or a physiological state characterised by a decreased response of cells, tissues, or organs after excessive stress or activity (Hirshkowitz, 2013).

The literal meaning of occupational fatigue is fatigue in an occupational setting. It represents a relative incapacitation involving changes in behaviour and attitude. Occupational fatigue may occur during or after work (i.e., acute fatigue), or before work when a person has not fully recovered from previous fatigue through the normal periods of rest and sleep before the onset of the next set of demands (i.e., chronic fatigue; Cameron, 1973). This situation is similar to conditions like burnout (Huibers et al., 2003) and stress (Tepas & Price, 2001).

There is no generally accepted definition of fatigue, however, since it has many different and complex symptoms depending on the work content. Hanowski et al. (2011) and Williamson and Friswell (2013) suggested that industries define fatigue for themselves. To better understand and manage fatigue, Phillips (2015) presented a new general definition of occupational fatigue by considering the experimental, physiological, and performance aspects of fatigue, which is suitable in different transport sectors:

> “Fatigue is a suboptimal psychophysiological condition caused by exertion. The degree and dimensional character of the condition depend on the form, dynamics and context of exertion. The context of exertion is described by the value and meaning of performance to the individual; rest and sleep history; circadian effects; psychosocial factors spanning work and home life; individual traits; diet; health, fitness and other individual states; and environmental conditions. The fatigue condition results in changes in strategies or resource use such that original levels of mental processing or physical activity are maintained or reduced”.

Occupational fatigue can occur with depletion of the physical, mental, or emotional resource. The physical resource involves muscular movement, the mental resource involves cognitive processing, and the emotional resource involves expression and regulation of emotions. Taking into account these energy resources, Frone and Tidwel (2015) proposed resource-specific definitions of work fatigue called Three-Dimensional Work Fatigue (3D-WF), which includes physical, mental, and emotional dimensions of occupational fatigue:

> “Physical occupational fatigue represents extreme physical tiredness and reduced capacity to engage in physical activity that is experienced during and at the end of the workday.
>
> Mental occupational fatigue represents extreme mental tiredness and reduced capacity to engage in cognitive activity that is experienced during and at the end of the workday.
>
> Emotional occupational fatigue represents extreme emotional tiredness and reduced capacity to engage in emotional activity that is experienced during and at the end of the workday.”

2.4 CAUSES OF FATIGUE

In general, the causes of occupational fatigue are varied, including generic causes not specific to the workplace (e.g., sleep loss, time on task, time of day), and work-related causes (e.g., job demands and control); it is also affected by individual differences and combined effects. The generic causes of fatigue include the duration of the task, sleep-related problems, and the circadian variations associated with time of day. Stress is the starting point of fatigue, and long-term stress results in fatigue. Cameron (1973) stated that the term fatigue is synonymous with a generalised stress response over time, which suggests that the risk factors of occupational stress will also result in fatigue. The work-related causes of fatigue, therefore, could be the stressor of occupational stress, including work demands, lack of control and support, and individual differences. The causes could also be the working environment, shift work and the combined effects of these factors.

2.4.1 Time on Task

The most prominent cause of fatigue is the time spent on tasks. Length of time-on-task leads to fatigue, and a decrement in cognitive performance. Time-on-task refers to the length of time spent involved in a task. Cameron (1973) pointed out that time is probably the most relevant variable which is uniquely associated with fatigue. In the course of prolonged tasks, it generally becomes increasingly difficult to maintain performance, which seems to reflect a cumulative increase in the effort required to deploy cognitive resources. In such cases, performance is impaired and fatigue accumulates over time.

The range of studies of the time on task effect involved periods of a few minutes in duration (e.g., Gates, 1916) to several weeks of 8-hour days' continuous time (e.g. Huxtable et al., 1945). The effect is particularly noticeable in tasks requiring sustained attention, especially vigilance performance tests (Davies & Paasuraman, 1982), with longer reaction times and/or greater numbers of errors. Gilbertova and Glivicky (1967) stated that this effect is amplified by monotony or boredom, while it may be suppressed in more interesting tasks. In addition, breaks (e.g. task switching) and rests provide fatigue recovery from such an effect (Bergum & Lehr, 1962; Komski, 1967).

2.4.2 Sleep Loss

Sleep loss is one of the main factors that leads to fatigue. Many of the fatigue studies involve sleep-related risk factors, including sleep quality, duration, and deprivation (Parkes, 1994a; Wadsworth et al., 2006; Wadsworth, Allen, McNamara, & Smith, 2008). Most people experience the feeling of fatigue after spending one or more nights without sleep. Technically, sleep loss is associated with significant declines in global metabolic activity within the brain, especially the pre-frontal inhibitory and thalamic information-processing system (Thomas et al., 2000). That is, alertness and attention decrease, and the probability of brief attentional lapses increases. Sleep deprivation also disrupts the normal functioning of the emotional-cognitive integration system, resulting in increased negative emotion (Dinges, 1997) and impaired decision-making (Killgore, 2006). Additionally, May and Baldwin (2009) noted that active and passive fatigue can impair performance, either directly through task effects, or indirectly by worsening sleep-related fatigue.

2.4.3 Time of Day

Human performance shows temporal changes, known as time of day effects, which are also a contributing factor to fatigue. It is driven by the circadian process, which is a key neurobiological process. The circadian process keeps track of time of day, and it originates in the biological clock in the suprachiasmatic nuclei of the hypothalamus (Moore, 1995; Van Dongen, Belenky, & Krueger, 2011). Studies on time of day effects and fatigue indicate that as far as the average performance, resistance to fatigue is higher during morning task session than it is in the afternoon or evening.

A review of time of day effects (Smith, 1992) has identified three important aspects of these effects. First, alertness (body temperature was used as the indicator of alertness) increases over the day until the evening. In 1963, Kleitman studied time of day and related performance on simple tasks, suggesting that parallelism existed between the time of day effects on performance and the circadian clock of body temperature, which consistently showed a peak at 9 p.m. and a trough at 4 a.m. Subsequent studies revealed that waking time was a key mediating factor in the relationship between performance and temperature. The basis of the body temperature study described how alertness increases over the waking day and reaches its peak in the early evening (Colquhoun, Blake, & Edwards, 1968). Studies on circadian variation in serial visual search performance also supported this view (Fort & Mills, 1976; Hughes & Folkard, 1976; Klein, Herrmann, Kuklinski & Wegman, 1977). Secondly, subjective ratings of alertness peaked in the late morning (Monk, Leng, Folkard, & Weitzman 1983). Thirdly, fatigue increased over the day due to daily activity. The result of cumulative fatigue was that performance in perceptual-motor tasks became faster but less accurate in the early evening, compared with the early morning (e.g., Monk & Leng, 1982). Later, Smith (1991a) noted that such changes in performance were observed in all of the three strategies used (priority was given to either speed or accuracy, or no priority was given). Performance was faster but less accurate in the early evening in all three conditions.

2.4.4 Work Demands, Control, and Support

Occupational fatigue is considered to be a result of job demands (Moos, 1988; Hockey & Wiethoff, 1990). Job demands refer to physical or mental workload, and the effects of some demands that continue beyond the demand itself are known as the after-effects. Although job demands are not necessarily negative, they may turn into stressors if meeting them requires high levels of effort. These stressors are, therefore, costly and are associated with negative responses such as depression, anxiety, and fatigue.

Besides, Karasek (1979) found that job control (i.e., the personal ability to control work activities) is a major moderator between high job demands and high strain. In Karasek's

(1979) job demands-control model (JDC), it is the combination of high job demands and low job control that associated with high job strain. Results of the studies focusing on job control support its moderating effect on the relationship between high job demands and fatigue (Marshall, Barnett, & Sayer, 1997; Van Yperen & Snijders, 2000). Van Yperen and Hagedoorn (2003) stated that as job demands increase, the high job control needed to limit fatigue also increase.

In the 1980s, a social support dimension was added to the JDC model, resulting in the job demand-control social (JDCS) model (Johnson & Hall, 1988). Social support at work was defined as the overall levels of helpful social interaction available on the job from co-workers or supervisors (Karasek & Theorell, 1990). The new model incorporated the concept of isolation-strain (i.e., iso-strain). Iso-strain stands for the proposition that high job demands combined with low control and low social support, results in feelings of isolation and leads to higher levels of fatigue and strain. Van Yperen and Hagedoorn (2003) suggested that either high job control or high social support is needed to enhance work motivation.

2.4.5 Work Time

Research on occupational fatigue has focused on the effects of irregular hours of work. Humans have important physiological requirements for sleep and a stable biological clock, but in many industries, the jobs of humans are designed to operate on a 24/7 basis. When people lose sleep or have their internal clock disrupted, they usually begin to feel fatigued. Previous studies have identified the start time (Smith, Folkard, Tucker, & Macdonald, 1998; Folkard & Tucker, 2003), shift work, and its duration (Duchon, Keran, & Smith, 1994), as potential causes of fatigue. Shift work, especially the early morning shift and the night shift, disrupts the sleep-wake cycle (Ferguson, Lamond, Kandelaars, Jay, & Dawson, 2008) and deprives workers of sleep (Akerstedt, 1991), which in turn reduces performance (Kjellberg, 1977). Shift workers may have little time to recover when working certain shift hours, which makes them more likely to suffer from chronic fatigue.

Furthermore, when reviewing the literature on shift systems, Folkard, Lombardi, and Tucker (2005) highlighted three key trends which have arisen from studies of shift schedules, fatigue, and safety:

1. The risk of an accident is higher when working at night (and, to a lesser extent, when working in the afternoon) compared to the morning.
2. The risk of an accident increases over a series of work shifts, especially at night.
3. The risk of an accident increases as the total shift length increases over 8 hours (in any 24-hour period).

2.4.6 Individual Differences

Individual differences play a role in fatigue as well. Many individual factors have been studied, including personality (Parkes, 1994a; Parkes, 1994b), coping type (Cox & Ferguson, 1991; French et al., 1982), health-related behaviours (Laaksonen et al., 2009), and even clock genes (Arendt, 2010).

Personality and coping type

Parkes (1994a) and Smith (2004) stated that individual differences in personality and coping can play important roles in the processes by which work conditions influence fatigue and health outcomes. Karasek (1979) noted that individuals can manage their job demands effectively in a controllable situation. In other words, the effect of job demands somehow depends on how individuals appraise stressors and act in response (Hockey & Wiethoff, 1990).

The demands, resources, and individual effects model (DRIVE; Mark & Smith, 2008) is an occupational stress model that includes not only job demands and job resources (support and control), but also individual differences. It demonstrates the important role of individual differences (such as coping styles) in influencing health outcomes, as well as job demands and job resources. It also suggests that individual differences may moderate the relationship (a) between job demands and well-being outcomes, (b) between the relationship of the environmental factor and perceived stress, and (c) between perceived stress and health outcomes. However, subsequent studies (Capasso, Zurlo, & Smith, 2016; Mark & Smith, 2012a, 2012b; Williams, 2013) have failed to find such a moderating effect.

Health-related behaviours

Health-related behaviours are collectively referred to as lifestyle. A healthy lifestyle can involve exercise, refraining from smoking and drinking excessive amounts of alcohol, and eating a balanced diet. Laaksonen (2009) stated that smoking and being overweight were the health behaviours most strongly associated with absences due to sickness, while the associations of other behaviours with sick leave were weaker. Drinking excessive amounts of alcohol was associated with feelings of fatigue and performance impairment (Dawson & Reid, 1997; Wiese, Shlipak, & Browner, 2000). Yamazaki et al. (2007) suggested that fatigue increased with an increase in the frequency of eating between meals, probably because this eating involved mainly snacks or sweets. That is, the overconsumption of sugar or carbohydrates can result in feelings of fatigue.

Clock Genes

Clock genes are also called clock circadian regulators, which play a central role in the internal time-keeping system of the human body. They regulate various physiological processes through the generation of approximately 24-hour circadian rhythms in gene expression. Although the investigation of polymorphisms in clock genes to occupational fatigue is in its infancy, some polymorphisms have already been identified, such as diurnal preference, an intrinsic period, responses to sleep deprivation and night shifts (Archer et al., 2003; Von Schantz, 2008; Arendt, 2010; Landgraf, Shostak, & Oster, 2012). For example, the length of the PER3 gene (a kind of clock gene) is correlated with diurnal preference. The longer allele carrying five repetitions (PER3 5/5) is associated with early morning type (i.e., extreme morning preference), while the shorter allele (PER3 4/4) is correlated with evening type (i.e., night preference) and delayed sleep phase syndrome (Archer et al., 2003; 2010).

Clock genes mainly synchronise the sleep-wake cycle with the external time, and also impact sleep-correlated functions, including memory formation, and immunity. Van Dongen and Belenky (2009) suggested that the selection of individuals with a specific diurnal preference or those who are relatively little affected by sleep loss or circadian effects for specific tasks (e.g., night shifts or early morning shifts) can help to improve productivity, reduce errors, and decrease incidents and accidents. Such selections, however, should be done judiciously within ethically and legally acceptable boundaries and avoid discriminating based on genetic information. Although clock genes provide an interesting angle to understand the individual difference in perceived fatigue, they will not be studied in the current project.

2.4.7 Environment Factors: Noise

Noise contributes to the fatigue caused by a working day. It is generally accepted that noise may interfere with normal sleep patterns and sleep quality (Smith & Broadbent, 1992). However, Smith (1991a) noted that it is not wise to separate the noise from other work characteristics in assessing psychological distress. Annoyance is a likely consequence of exposure to noise and may be associated with the development of psychological distress.

Evidence shows that reports of fatigue are more common among workers exposed to high levels of noise (Landstrom, 1990; McDonald & Ronayne, 1989; Melamed & Bruhis, 1996) and that noise results in an increase in reaction times (Kjellberg, Muhr, & Skoldstrom, 1998). Kjellberg (1998) suggested that the effects of exposure to high noise levels may continue into subsequent days and cause a cumulative effect over the working week. The after-effects of noise are predictable; performance is consistently impaired by both variable continuous and steady-state continuous noise (reviewed by Cohen, 1980). Such effects can be found in varied occupations, such as seafarers (reviewed by Smith, Allen, & Wadsworth, 2006), aeroplane mechanics (Kjellberg et al., 1998), and nurses (summarised by McNamara, 2008).

2.4.8 Combined Effects

The combination of above risk factors has a cumulative effect on occupational fatigue. In a large survey of the general working population (Smith, McNamara, & Wellens, 2004), high demands, low control and support, and exposure to physical hazards, combined with shift-work and long hours, showed significant associations with occupational fatigue. The Negative Occupational Factors (NOF) score represents the strength of the combined-effect approach. It was calculated by first dichotomising each factor into high (i.e., negative) and low (i.e., positive) risk groups. Then, the NOF was calculated for each subject by adding the number of high-risk factors together. When treating the NOF as a continuous variable, the combined effect can linearly relate to the outcomes. Subsequent studies of seafarer fatigue (Smith, Allen, & Wadsworth, 2006; McNamara & Smith, 2002) suggested that the combined effect of many risk factors is the strongest predictor associated with fatigue. The combined effect of a range of factors associated with fatigue and its consequences, including reduced personal risk, health, and well-being, is more significant than any individual factor.

2.5 CONSEQUENCES OF FATIGUE

In general, the physiological outcomes of fatigue include muscular fatigue, subjective feelings of tiredness, and performance impairment (Bartley & Chute, 1947). Muscular fatigue is physical fatigue resulting from prolonged physical activity. It is associated with the failure of oxygenation, the depletion of chemical energy, and the accumulating harmful metabolites produced by activities. Modern fatigue research is more concerned with mental fatigue, including increased subjective tiredness and decrements in performance. Performance tests have been used to assess fatigue, as it has been found to impair people’s ability to perform efficiently in laboratory studies (Craig & Cooper, 1992). There have also been studies which have simulated the working environment and workload (e.g., Desmond & Matthews, 1997; Thiffault & Bergeron, 2003), and also workplace studies (e.g., Parkes, 1995).

In the workplace, the failure to manage occupational fatigue can have disastrous results. It has been identified as a cause of major incidents, such as the Chernobyl nuclear reactor meltdowns, the Challenger Space Shuttle disaster, and the Bhopal gas explosion (Mitler et al., 1988; Dinges, 1995). A fatigued worker will feel tired, sleepy, or lacking motivation, and will consequently take a longer time to react and make decisions; this, in turn, can cause a dangerous situation. In a review, Krueger (1989) stated that fatigue at work appears to result in increased reaction time, decreased vigilance, and perceptual and cognitive distortions. The consequences of occupational fatigue can appear either in the short term, such as poor performance, or in the long term, such as ill health and absenteeism.

The next section consists of two parts. First, the effects of fatigue on performance in laboratory studies and in the workplace are considered. Second, the associations between fatigue and job outcomes, including perceived well-being and health, are examined.

2.5.1 Performance

Fatigue affects performance, and its effects can carry over to subsequent performance on the same or other tasks. In early research, the term fatigue was considered similar to muscular fatigue, which results from vigorous exercise or repeated muscular contraction. A heavy muscular task typically results in work output declining over time (Goldmark, Hopkins, Florence, & Lee, 1920), while a lighter one (e.g., visual inspection) may result in increases in performance (Link, 1919). Later, fatigue was considered as an effect related to boredom (Wyatt, Langdon, & Stock, 1937), which is closer to the modern definition of fatigue, and it was found to be associated with slower response time and errors (Bertelson & Joffe, 1963; Kogi & Saito, 1973). Craig and Cooper (1992) summarised the direct performance indicators of fatigue in laboratory studies, which are simple response decrements and increased response errors and blocking. Reaction time (RT) and errors are assessed together in the research, and many laboratory studies show that fatigue results in either longer RT or more errors. Rabbitt (1981) suggested that this result may reflect a speed-error trade-off.

In occupational settings, fatigue is associated with poor work performance. Drew (1940) investigated pilot fatigue and noted that memory-lapses and inattention appeared after an hour of working, with increased manoeuvring control errors and failures to check gauges. Drew also noted drops in skill effectiveness, and that tasks seemed to lose their integrity when the pilots were fatigued. By reviewing studies of fatigue in skilled work, Craig and Copper (1992) stated that fatigue disturbs essential timing and attention, and impairs memory and information processing. Charlton and Baas (2001) confirmed that fatigue impairs psychomotor performance, and Beurskens et al. (2000) found that it also leads to reductions in concentration, motivation, and activity. In the road transport sector, the symptoms of fatigue include poorer vehicle control and reduced arousal (Feyer & Williamson, 2001). Moreover, fatigue increases the variation in driving and incidence of close calls, as well as near-misses and the risk of accidents (Morrow & Crum, 2004). The result is severe and unpredictable reductions in safe performance by the motor vehicle operator.

There are two different experimental paradigms used in these studies: the *direct* method and the *indirect* method (Ackerman, 2011). The *Direct* method observes performance on a fatiguing task over an extended period of task performance. The *Indirect* method uses a second task that serves as the baseline measure. It is administered before and after work or the fatiguing task to avoid the influences of boredom and a loss of interest in the task.

2.5.2 Job Outcomes

Ill health

Fatigue is highly associated with ill health, such as depression, anxiety, or emotional stress, in both the general population (Chen, 1986) and the working population (Mohren et al., 2001; Bultmann, 2002). As Kroenke et al. (1988) stated, long-term fatigue is associated with impairments comparable to chronic medical conditions, and it increases the risk of acute illnesses and serious chronic disease (e.g., cardiovascular disease). Among the working population, fatigue is a common reason people consult a general practitioner (GP). These visits are, in particular, associated with high levels of fatigue and health problems (Andrea, Kant, Beurskens, Metsemakers, & Van Schayck, 2003). In addition, fatigue causes high rates of sickness absence (Janssen, Kant, Swaen, Janssen, & Schroer, 2003; Kinkier & Whittick, 1991, cited in McNamara, 2008).

Fatigue is clearly linked to injury and disability (Swaen, van Amelsvoort, Bültmann, & Kant, 2003; van Amelsvoort et al., 2002). Fatigue has been identified as a cause of incidents and injury (Dinges, 1995; Mitler et al., 1988). It decreases the ability of a worker to process important visual and perceptual information which are relevant to avoiding an accident. Swaen and his colleagues (2003) determined that fatigue and the need for recovery from fatigue were independent predictors for being injured in an occupational accident, beyond social demographics and other factors. It has also been suggested that fatigue syndrome is associated with considerable work-related disability, with a number of people losing their jobs due to their ill health (Taylor & Kielhofner, 2005). This outcome makes fatigue-related sickness difficult to detect, as regular medical examinations prevent those with ill health from working. Even more concerning, the Cardiff seafarer research (Smith, Allen, & Wadsworth, 2006) has indicated that fatigue is associated with impaired health that could lead to long-term disability and even premature death.

Absenteeism and presenteeism

Fatigue is perceived as contributing significantly to work absenteeism. According to the Cambridge Business English Dictionary, the term *absenteeism* refers to the act of staying away from work. Daley and his colleagues (2009) probed the reasons for absenteeism, and the most frequently reported reason was health problems and fatigue. Fatigue itself leads to cumulative health deterioration under conditions of prolonged exposure to work-related stressors and insufficient recovery (de Croon, Sluiter, & Frings-Dresen, 2003; Kompier, Mulders, Meijman, Boersma, Groen, & Bullinga, 1990). It is associated with both short-term and long-term sickness absence, and it also predicts future absence (Janssen et al., 2003; Ricci, Chee, Lorandeau, & Berger, 2007). Janssen et al. (2003) stated that such a relation holds when controlling for social demographic and work-related confounders.

Alternatively, *presenteeism* is the act of staying at work longer than usual or attending work while ill to show the employer that the employee works hard (Cambridge Business English Dictionary; Smith, 1970; Kivimäki et al., 2005). Similar to absenteeism, presenteeism is also associated with fatigue and ill health, it can also cause productivity loss and workplace epidemic diseases (reviewed by Johns, 2010; Aronsson, Gustafsson, & Dallner, 2000). A study among civil servants (Kivimäki et al., 2005) showed that employees with sickness presenteeism were twice as likely to suffer serious coronary diseases as those with the moderate level of absence. Johns (2009) suggested that the potential for presenteeism to cause accidents merits attention. Sickness symptoms themselves and certain medications taken to relieve them might result in sleepiness or inattention at work.

The nature of the health event mainly dictates whether *absenteeism* or *presenteeism* ensues (Johns, 1991). After accounting for illness, either work contextual factors (e.g., job demands, absence policy) or personal factors (e.g., personality, stress) further influence the choice between them (reviewed by Johns, 2010). For example, Grinyer and Singleton (2000) reported that teamwork meetings among staff members of UK public sector resulted in presenteeism because they felt compelled to attend even when ill.

2.6 FATIGUE MEASUREMENT

Fatigue studies use either subjective measures or objective measures, or the combination of both to assess fatigue. There is no ‘golden standard’ of fatigue measurement, but Broadbent (1979) suggested that an ideal fatigue test would, without changing people’s normal behaviour, connect a person’s own actions and changes in the outside world, and would be applicable in realistic situations. These concepts should be noted during the design and development of the fatigue test. In previous fatigue studies, researchers employed many validated measures to assess occupational fatigue. These measures were originally developed for use with either clinical samples, the general population, or particular occupational or transport operator samples (Ahsberg, 2000; Matthews, Desmond, Neubauer, & Hancock, 2012; Smith, Allen & Wadsworth, 2006).

2.6.1 Subjective Measures

Bartley and Chute (1947) and Cameron (1973) argued that subjective fatigue had no predictive power, but self-reports of fatigue were found to be strongly associated with poor performance in later studies. In the 1970s, Japanese ergonomists worked hard on the development of a scale to measure subjective fatigue, and this enhanced the research in fatigue ratings. The fatigue rating scale Japanese researchers developed and validated consisted of three components: (a) drowsiness and dullness, (b) difficulty concentrating, and (c) feelings of physical disintegration (reviewed by Craig & Cooper, 1992). Many of these subjective fatigue scales have been proven reliable in distinguishing between fatigued and non-fatigued staff (Chalder et al., 1993; Kim et al., 2010). They also have reliably distinguished fatigue in different types of job disciplines, both within (Kishida, 1991) and between industries (Beurskens et al., 2000; Kogi, Saito, & Mitsuhashi, 1970).

Several researchers have evaluated chronic fatigue and empirically related it to the failure to recover from acute fatigue. However, existing fatigue measurement scales have many drawbacks. For example, the Profile of Mood Scale (POMS), the Checklist of Individual Strength, the Multifactorial Fatigue Inventory, and the Fatigue Severity Scales (FSS) lack validity for measuring work-related fatigue. The Swedish Occupational Fatigue Inventory (SOFI), the Fatigue Assessment Scale (FAS), and the Need for Recovery from Work Scale (NRFW) meet this requirement, but none of these scales measure recovery from fatigue.

Winwood et al. (2005) developed and validated a 15-item Occupational Fatigue Exhaustion Recovery (OFER) scale, which includes three subscales: chronic fatigue (OFER-CF), acute fatigue after work (OFER-AF), and inter-shift recovery (OFER-IR). The OFER-CF measures both mental and physical elements, the OFER-AF measures the energy lost during work, and the OFER-IR measures the recovery from acute work-related fatigue between work shifts. The analysis showed that the OFER was successful, with strong predictive power and excellent internal consistency.

However, due to practical constraints, a very limited number of measures are appropriate in an occupational context. For this situation, single-item fatigue measures are used because they are quick and easy to administer, whether paper-based or computer-based, and pose minimal disruption to the workers. For example, the visual analogue scales (VAS) and Samn-Perelli seven-point fatigue scale (Samn & Perelli, 1982) are two well-established single-item subjective measures, which are broadly used to measure pilot fatigue management. Recently, by comparing the performance of single-item measures to that of the multi-item measures, Williams (2014) suggested that single-item measures are able to identify the broad and fine relationships between predictor variables and outcomes, similar to the multi-item measures. The total prediction of outcomes using the single-item measures is significant and similar to that of multi-item measures, which suggests that the single-item approach is generally suitable in terms of predictive validity.

2.6.2 Objective Measures

Objective and quantitative assessments are necessary to evaluate the presence of fatigue-related deficits. Several objective measures have already been used in fatigue studies to investigate fatigue-related impairment of performance, including RT tests, vigilance tasks, and the Stroop task (Craig & Cooper, 1992).

The RT test assesses motor and mental response speeds, as well as measures of RT and response accuracy. It usually is either a simple RT test or a choice RT test. The *simple RT test* is a test which measures RT through showing a stimulus to a known location to elicit a known response. The stimuli are usually presented at a high rate of speed (i.e., every few hundred milliseconds; Smith, 1995). The *choice RT* test contains two or more choices, and it is more uncertain than the simple RT test because it has more possible stimuli and responses. This test is used to measure alertness and motor speed. Classically, five-choice RT tasks have shown the effect of prolonged work by an increased number of abnormally long response times, initially called *blocks* (Bills, 1931), and later called *gaps* with specific reference to Leonard's five-choice test (summary by Poulton, 1970). Wilkinson and Houghton (1975) indicated that the four-choice RT test appeared to reflect fatigue in the same way as the RT test with five choices, but with a shorter time scale and greater internal consistency.

Vigilance tasks also measure reaction times when the onsets of stimuli are widely spaced in time (e.g., 12 stimuli per 20 minutes; Mackworth, 1950). Vigilance is an area in information processing psychology that developed because of practical fatigue issues in World War II (Broadbent, 1958; Mackworth, 1950; Welford, 1968). Frankenhaeuser et al. (1986) indicated that a vigilance task can be just as demanding and stressful as a fast-paced, complex RT task.

The Psychomotor Vigilance Task (PVT) is another widely accepted measure of neurobehavioural performance that assesses the functional consequences of fatigue. It measures vigilant attention based on simple reaction time (RT) to stimuli that occur at random intervals. The current PVT standard version is a hand-held electronic device developed by Dinges and Powell (1985), enclosed in a plastic case (21 X 11 X 6 cm) and weighing 658 g. The current version of a standard PVT is 10 minutes in duration with 2- to 10-second random inter-stimulus intervals (ISIs). This sustained attention task is popular due to its portability and simplicity. It can also be carried out in noisy surroundings (Elmenhorst et al., 2012). More importantly, in aviation, the PVT has been validated as sensitive to changes in fatigue levels (e.g., Dorrian et al., 2007; Lee et al., 2010; Petrilli et al., 2006). A 5-minute handheld version of the PVT already exists (Lamond, Dawson, & Roach, 2005; Lamond et al., 2008; Loh et al., 2004; Roach, Dawson, & Lamond, 2006; Thorne et al., 2005). Due to practical constraints, however, it requires equipment to be purchased or leased and distributed to the workers and requires at least 5–10 minutes without any disturbance. Basner et al. (2011) developed a 3-minute brief version of the PVT (PVT-B), but its reliability needs to be further validated. Additionally, both the 2-minute and 90-second versions of the PVT (Loh et al., 2004; Roach, Dawson, & Lamond, 2006) are not sensitive enough to be used as valid tools for detecting effects of fatigue.

2.7 FATIGUE PREVENTION AND MANAGEMENT

2.7.1 Staff Training

In general, fatigue risk management is a shared responsibility between an organisation and its staff (Reason, 2016). The organisation must arrange working schedules with sufficient opportunities for rest as well as provide training and information on fatigue management, and procedures for fatigue monitoring and management in the workplace. The staff members are responsible for using their available time to be rested and fit for duty, to attend training and implement recommendations, and to report cases of fatigue so that they can be better avoided in the future.

Staff training on fatigue is an appropriate and effective approach in the management of fatigue and plays an important role in the fatigue risk management system (FRMS). The prevention of work-related fatigue includes training and information on risk factors for fatigue, symptoms of fatigue, consequences of fatigue, procedures for preventing fatigue (e.g., incident reporting), balancing work and life demands, and the effects of medication, drugs, and alcohol (WorkSafe Victoria, 2008). The training can help staff to detect and recover from fatigue, avoid errors, and mitigate their consequences (Lerman et al., 2012; ORR, 2012).

2.7.2 Fatigue Countermeasures

In order to prevent fatigue and mitigate its consequences, countermeasures are needed. The classical approach has been to place the limitation on working hours as a control measure. Laws and regulations limiting hours of work have been placed to prevalent fatigue across many industries, such as The Working Time Regulations 1998 in the UK, the Working Time Directive (2003/88/EC) in the EU, the Commission Regulation (83/2014) for aviation, and the Contract Work Hours and Safety Standards Act in the US. Meanwhile, the Driving and Rest Time Hours in International Rail Transport Act (2008:475) suggested taking a minimum 45-minute rest after every 4.5 hours working period. Such laws and regulations are undergoing revision in response to expanding scientific knowledge on fatigue, sleep, rest, and recovery (Rosa, 2012).

Simply limiting work and rest hours, however, is insufficient for fatigue management, as it is possible to work within these limits and still suffer from fatigue. Haddon (1972) suggested that the most promising countermeasures are those that contribute to the decision not to take part in safety-critical work when fatigued (Anund, Fors, Kecklund, Leeuwen, & Akerstedt, 2015). At the individual level, staff need to make critical decisions while working to avoid the risk of fatigue-related incidents. First, such individuals must recognise their feelings of fatigue. Then, they must be motivated to take corrective actions, and know which countermeasures are effective and lasting. Finally, they must decide whether the situation allows them to act based on an effective strategy (i.e. no prevented to act).

The countermeasures can also be addressed on an organisational level using FRMS. Anund and her colleagues (2015) reviewed a total of 61 different FRMS programs consisting of different control mechanisms. They noted that there were five levels of identifiable hazards and controls: rest opportunities, actual sleepiness, behavioural symptoms, fatigue-related errors, and fatigue-related accidents. In addition, there are a wide range of possible control mechanisms, such as fatigue symptom checklists, self-report behavioural scales, fatigue proofing strategies, prior sleep-wake-data, and sleep-awake-modelling (Anund et al., 2015; Dawson & McCulloch, 2005; ORR, 2012).

2.7.3 Fatigue Mathematical Models

Recently, fatigue management approaches based on mathematical models have become available (reviewed by CASA, 2014; Lerman et al., 2012; ORR, 2012). These approaches, based on the mathematical expression of the factors causing fatigue, attempt to predict the level of fatigue. Such mathematical models (or bio-mathematical models) are used to identify work characteristics with high fatigue risks, reflecting scientific data concerning the relationships between work hours, sleep, performance, and fatigue (van Dongen, 2004). Moreover, they can be used to compare and improve work scheduling, especially shift planning, and can be used as a part of incident investigations to help indicate whether fatigue may have been a contributory factor (ORR, 2012). These fatigue models are widely used in aviation, road transport, rail, and marine sectors (Anund et al., 2015).

The appeal of using fatigue mathematical models in the workplace is because as advanced technical solutions, they allow organisations to make ‘objective’ decisions about contested issues related to working conditions efficiently (Dawson, Noy, Härmä, Åkerstedt, & Belenky, 2011), which can improve the productivity and health of the community. They provide a transparent way to make evidence-based decisions, minimising the risk of fatigue-related errors and incidents.

However, such models merely make a mathematical prediction, without ‘knowing’ the level of fatigue staff will encounter when working a particular pattern in certain situations (ORR, 2012). Further, the decision on which variables will be included is not an entirely scientific one. It may reflect the ideology and value system of a model's creators and users. The field of fatigue model is still young; there is currently very little published data on how models are being used in workplace settings (Dawson et al., 2011). Van Dongen (2014) stated that a long implementation can typically last three to five years. Thus, it is important to continue developing, using and evaluating these models.

2.8 TRANSPORT FATIGUE

Fatigue is a severe problem in the transport sectors, especially for those in safety critical job roles. For example, fatigue-related “nodding off” can result in crashes and accidents at work. It is an act in which people fall asleep for a few seconds anywhere, and then suddenly return to a state of wakefulness again. Anund et al. (2015) summarised that unintentional “nodding off” at work has been demonstrated through measuring electrical brain activity (EEG) in all the main transport modes, including truck drivers, aviation pilots, bridge officers at sea, and train drivers.

2.8.1 Road Transport

Driver fatigue is a major contributing factor in 15–30% of all road crashes (Connor Norton et al., 2002, cited in Smith, 2016). Smith’s study (2016) identified that driving when fatigued (i.e. driving late at night, prolonged driving, driving after a demanding working day, and driving with a cold) and poor driving behaviour are predictors of road traffic accidents. To ensure safety, drivers often use their off-duty time and short breaks during a journey to recover from fatigue, which involves stopping to take a short walk or a nap. Research on truck drivers (Chen & Xie, 2014) has indicated that two breaks should be taken generally in a 10-hour journey and that the adequate break time to reduce safety risks is 30 minutes. It is essential to take a longer break if a third break is necessary. Drinking caffeine and functional energy drinks have also been proven effective in both a simulation study (Horne & Reyner, 1996; Reyner & Horne, 2002) and a real road driving study (Schwarz et al., 2012). Reyner, Flatley, and Brown (2006) concluded that such a rest break helps in reducing fatigue-related crashes on the road. Additionally, although turning on the radio is a common self-administered countermeasure in road transport, it does not show significant effects on reducing fatigue.

Road driver fatigue detection and prediction systems can be categorised into four groups (Dinges & Mallis, 1998): fitness-for-duty tests, mathematical models of alertness, vehicle-based performance technologies, and in-vehicle on-line driver monitoring systems. First, fitness-for-duty tests are used to identify a driver who is extremely tired and not fit to drive, usually based on eye detection. For example, some of these systems use infrared cameras to measure eye blinks and pupil size. Such systems, however, cannot deal with false alarms and have difficulty handling eyeglasses, thus still needing improvement. Second, the mathematical models of alertness are based on physical activity, but still immature with unproven impact (Anund et al., 2015). Third, vehicle-based performance technologies are developed by car manufacturers. This type of system mainly uses vehicle-integrated sensors to track drivers' performance in steering and maintaining a stable position in the lane. Finally, in-vehicle on-line driver monitoring systems use multiple measurements to monitor the bio-behavioural characteristics of the driver (e.g., head movements, EEG) while driving. These technologies are relatively unobtrusive to the driver and practical to use in the real world. Although Dawson, Searle, and Paterson (2014) concluded that none of the available detection systems provides a comprehensive solution to managing fatigue-related risk, several of them may be considered as potentially useful FRMS factors.

2.8.2 Aviation

Fatigue is a severe problem in air transport if it happens at the wrong time or becomes out of control. Unpredictable work hours and long duty periods are common in both civilian and military flight duties. Flight crew lose sleep and have their biological clocks disrupted during the 24/7 duty. The 24-hour operations, ultra-long range flights, overnight transport, and on-demand air medical flights are just a few examples of the types of duty with a high risk of fatigue seen in aviation. The negative effects of fatigue on work performance may lead to aviation errors and accidents.

Fatigue countermeasures in aviation include pre-flight, in-flight, and post-flight approaches (Caldwell et al., 2009). The pre-flight approaches include prophylactic napping before flight, and the use of pharmacological countermeasures, such as melatonin and mild sleep medications. Napping is effective for managing fatigue because it directly addresses the physiological need for sleep. It can also be used to reduce fatigue during or after work. In general, pharmacological fatigue countermeasures are not common recommendations in Europe (Anund et al., 2015). Although melatonin improves one's adaptation to a night shift and reduces fatigue at night, it can increase fatigue if it is taken at the wrong time, such as early daytime. Short-acting hypnotics (sleep medication) can mitigate sleep loss by increasing sleep length, but they are mainly used among military pilots. The in-flight approaches include napping and taking caffeine. Strategic napping reduces fatigue and improves alertness by reducing the hours of continuing wakefulness. Compared with other transport workers, flight crew often have better rest policies and rest environments (Gregory, Winn, Johnson & Rosekind, 2010). On some long-haul flights, pilots even have a room for rest with beds inside. Caffeine is also effective for helping individuals remain awake and boosting their physiological alertness. Research shows that using caffeine can provide great benefit for individuals with up to a 30% boost in performance (Gregory et al., 2010). The post-flight approaches mainly focus on rest during layovers. Lowden and Åkerstedt (1998) suggested that retaining the home-base sleep/wake pattern during layovers can reduce fatigue on the return flight. Obviously, these strategies mean that unintentional nodding off at work is rare in aviation.

Commercial aircrafts are equipped with various warning systems to alert the pilot if the aircraft is in immediate danger (e.g., flying into the ground or having a collision with an aircraft). Recently, real-time fatigue detection technology was proposed, such as eye tracking systems, but has not been tested in real flight (Caldwell et al., 2009). In addition, Flight Data Monitoring (FDM) has been applied since the 1970s to better manage pilot fatigue and to avoid human error caused by fatigue. FDM is a process whereby the data from “black boxes”, an on-board recorder, are analysed after every journey to detect subtle trends which may lead to an accident.

2.8.3 Seafarers

Maritime work often has no clear boundary between work time and rest time. Seafarer’s fatigue increases day by day, and this cumulative fatigue has effects at sea and continues on leave (Bal, Arslan & Tavacioglu, 2015). The Cardiff seafarer research programme (Smith, Allen, & Wadsworth, 2006) showed that fatigue is associated with impaired health and poor objective performance. In addition, several work-related factors were associated with levels of fatigue, including high job demands, low social support, high job stress, poor environment, and combined effects (McNamara & Smith, 2002; Smith, Allen, & Wadsworth, 2006).

To avoid the risk of accidents or incidents caused by fatigue in the maritime transport, a number of international regulations and initiatives limit the working hours and rest time of seafarers. One of the well-known regulations is the Seafarers' Hours of Work and the Manning of Ships Convention established by the International Labour Organization (ILO), and enforced in 2002. This convention mandated that the maximum working hours for seafarers are 14 hours in any 24-hour period and 72 hours in any 7-day period, and the minimum hours of rest are 10 hours in any 24-hour period and 77 hours in any 7-day period.

The fatigue countermeasures in the maritime sector can be divided into reactive and proactive measures (Starren et al., 2008). The reactive measures aim to help individuals recover from fatigue, with the most common approaches involving naps and caffeine. The proactive measures aim to prevent the onset of fatigue, mainly related to good sleep habits. Additionally, Vessel Traffic Services (VTS) continuously monitor all ships to ensure the watch-keepers are alert and the ships are on the planned trip with no deviation.

2.8.4 Link to Railway Fatigue

As in other transport sectors, fatigue in the rail industry is an issue that contributes to human error, incidents, and accidents. It also subjects to industry-specific factors, such as a harsh working environment, tasks requiring sustained vigilance, and shift-work systems (Lal & Craig, 2001; Office of Rail Regulations [ORR], 2012). The amount of rail crew fatigue research, however, has been smaller than other transport sectors, with very little relevant literature (Anund et al., 2015).

Current literature on occupational fatigue has established the general causes and consequences of fatigue in the workplace. The majority of such knowledge has applied in transport industries, while some of the relevant fatigue research has not done in the rail industry. This brought a question to the research of occupational fatigue in the rail industry: whether these "occupational fatigue" under different industry context the same thing. In other words, it is essential to be aware of the general picture of existing knowledge and research gap on rail staff fatigue before conducting further studies. Thus, a systematic review on current studies of railway fatigue is needed.

2.9 LINK TO THE NEXT CHAPTER

This chapter reviewed the literature related to the definition of occupational fatigue, its causes, and its effects on working performance and physiological problems. It also summarised the existing countermeasures for fatigue in the road transport, aviation, and maritime industries, offering insight for the research on railway fatigue. The next chapter is a systematic review of fatigue in the rail industry. It assesses the progress of research on railway fatigue, including research on the main risk factors of railway fatigue, on fatigue management in the train industry, and on fatigue-related incident reports.

CHAPTER 3: PRELIMINARY REVIEW OF FATIGUE AMONG RAIL STAFF

3.1 CHAPTER INTRODUCTION

The previous chapter summarised the literature relating to the definition of occupational fatigue, its causes, and its effects both on work performance and on physiological problems in general. Nonetheless, a preliminary review of all empirical evidence for train crew fatigue is still lacking. This chapter, therefore, aims to provide a preliminary description of occupational fatigue in the rail industry. It reviews the literature with the research question examining the risk factors associated with train crew fatigue, covering both papers published in refereed journals and reports from trade organizations and regulators. It assesses the progress of research on railway fatigue, including research on the main risk factors for railway fatigue, the association between fatigue and railway incidents, and how to better manage fatigue in the railway industry.

3.2 BACKGOUND

3.2.1 History of Railway Industry in the United Kingdom

From steam pioneers through the railway entrepreneurial boom, to a loss-generating nationalised British Rail, then to the privatisation of railway operations, the history of the UK rail industry has ridden a technological and social wave for nearly 200 years. The railway system of the United Kingdom is the oldest in the world. It was originally built as a patchwork of local rail links operated by small private railway companies. During the railway boom in the 1840s, these isolated links developed into a national network. After World War I, according to the British Railways Act 1921, almost all the railway companies were grouped into the "Big

Four" train operators: the Great Western Railway, the London and North Eastern Railway, the London, Midland and Scottish Railway, and the Southern Railway. After World War II, as a result of the Transport Act 1947, the "Big Four" were combined and nationalised to form British Railways under the control of the British Transport Commission. Over time, with the growth of the road haulage sector, passengers replaced freight, especially coal transport, as the railways' main source of income.

In 1963, the government dissolved the British Transport Commission under the Transport Act 1962 and created the British Railways Board to take over the railway duties; this board oversaw the transformation of the UK rail network until its privatisation in the 1990s. Between 1994 and 1997, British Railways was privatised under the Railway Act 1993. Track and infrastructure were passed to Railtrack (i.e., the privatised national railway infrastructure company), passenger services were franchised to private-sector operators, and freight services were sold outright. Overall, ownership and operation of the network became highly fragmented as operations were split among more than 100 companies.

Since privatisation, the number of rail passengers has grown rapidly. The public image of rail travel, however, was damaged by some prominent accidents shortly after privatisation. These accidents included the Southall rail crash and the Ladbroke Grove rail crash, which both resulted in deaths and hundreds of injuries, and, the Hatfield accident which had a serious effect on rail services. Although the Hatfield accident did not result in a large number of deaths, it exposed major stewardship shortcomings of Railtrack, including a lack of communication and lack of awareness of some staff members of maintenance procedures (ORR, 2006). Railtrack subsequently went into administration and was replaced by Network Rail, a state-owned, not-profit-company in 2002.

3.2.2 Structure of Railway Industry in the United Kingdom

Railways in the United Kingdom are run under a structure established by the Railways Act 1993 (as amended), which provided for the break-up of the former vertically integrated state railway, the British Railways Board, and the transfer of its operations to the private sector. The Secretary of State for Transport has overall responsibility for the railways within the UK Government, and government departments provide strategic direction and funding to the railways and procure rail franchises and projects. According to the information on the ORR website, the main structure of the railway industry also includes the regulatory body, the regulated entities, and the safety bodies.

Regulatory body – ORR

The ORR is the independent safety and economic regulator for the railways in the United Kingdom. It regulates and works with all regulated entities and safety bodies across the whole rail industry. On the safety side, ORR seeks to keep trains and railways safe. It works with safety bodies and regulated entities to secure the safe operation of the railway system and to protect staff and the public from health and safety risks arising from the railways. Inspectors from ORR are out on the network every day and step in to take enforcement action when they find safety failings. On the economic side, ORR regulates Network Rail's stewardship of the national rail network and approves access to the tracks to ensure passenger and freight train companies have fair access to the rail network. ORR also oversees competition and consumer rights issues. It works to ensure that the rail market is competitive and fair for passengers, freight customers, railway operators and taxpayers. Alongside the Office of Fair Trading, it investigates potential breaches of the Competition Act 1998.

Regulated entities

The regulated entities mainly include Network Rail, passenger train operating companies (TOCs), and freight operating companies (FOCs), all of which are regulated by ORR. The railway track and infrastructure is owned and operated by Network Rail, which is regulated by ORR. As mentioned in Subsection 2.2, Network Rail is a state-owned, not-for-dividend company. It owns, operates, maintains, and develops railway track and infrastructure, and it also manages 18 key train stations. Most other stations are managed by TOCs but are owned by Network Rail.

Passenger train services are managed and operated by TOCs, and the freight services are run by FOCs. The TOCs usually operate under regional franchises awarded by the Department of Transport. The franchises specify which passenger services are to be run, the quality of services, and other conditions (e.g., cleanliness of trains, station facilities, and reliability). There are exceptions to this structure that the franchise in Scotland is awarded by Transport Scotland, and in Wales, the franchise is awarded by the Wales Government. In addition, TOCs are able to bid for ‘slots’, the specific parts of the National Rail timetable, to operate their own services outside of a franchise arrangement with the central government. These are known as ‘open-access operators,’ and two of the current TOCs are such operators.

In contrast, the FOCs are fully in the private sector. According to the Rail Freight Group, there are currently eight rail FOCs. All of them are open-access operators that can bid to run services on any part of the network.

Compared to passenger train service, freight transport occurs more often at night and tends to travel longer distances with fewer stops. Passenger train service is characterised by more time pressure due to more frequently scheduled stops. In both forms of rail transport, the train drivers are subject to extreme routine, periods of high demands, and a driving task requiring vigilance.

Safety bodies – HSE, RAIB, RSSB

There are three main safety bodies in the railway industry: the Health and Safety Executive (HSE), RAIB, and RSSB. The HSE provides advice to the government on health and safety matters. The RAIB carries out the investigation into rail accidents and incidents without apportioning blame or liability. Its work aims to enable lessons to be learned, improve safety on railways, and prevent similar accidents and incidents. The RSSB helps the mainline railway industry's work to achieve continuous improvement in health and safety performance.

3.2.3 Overview of Fatigue in the Railway Industry in the United Kingdom

Fatigue in the rail industry is a major problem. Rail crew fatigue can lead to a high risk to both train safety and personal well-being. Failure to manage fatigue may have disastrous consequences in train safety. For example, staff fatigue caused by excessive overtime was a contributory factor in the 1988 Clapham Junction collision, which killed 35 people (ORR, 2012). Increased evidence shows that working long hours over long periods raises the risk of rail accidents and incidents. In the study from RAIB (2009), fatigue was considered a possible causal factor in at least 74 train accident or incident reports from 2001 to 2009.

In addition, due to work features, fatigued rail staff suffer severe occupationally-related ill health. The main work-related health problems in the rail industry are musculoskeletal disorders (MSDs), stress, and physical injuries (ORR, 2010). Actually, the current situation with occupational health problems in the rail industry has an impact both at an organisation level and at a personal level. At a company level, absences due to illness cost the rail industry £218 – 327 million per year (RAIB, 2009), which is even greater than the annual budget for the NHS (OOR, 2011). At the personal level, fatigue brings negative well-being and long-term ill health to members of the staff, which can, in turn, negatively impact train safety.

According to ORR (2011), many rail companies still appear to adopt a reactive approach to ill health, with an emphasis on pre-employment screening, palliative care, and managing for attendance, rather than on preventing and managing work-related fatigue. To address this concern, ORR implemented a 5-year project (ORR, 2010) to promote a culture of fatigue management and health management in the UK rail industry. Recently, the rail industry became aware of the importance of managing fatigue (ORR, 2012), and the ORR (2014) implemented another 5-year project (i.e., from 2015 to 2019) for monitoring and managing fatigue in the workplace.

3.2.4 Previous Studies of the Railway Fatigue

Fatigue is a severe problem in the transport sectors, including road, sea, air and rail. Smith (2007) reviewed fatigue in these transport sectors. This research indicated that the different transport sectors have similar fatigue-related problems and the scientific approach to fatigue used to define general principles should apply to all these sectors. However, Smith also suggested that a “one size fits all” approach to regulation may be inappropriate to all, as there are different features between industries. Phillips (2014) reviewed research on fatigue in operators working on road, sea, and rail. His review found that although the features of the transport sector influenced the focus of studies, there was good coverage of the effects of both psychosocial work factors (e.g., workload, control support) and working time on sleep and fatigue. Also, the outcomes of fatigue in transport sectors are self-reported well-being, general health, shift-work disorder, mood, and objective psychomotor performance. In the rail industry especially, poor work-life balance and sickness absence are considered to be the outcomes of fatigue.

Just like other workers, rail staff are exposed to general work characteristics associated with fatigue. They are also subject to industry-specific factors potentially related to fatigue. For example, harsh working environments, tasks requiring sustained vigilance, and shift-work systems have been associated with fatigue (Lal and Craig, 2001; British Office of Rail Regulation, 2012). Since automation technology has been applied in the workplace, work in the railway industry imposes more cognitive demands while physical demands have diminished (Young et al., 2015). The jobs requiring sustained vigilance in the modern rail transport may result in heavy mental workload and increased fatigue. Moreover, fatigue is considered to be a causal factor in train accident and incident reports (British Rail Safety Standards Board, 2005; British Rail Accident Investigation Branch, 2008, 2010). Recently, fatigue and its impact on safety-critical performance have been suggested as a key issue in the rail industry (Bowler and Gibbon, 2015); however, thus far, no systematic attempt to determine levels of staff fatigue in the rail industry, and the associated risk factors has been made.

In order to address fatigue in the rail industry, it is important to first place the research questions in context by systematically reviewing the existing literature. The present article aims to provide a preliminary description of the literature on fatigue in the rail sector. It is intended to cover both papers published in refereed journals and reports from trade organizations and regulators. In light of past studies, the features of rail crew fatigue and mechanisms for measuring the effect of fatigue on performance are suggested as search areas.

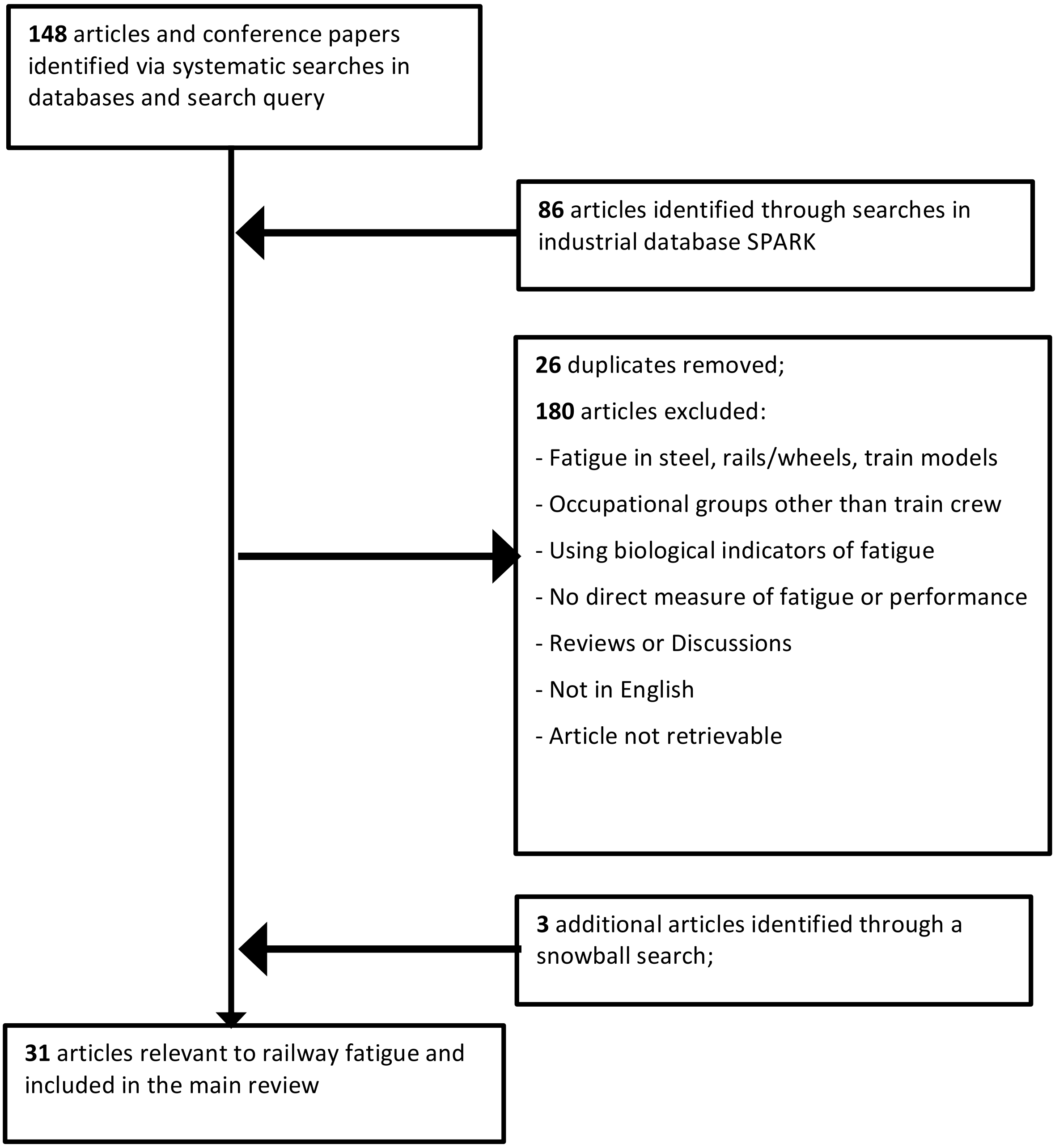
3.3 SEARCH METHODOLOGY FOR REVIEW OF RELEVANT LITERATURE

The main search engines used for literature searches were PubMed, Google Scholar, and Scopus. The search terms used were “railway fatigue,” “rail fatigue,” “train staff fatigue,” and “train driver/controller/conductor fatigue.” References within the resulting papers were also checked for useful research.

The papers reviewed in this article described original research concerning the predictors of fatigue and the effects of fatigue on performance in the railway industry. Studies were considered eligible if (a) participants were members of the train crew, (b) research questions involved the factors associated with train crew fatigue, (c) fatigue was assessed through subjective ratings of fatigue or its synonyms (e.g., tiredness or alertness), or through objective measures of fatigue or performance, and (d) research articles provided data. Duplicate articles and research that primarily concerned ergonomic factors, train models, and biological indicators of fatigue (e.g., heart rate) were excluded. The numbers of papers excluded and included are summarized in Figure 3.1.

Historically, the field of rail fatigue research has been smaller than that of other transport groups; thus, there is very little relevant literature on train crew fatigue and its countermeasures. For example, a search of “railway fatigue” via Google Scholar, showed there were 84 results in total, only one of which actually related to the current study. SPARK, a database for the railway industry sector incorporating the Rail Safety and Standards Board (RSSB) Human Factors library, was used, therefore, for searching further related literature. In addition, 13 government or organization documents published on the websites of the United Kingdom's ORR, RAIB, and RSSB, the Swedish National Road and Transport Research Institute, and the Japanese Railway Technical Research Institute were related to this study and were also reviewed.

Figure 3.1 *Flow chart illustrating the process of selection of articles for main body of literature review*



3.4 RESULTS

As shown in Figure 3.1, 148 papers from science databases and 86 papers from the industrial database SPARK were identified through systematic searches. Based on full-text reading, 31 studies were included in the main review and these articles are marked with an asterisk in the reference list. The main exclusion criterion was fatigue not being measured through subjective or objective methods. Table 3.1 shows the details of the reviewed studies. The sample size of these studies varied from n = 9 in a field study with continuous rest time and vigilance performance measured over 3 days, to n = 1,758, in a large-scale cross-sectional online questionnaire. Sixty-five percent of the studies were based on large samples (i.e., sample size equal or larger than 50). Train drivers were the most commonly examined group, followed by engineers and controllers (i.e., dispatcher or signalman). Five studies compared more than two job role groups. The most common focus in terms of risk factors for fatigue was the working time factor (65%; n = 20) and the working demands factor (61%; n = 19), followed by the sleep and rest factor, working environment factor, and individual differences. As for fatigue measurement, 17 studies used subjective measures, three studies used objective measures, and the remaining studies used both.

3.4.1 Risk Factors for Railway Fatigue

Fatigue is difficult to define, with many different and complex symptoms in different jobs, but the British Office of Rail Regulation (2012) defines railway fatigue as a state of “perceived weariness that can result from prolonged working, heavy workload, insufficient rest, and inadequate sleep” (p. 6). This definition implicates potential causes of fatigue and makes the distinction between task-related and sleep-related fatigue. Task-related fatigue usually reflects the workload of the task being carried out, working hours, and shift-work, while the sleep-related fatigue is affected by sleep loss and insufficient rest.

In earlier research, Pollard (1990) explored the risk factors of different working patterns for train drivers, particularly those factors which might contribute to fatigue. The main causes of fatigue that interviewees frequently mentioned were long working times, heavy workload, shift-work, and poor working environments. In addition, long commute times, uncertainty of on-call jobs, and conflicts with other job roles were reported to be potential stressors causing fatigue. In later studies, such risk factors for fatigue were identified in different job roles of train crew (e.g., controllers; Gertler and Nash, 2004). The risk factors described in the following sections are working hours, workload, timing of work (i.e., shift-work), job type and environment, lifestyle and other individual factors, sleep and rest.

3.4.1.1 Working Hours

Seventeen studies reported the effects of work demand factors on fatigue. Among these studies, nine longitudinal/process studies investigated the length of work time, with seven focusing on train drivers (McGuffog et al., 2004; Darwent et al., 2008; Dorrian et al., 2008; Prakash et al., 2011; Cabonl et al., 2012; Robertson et al., 2013; Kazemi et al., 2016), and two on controllers (Popkin et al., 2001; Korunka et al., 2012). Overall, no matter whether in passenger or freight train operating companies, the train drivers working longer hours had higher fatigue scores than those working fewer hours. Darwent et al. (2008) stated that significant cumulative fatigue and sleep loss appeared throughout the duration of driving. Drivers were, however, able to sustain vigilant performance during driving despite having incurred a significant sleep debt. Kazemi et al. (2016) suggested that train drivers on long-haul trips usually had longer rest periods between the outward trip and return, which could compensate for the side effects of long working times. The results of the fatigue studies on controllers were similar to those on train drivers.

3.4.1.2 Workload

Workload was examined in 12 studies, with five cross-sectional mail surveys (Prakash et al., 2011; Zoer et al., 2011; Cotrim et al., 2017; Fan and Smith, 2017; Tsao et al., 2017) and eight longitudinal studies (Popkin et al., 2001; Roach et al., 2001; McGuffog et al., 2004; Dorrian et al., 2007b, 2008, 2011; De Luca et al., 2009; Dunn and Williamson, 2012). These studies all showed positive associations between workload and fatigue either in train drivers or in other train crew members. Tsao et al. (2017) found that workload and overtime work led to fatigue in both drivers and engineers, while Fan and Smith (2017) found that high workload resulted in higher subjective fatigue across the train crew. A study of train drivers (Dorrian et al., 2007b) showed that with a high workload, high levels of fatigue resulted in cognitive disengagement from the driving task, leading to a dramatic increase in accident risk. Zoer et al. (2011) noted that the high workload in train crew (especially in the younger crew members) was associated with higher levels of fatigue, as well as higher risk of mental health complaints. De Luca et al. (2009) explained that the physiological effort required to remain a necessary level of alertness and performance under monotonous conditions resulted in oxidative stress which indicated fatigue.

3.4.1.3 Timing of Work

Twenty-three studies investigated the effect of time into the work period and the differences between night shifts and day shifts. Among these, six were cross-sectional mail surveys (Kibblewhite, 2003; Ku and Smith, 2010; Zoer et al., 2011; Zimmermann et al., 2015; Cotrim et al., 2017; Fan and Smith, 2017), and 17 were longitudinal/process studies (Popkin et al., 2001; Roach et al., 2001; Harma et al., 2002; McGuffog et al., 2004; Dorrian et al., 2006, 2007a, 2008, 2011; Darwent et al., 2008, 2015; Jay et al., 2008; Cabonl et al., 2012; Korunka et al., 2012; Paterson et al., 2012; Cebola et al., 2013; de Araújo Fernandes et al., 2013; Robertson et al., 2013). Most of these studies showed that night shifts result in fatigue (e.g., Dorrian et al., 2011), as well as sleepiness and cumulative sleep loss (Darwent et al., 2008; Cotrim et al., 2017). First, Popkin et al. (2001) observed that fatigue developed more quickly during night shifts than during day and evening shifts. Then, Harma et al. (2002) found that in both night shifts and early morning shifts, fatigue and severe sleepiness at work were very common. Darwent et al. (2015) suggested that fatigue during the shifts was mainly affected by amounts of rest and sleep before work. Korunka et al. (2012), however, suggested that fatigue during the shift was not only affected by recovery during break phases before work, but also by fatigue at shift onset and perceived workload during the shift.

3.4.1.4 Job Type and Environment

Generally, most of the existing research investigated fatigue in train drivers; however, train drivers are not representative of all rail staff. In this review, 15 studies sampled different job roles in the rail industry, including railway controller, conductor, engineer, or station worker (Popkin et al., 2001; Roach et al., 2001; Harma et al., 2002; Sherry and Philbrick, 2004; Ku and Smith, 2010; Dorrian et al., 2011; Prakash et al., 2011; Zoer et al., 2011; Korunka et al., 2012; Paterson et al., 2012; Cebola et al., 2013; ärmä et al., 2014; Zimmermann et al., 2015; Cotrim et al., 2017; Fan and Smith, 2017; Tsao et al., 2017).

Three studies focused on fatigue in railway controllers (Popkin et al., 2001; Korunka et al., 2012; Cotrim et al., 2017), two in engineers (Roach et al., 2001; Cebola et al., 2013) and one in conductors (Härmä et al., 2014). The results of these studies showed a high prevalence of fatigue in these job roles during night shifts. In addition, fatigue caused the train engineers to disengage from work, and there was a trade-off between safety and efficiency (Roach et al., 2001), particularly for those who were working on-call (Cebola et al., 2013). Härmä et al. (2014) studied fatigue in conductors and noted that the conductors were exposed to very high levels of noise, which could be above the recommendation of the World Health Organization (WHO). Such noise could adversely affect working performance, cause intolerance or distraction, and result in poor health outcomes (e.g., fatigue, tinnitus).

Another 10 studies compared two or more job roles in the railway industry. Differences in workload, work hours (i.e., length of work, the percentage of night shifts, and the number of consecutive shifts), and sleep loss were found across different job roles (Harma et al., 2002; Dorrian et al., 2011), and were consistent with the nature of each role. For example, the engineers worked a high percentage of night shifts because most train maintenance and rail repairs were scheduled at night to avoid daytime traffic and allow trains to be used in the day. Additionally, environmental factors such as noise level in the workplace seemed to appear in particular job roles and affect fatigue (Prakash et al., 2011; Härmä et al., 2014). For instance, noise and vibration had more impact on conductors and drivers and were associated with their fatigue, while fumes were more likely to affect the engineers but were not found to contribute to their fatigue (Fan and Smith, 2017).

3.4.1.5 Lifestyle and Other Individual Factors

Five studies investigated individual differences, with three investigating lifestyle (Roach et al., 2001; Paterson et al., 2012; Fan and Smith, 2017), one age (Zoer et al., 2011), and one chronotypes (de Araújo Fernandes et al., 2013). Fan and Smith (2017) found that train crew members with an unhealthy lifestyle or negative personality were more likely to report high fatigue. The other two studies involving lifestyle suggested that smoking and drinking alcohol were related to performance impairment, while no effect of caffeine consumption was found. Smokers reported lower subjective sleep quality, which could increase fatigue-related risk. The impairment in performance and safety due to fatigue was in a range similar to that associated with the levels of alcohol consumption (Roach et al., 2001). Zoer et al. (2011) noted that heavier emotional and mental workloads in the younger staff members and lack of social support for older staff members were associated with fatigue and ill health. de Araújo Fernandes et al. (2013) stated that evening chronotypes remained awake for a longer time before the night shift and had worse life quality compared to morning types. However, there was no significant difference in fatigue and performance between these two chronotypes.

3.4.1.6 Sleep and Rest

Twelve studies reported the effect of sleep and rest on fatigue. Sleep and rest variables commonly studied were usually collected using standard self-report measures and included sleep length, sleep quality, rest time during work, and frequency of rest (Jay et al., 2008; Dorrian et al., 2011; Prakash et al., 2011; Cabonl et al., 2012; Cebola et al., 2013; Robertson et al., 2013; Zimmermann et al., 2015; Tsao et al., 2017). Sleep quantity and quality were also collected objectively in several studies using actigraphs (Sherry and Philbrick, 2004; Dorrian et al., 2007a, 2011; Paterson et al., 2012; Darwent et al., 2015). These studies supported the view that sufficient sleep and rest helps the train crew recover from fatigue. Also, the prophylactic napping before starting shift-work helps crew members cope with fatigue (Jay et al., 2008; Darwent et al., 2015). Sleep deprivation which is influenced by shift-work, results in fatigue and sleepiness at work (Cabonl et al., 2012). Darwent et al. (2015) found that higher levels of fatigue were generally associated with significant reductions in the amount of sleep obtained before shifts, despite the individual differences in fatigue resistance (e.g., smoking or not, different chronotypes).

3.4.2 Fatigue Measurement in These Studies

Thirty studies used subjective measures, objective measures (mainly the Psychomotor Vigilance Test; PVT), or both. There was one study which used a biological measurement of oxidative stress as an indicator of fatigue (De Luca et al., 2009). Seventeen studies only used subjective fatigue measures, including visual analog scales (VAS), the Samn–Perelli Fatigue Checklist, the Job Stress Rating Scale (JSRS), and other self-assessments (Harma et al., 2002; Kibblewhite, 2003; McGuffog et al., 2004; Ku and Smith, 2010; Dorrian et al., 2011; Prakash et al., 2011; Zoer et al., 2011; Cabonl et al., 2012; Dunn and Williamson, 2012; Korunka et al., 2012; Paterson et al., 2012; Cebola et al., 2013; Robertson et al., 2013; Härmä et al., 2014; Zimmermann et al., 2015; Kazemi et al., 2016; Cotrim et al., 2017; Tsao et al., 2017). In contrast, three studies used only objective fatigue measures, including the PVT (Darwent et al., 2008) and the Fatigue Audit InterDyne (FAID; Dorrian et al., 2007a; Darwent et al., 2015). The rest of the studies used both kinds of measures (Popkin et al., 2001; Roach et al., 2001; Sherry and Philbrick, 2004; Dorrian et al., 2006, 2007b, 2008; Jay et al., 2008; Dunn and Williamson, 2012; de Araújo Fernandes et al., 2013). The subjective fatigue measures were suitable for diary studies, where train crew could report their acute fatigue levels before, during, and after a shift (Harma et al., 2002; McGuffog et al., 2004; Jay et al., 2008; Dorrian et al., 2011; Korunka et al., 2012; Paterson et al., 2012; Cebola et al., 2013; Robertson et al., 2013). Dorrian et al. (2008) compared simulated driving, the PVT, and subjective ratings. They found that the self-ratings were more strongly associated with PVT performance than the “real world” tasks.

Table 3.1 *Characteristics of Reviewed Studies about Risk Factors of Fatigue in the Railway*

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
Cabonl et al. (2012)	Survey: N =565 Field Study: N = 25 Train Driver In France	Evaluation of the impact of hours of work on fatigue.	Survey: Fatigue & Shift-work Questionnaire Field study: Karolinska Sleepiness Scale (KSS)	Working demand factor: working hour Working time factor: time to work Sleep & rest factor: sleepiness, sleep loss, sleep quality	A large amount of sleep deprivation is associated with some duty hours (night and morning) which result in fatigue. Sleep loss is significantly increased when working periods have more than 5 to 6 duties. Subjective sleepiness is at a moderate level before the trips and increases after the trips. Fatigue should be managed both at organisational and individual level.
Cebola et al. (2013)	N = 24 Engineer (Fleet) In the U.K.	Investigation of the particular relationship between on-call work, shift work, fatigue, anxiety performance, and mood.	5-point rating scales Diary	Working time factor: uncertainty on-call job, shift work Sleep & rest factor: poor quality of sleep	The results show that on-call work leads to an increase of anxiety, affects the sleep quality of on-call workers, and leads to increased fatigue when compared to not on-call work.
Cotrim et al. (2017)	N = 97 (all males) Railway controllers	Investigation of the influence of work and individual determinants in sleepiness.	5-point rating scales in the Questionnaire REQUEST	Working demand factor: job demand Working time factor: night shift	The main predictors of sleepiness were job demands, job satisfaction, and night shift fatigue.

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
	Age: M = 44.8 Seniority M = 21.7, with 50% of the sample worked for more than 13 years In Portugal		Copenhagen Psychosocial Questionnaire II (COPSOQ II)	Psychosocial work factors: job satisfaction	High prevalence of fatigue during the night shift. High levels of dissatisfaction with shift system may have influenced fatigue perception.
Darwent et al. (2008).	N = 10 (all males) Train driver Age: mean(SD) = 43.30 (±7.42) In Australia	Examination of the sleep and vigilance performance of train drivers during an extended 106-hr relay operation (included a 16-hr layover).	Hand-held psychomotor vigilance task (PVT)	Working demand factor: long time work Working time factor: shift-work	Significant cumulative sleep loss appeared across duration of the operation. Drivers sustained vigilant performance for the duration of operation despite significant sleep debt.
Darwent et al. (2015).	N = 322 (309 males, 15 females) Train driver Age: 39.5 (±14.2)	Development of sleep transfer functions describing the likely distributions of sleep around fatigue level.	Fatigue Audit InterDyne (FAID)	Working time factor: shift-work (6:00 am to 1:59 pm, 2:00 pm to 9:59 pm, and 10:00 pm to 5:59 am.) Sleep history	Higher fatigue score categories were associated with significant reductions of sleep obtained before shifts. Only minor differences in prior sleep amounts were observed between morning, afternoon, and night shifts.

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
	Been shift workers for 19.3 (±9.0) years In Australia				
de Araujo Fernandes et al. (2013)	N = 91 (all males) Train driver In Brazil	Comparison of the sleep pattern, fatigue and life quality between different chronotypes in train drivers.	Visual analogue scale; Subjective questionnaire Psychomotor Vigilance Task (PVT)	Working time factor: shift-work, time into work period (four days) Individual difference: chronotypes	Evening types remained awake for a longer time before the night shift and had worse life quality compared to morning types. No significant difference of fatigue and PVT performance between different chronotypes.
de Luca et al. (2009)	Total N = 136 Rail group N = 63 (60 males, 3 females) Train engine drivers Age: 26–53 Professional seniority (years): 3 – 30	Studying the biochemical features of oxidative and neurological stress in the blood and urine of three selected groups of professionals at high health risk (e.g., train engine drivers, pilots, and cosmonauts) to prove the working hypothesis that a relevant molecular basis for their fatigue and professional	Lipophilic/hydrophilic low-molecular weight antioxidant (AO) and AO enzyme activities Nitric oxide, superoxide anion, hydroperoxide production Urinary catecholamine/ serotonine metabolites and lipoperoxidation markers	Working demand factor: the physiological effort required to regain a level of alertness which allows adequate performance under monotonous conditions	The Rail group displayed a significant AO depletion, with severely depleted plasma levels of vitamin C, accounting for inadequate diet regimen. Detoxification mechanisms were also impaired in the whole group. This group are subjected to alteration of sleep schedules and circadian rhythm and, most importantly, to monotony stress, which is a consequence of the physiological effort required to regain a level of alertness which allows adequate performance under monotonous conditions,

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
		stress-related health disorders could be the impaired equilibrium between oxidant/antioxidant levels in the organism.			necessary to avoid train malfunction and life-threatening accidents. The consequent psychoemotional wear, connected with the responsibility for the life of passengers, is among the main causes of frequent occurrence of burnout syndrome and immunological dysfunction. To control the health hazards, it is strongly recommended the supplementation of chemopreventive agents, to allow the restoration of adequate AO defenses.
Dorrian et al. (2007a)	N = 50 (all male) Age: 24–56 Train driver	Investigation of the effects of fatigue on train driving using data loggers.	Fatigue Audit Interdyne (FAID)	Working time factor: shift work Rest and sleep factor: rest time	Fatigued driving becomes less well-planned, resulting in reduced efficiency (e.g. increased fuel consumption) and safety (e.g. braking and speeding violations). Fatigue may manifest differentially depending on track grade. In certain areas, fatigue causes increased fuel use and economic cost, and in others, reduced safety through driving violations.

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
Dorrian et al. (2006)	N = 20 (all males) Train driver Age: 39.4 ± 9.4 In Australia	Investigation of the relationship between fatigue, braking behaviour and speeding during four speed-restricted areas on a simulated train track.	10-min PVT VAS alertness rating	Working time factor: shift-work (10:00 to 18:00, 23:00 to 07:00) Outcomes: more errors, less brake, higher speed	As expected, increases in fatigue produced increases in frequency and duration of attentional lapses. Translating PVT lapse durations into operational terms, a train driver will have travelled between 25 m and 125 m during the lapse period. Clearly, this could have a significant effect on the ability to plan and negotiate a speed restriction adequately, and as a consequence, pose a serious safety risk.
Dorrian et al. (2007b)	N = 20 (all males) Train driver In Australia	Investigation of the effects of sleep loss and fatigue on performance in a rail simulator.	PVT Self-rated performance Visual Analogue Scales: alertness	Working demand factor: workload (number of penalty brake applications)	High levels of fatigue result in a cognitive disengagement from the driving task, lead to a dramatic increase in accident risk. Ratings were more accurate for PVT performance than for the “real world” task.
Dorrian et al. (2008)	N = 15 (9 males, 6 females) Train crew In Australia	Examination of the validity and reliability of using the EDA to assess elevated levels of sleepiness	Samn–Perelli Fatigue Checklist Psychomotor vigilance (PVT)	Working hour factor: time into work period (3 days)	Simulated driving, PVT, and subjective ratings indicated increasing sleepiness and fatigue during the experimental period. The electrodermal activity (EDA) indicator did not sense increased

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
		and reduced alertness.		Work demands factor: 28 h of sustained wakefulness	sleepiness and fatigue at levels produced in the present study.
Dorrian et al. (2011)	N = 90 Driver, controller, guard, resurface crew, signaller, terminal operator In Australia	Investigation of sleep, work hours, workload, and fatigue in a series of field studies involving a wide variety of job types in the railway industry, including drivers, train controllers, guards, resurface crews, signallers, and terminal operators.	Samn–Perelli Fatigue Scale Actigraphs	Working demand factor: workload, working hours Working time factor: shift work Sleep & rest factor: sleep hours Other: job role	Sleep length, wakefulness, work hours, and workload significantly influences fatigue. Fatigue at work is likely to be as prevalent for other job roles (e.g., signallers) as it is for drivers. Differences in work hours (shift length, percentage of night shifts and number of consecutive shifts) and sleep/wake cycle were found across different job roles. For example, the resurfacing crew worked a high percentage of night shifts because most track repairs are scheduled at night to avoid daytime traffic. Differences in reported workload across job roles were clear and consistent with the nature of each role.
Dunn and Williamson (2012)	N = 58 (all males) Train driver	Examination of the effect of cognitive demand on train drivers' driving	Visual analogue scale, Driving Fatigue Questionnaire (slightly modified for train	Work demand factor: cognitive demands	There were seriously detrimental effects of the combination of monotony and

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
	In Australia	performance on monotonous routes	driving rather than car driving)		low task demands on fatigue and performance. A relatively minor increase in cognitive demand can mitigate adverse monotony-related effects on performance for extended periods of time.
Fan and Smith (2017)	N = 1067 Conductors, drivers, station workers, engineers, administrators, managers, at-seat catering stewards, and controllers.	A large-scale survey investigating whether workload (high job demands) was associated with fatigue.	Smith Well-being Questionnaire (SWELL), derived from the Well-being Process Questionnaire (WPQ)	Work demand factor: job demand Working time factor: shift work Job resources: job support and control, organisational factors Working environment factor: exposure to noise and vibration Individual difference factor: personality, health-related lifestyle	High workload, poor job control and support, shift-work, exposure to noise and vibration, unhealthy lifestyle and negative personality would result in fatigue. As one of the several predictors of subjective fatigue, high workload results in higher levels of subjective fatigue. Meanwhile, both high workload and high levels of subjective fatigue were found to correlate with poor subjective reports of performance efficiency.
Hamidi et al. (2014)	N = 167 (all males)	Investigation of noise among train	Self-assessment of fatigue	Working environment factor: noise	Conductors' noise exposure level was very high and much above the recommendation of the

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
	Conductor Age: 29.3 ± 3.2 In Iran	conductors and its consequences.			World Health Organization (WHO). Noise adversely affects work performance and causes intolerance or distraction. High level of noise and noise annoyance among train conductors resulted in poor health outcomes (e.g. fatigue, sleeplessness, tinnitus) of the conductors.
Harma et al. (2002)	N = 230 (all males) 60.4% train driver, 51.1% controllers In Finland	Examination of the prevalence of severe sleepiness at work in train drivers and controllers. The effect of different shift and sleep history on the risk of severe sleepiness at work.	5-point Visual analogue scale Diary	Working time factor: shift work (i.e., early morning shift, day shift, evening shift, night shift), time to work	Fatigue and severe sleepiness at work are very common among train drivers and controllers, especially during night shifts and early morning shifts. Shift timing, shift length, and off-duty time, in addition to actions aimed at extending the main sleep period, would probably decrease severe sleepiness in railway transportation.
Jay et al. (2008)	N = 9 (all males) Train driver	Investigation of the impact of a shift system on drivers' fatigue and recovery	Samn–Perelli Fatigue Checklist	Working time factor: 8h-8h-off	While there was a clear trend for fatigue levels to be elevated at the end of each working shift, each 8-hour rest period

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
	In Australia	in 3 days following each trip.	Psychomotor vigilance task (PVT)	Sleep & rest factor: rest time	appeared sufficient to reduce fatigue to levels recorded prior to departure.
Kazemi et al. (2016)	N = 97 (all males) Train driver In Iran	Comparison of train drivers' fatigue and workload between long-haul and short-haul trips.	7-point Samn-Perelli Fatigue Scale	Working demands factor: long/short work hours	Fatigue reached a high level at the end of work. Fatigue and workload were not very different in both long shifts and short shifts.
Kibblewhit (2003)	N = 15 (14 males, 1 female) Driver in Train Operating Company (TOC)	Investigation of the risk factors of fatigue-related inattention and distraction for train safety.	Self-report fatigue 45-min interview	Working time factor: shift work, shift length Job resources: communication, job control Work environment factor: cab temperature	Shift work was identified as an aspect of the role and the consequent which fatigue accrued, leading to potential inattention. Heat, fatigue, and monotony are factors that may reduce the driver's ability to maintain active cognitive control.
Korunka et al. (2012)	N = 626 Controller In Europe	Investigation of the role of recovery and detachment in the break period between two shifts for fatigue.	Diary study: self-assessment of the current level of fatigue	Work demand factor: long work times (12 hr day shift-24 hr off- 12 hr night shift, 24 hr off-12 hr night shift, 48 hr off-12 hr day shift)	Fatigue during the shift was not only affected by recovery and psychological detachment during break phases before work but also by fatigue at shift onset and perceived workload during the shift. Workload affects fatigue in the day shift but fades away in the night shift. Both

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
				Working time factor: time to work	psychological detachment and recovery are important off-the-job inhibitors of fatigue after 4-hour shifts but not 8- or 12-hour shifts.
Ku and Smith (2010)	N = 125 (124 males, 1 female) 45.9% engineers, 54.1% conductors In United States	Examination of the job-related factors on fatigue, health, and social well-being	Four questions about fatigue: Sleep Quality, Anxiety and two POMS factors (Fatigue – Inertia, Vigour – Activity)	Working time factor: work scheduling Job resources: social support, organisational factors	Social support is an important mediator between scheduling and fatigue. Organisational factors and scheduling items had the same underlying structures and could be combined into one factor.
McGuffog et al. (2004)	Questionnaire: N = 460 Diary Study: N = 22 Train driver In the UK	Investigation of the fatigue-related risk of current shift patterns and the strategies for risk reduction and control.	Questionnaire 28-day diary	Working demand factor: mental workload, cumulative duty hours, without break Working time factor: shift work (early morning shift), time of day, commuting time Work environment factor: noise	The main issue that has been identified relating to fatigue and accident risk was shift-work. Early starts are a feature of railway operation and may be associated with particular problems when effects due to the restriction of sleep prior to duty are exacerbated by high work rates in the morning hours. Another issue is the role of rest days in limiting the build-up in fatigue after a long sequence of consecutive shifts.

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
Paterson et al. (2012)	N = 40 (37 males, 3 females) 23 train driver 17 other (engineer, shunters, and team leaders) Age: 45.1 (±12.5)	Investigation of the sleep behaviour of shift workers to identify employees who are more likely to be impaired by fatigue.	Samn–Perelli fatigue scale Work diary (2 weeks) Actigraphs	Working time factor: shift work Individual difference: parent or not, smoking or not Sleep & rest factor: sleep quantity and quality	Differences in work type and workload may influence sleep. Participants with dependents were found to obtain significantly less sleep than participants without dependents. Smokers reported lower subjective sleep quality, independent of sleep type (i.e., day or night).
Prakash et al. (2011)	N = 200 50% health train driver, 50% controller (a sedentary job)	Identification of job-related factors in the railway and environment stressors of railway engine pilots' fatigue and their level of occupational stress.	Job Stress Rating Scale (JSRS)	Work demand factor: workload/ long duties Rest & sleep factor: improper rest Working environment factor: noise, vibration Other: job role	The study reveals that Railway Pilots have high levels of job stress while controllers have mild levels of job stress. Job stress has been found to significantly correlate with stressors like vibration, noise, long duties, improper rest, sleep disturbances, irregular food habits, and fatigue.
Popkin et al. (2001)	N=37 Controller	Examination of sources and levels of railroad controller's	Subjective rating 14-day sleep log	Working demand factor: overwork	The results identified that shift work contributes to fatigue. Fatigue for both freight and passenger operation despatchers accumulated more

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
	20 from freight, 17 from passenger train In United States	workload, stress, and fatigue.	Actigraphy (sleep/awake cycle)	Working time factor: Shift work (especially night shifts)	quickly during night shifts than day and evening shifts.
Roach et al. (2001)	N = 20 (all male) Engineer Age: 39.4 (±9.4) In Australia	Quantify the effects of fatigue on performance in a simulated work environment (the rail simulator) and compare them with the effects of alcohol consumption.	Psychomotor vigilance (PVT) Self-assessments of alertness and performance	Individual difference factor: alcohol Working time factor: Night shift Work demand factor: workload (two or three consecutive night shifts)	Fatigue caused participants to disengage from operating the simulator so that the safety was traded off against efficiency. The neurobehavioural performance impairment due to fatigue was similar to that associated with moderate levels of alcohol consumption.
Robertson et al. (2013)	N = 102 Freight train driver Mean age: 46	Investigation of the factors which contribute to the onset of fatigue. Evaluation of fatigue effect on work, accidents, and incidents.	Samn–Perelli Fatigue Scale Diary	Working demand factor: length of work Working time factor: time of day, shift work Sleep & rest factor: the extent of the recovery	Freight drivers often experience long periods of inactivity waiting for track access and long periods without a break, plus requirements to work at night. There are also last-minute extensions to the shift duration due to delays. These factors have the potential to contribute, singly or in combination, to levels of fatigue and the overall risk of accidents.

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
Sherry and Philbrick (2004)	N=21 Engineer	Evaluation of the functionality of improving individual fatigue management in railroad engineer with actigraph feedback.	Self-assessment (Denver Fatigue Adjective Checklist, Stanford Sleepiness Scale, etc.) 30-day sleep log, Actigraphy	Rest and sleep factor: sleep activity, work/rest habits	The readings (or the feedback) of performance on actigraphs made participants more aware of their fatigue levels to a considerable or greater degree and increased their awareness of the need for rest.
Tsao et al. (2017)	N = 524 297 engineers (male = 282, female = 15) 227 drivers (all male, 95.2% from freight) In China	Investigation of fatigue prevalence in Chinese railway employees, and the influential factors of their fatigue.	Self-assessment (MFI-20, NASA-TLX, questionnaire of fatigue-related factors)	Working demand factor: workload, overtime work Working environment factor: Physical working environment (noise, vibration, light, temperature, comfort) Job resources: job control work/rest rhythm	For the locomotive employees, higher workload and working overtime led to fatigue. For the rail maintenance department, workload and work/rest rhythm directly influenced fatigue, while workload was influenced by work/rest rhythm and the intensity of overtime work. They suggest that managers in the railway system should arrange an appropriate work/rest schedule and improve the physical working environment for the operators to manage the fatigue of railway employees.

Reference	Sample Size and Characteristics	Study Purpose	Fatigue Measurement	Risk Factors	Fatigue-Related Outcome
Zimmermann et al. (2015)	N = 1758 Train crew In Canada	Investigation of the overall picture of the fatigue status in the Canadian on-call freight rail staff.	Subjective fatigue rating (online)	Work demand factor: long working hours Working time factor: unpredictable schedule (earlier shift), on-call job task. Sleep & rest factor: sleep, opportunities for rest	Train crews routinely operate while fatigued, which remains a safety issue. Fatigue is normalized as part of the job and not taken seriously as a safety issue at various management levels. Such cultural issues and the production goals are usually prioritised over safety. The conflict of interest created by remuneration schemes may pose obstacles to progress on fatigue risk management.
Zoer et al. (2011).	N = 827 278 Train driver 193 Conductor 193 Station worker 155 Service electricians (engineer)	Exploration of the associations between aspects of psychosocial workload and mental health complaints in four age groups of railway workers.	Questionnaire on the Experience and Evaluation of Work (QEEW; Van Veldhoven et al. 2002)	Individual differences: age (22-35, 36-45, 46-55, 55+) Work demand factor: workload Other: job type	Worse emotional and mental workload in the younger employees and lack of social support in older employees were associated with fatigue and related to a higher risk of having mental health complaints.

3.4.3 Fatigue in Railway Accident or Incident Investigations

There were 98 rail investigation reports found in the SPARK database, 23 of which identified fatigue as one of the contributory causes of the train incident or accident (shown in Appendix A). Two Japanese reviews (Kogi and Ohta, 1975; Ugajin, 1999) state that the human error in railway accidents was associated with drowsiness, motivation, and time of day, which might also be related to fatigue. In Buck and Lamonde's (1993) review, evidence supported such relationships between critical railway accidents and train crew fatigue, as well as such factors as time of day, shift-work, and work-sleep-rest cycles. Recently, reviews of British rail incidents confirmed that fatigue was a cause in about 21% of the sampled high-risk railway incidents, in which fatigue mainly resulted from negative work-life balance, insufficient sleep, shift pattern design, and the control of working length (Gibson et al., 2015; Gibson, 2016).

These views were supported by an exploratory study of UK rail workers' perceptions of accident risk factors (Morgan et al., 2016). This study demonstrated the impact of shift-work, commuting time, work-life balance, and time pressure on perceived stress and fatigue at work. Moreover, decision-making and risk-management abilities were challenged and impaired by fatigue and the job demands caused by time pressure, resulting in increased risks of error, accidents, and incidents, and the increased likelihood of near-miss occurrences and underreporting. Dorrian et al. (2007a) observed that train operators with a higher risk of fatigue had more frequent speed violations and heavier brake use on flat sections of the route, both of which would increase the safety risk. In addition, time of day was found to affect fatigue and increased both the non-fatal and fatal injury risks of train crew during night-time work (Calabrese et al., 2017). Particularly for engineers and conductors, night time work was more hazardous than daytime work.

3.4.4 Fatigue Prediction Systems and Countermeasures in the Railway

The Driver's Safety Device is a basic safety protection system in most trains to prevent train catastrophes should the driver become incapacitated (e.g., fall asleep, lose consciousness). It is also commonly called the “dead man's handle” or “dead man's pedal.” When this safety device is not held in place by the driver, the brake will be activated. If the driver ignores audible and visual warnings that they should be taking appropriate action, automatic braking systems will be activated to stop the train (Phillips and Sagberg, 2014). Despite such devices, fatigue is still a serious risk to railway safety. Fatigue also presents dangers other than those related to sleepiness, such as inattention or poor decision-making (Phillips and Sagberg, 2014). Considering that drivers often have the power to override automatic systems, the mentally fatigued driver may be as much a risk as a sleepy driver to railway safety. Besides, the automatic braking system works only when the driver is fatigued already and is not adequate for addressing other train crew members' fatigue (e.g., controllers). Detecting and managing the train crew's fatigue in advance, therefore, is another strategy for safety protection.

Current fatigue detection by prediction systems in the railway industry can be classified into four categories (reviewed by Anund et al., 2015). The first group of systems is based on eye detection. This group of systems usually uses infrared cameras and measures eye blinks, gaze, and pupil size, but false alarms still occur. The second group of systems is based on physical activity, but is still being developed. The third group is part of the prediction system developed by the transport machine industry (e.g., the Automatic Train Control and Automatic Train Protection system). The final group of systems uses multiple measuring approaches and combines different types of sensors. The understanding of fatigue prevention and management, however, is hampered by a lack of instruments needed to measure fatigue.

The UK Health and Safety Executive (HSE) has its own fatigue prediction tool called the Fatigue and Risk Index (British Health and Safety Executive, 2006). It was designed primarily to assess and compare the risks from fatigue associated with rotating shift patterns, but it can also be used to identify any particular shift within a given schedule, that may be of concern. It calculates one fatigue index and one risk index based on cumulative fatigue, workload, alertness, shift length, time of day, commuting time, frequency and length of breaks, and the recovery from a sequence of shifts. It is important to note, however, that this assessment is limited, as it does not consider individual differences (e.g., lifestyle, age) or specific work-related issues (e.g., exposure to noise or vibration). The job role might also affect the risk of fatigue, but the mathematical formulae used in this assessment could not account for such variations.

The main coping strategies in the rail industry are breaks, napping, and caffeine use (British Rail Safety Standards and Board, 2012). Breaks are an effective way of controlling the build-up of fatigue. The finding of TRAIN, a Swedish research project, suggests that workers should take a 12-h break between shifts to avoid serious fatigue problems (Kecklund et al., 2001). Fatigue should be compensated with recovery and rest, not with economic compensation. Meanwhile, the Driving and Rest Time Hours in International Rail Transport Act (2008, p. 475) suggested taking a minimum 45-min rest after every 4.5-h working period. Shifts longer than 12 h lead to fatigue and increase the risk of accidents, and fatigue builds cumulatively with every successive shift when breaks in between are insufficient (Anderson et al., 2013). Although it is difficult to develop prescriptive rules that balance security and operational effectiveness efficiently at the organizational level covering the entire rail industry, it is important to build a framework of fatigue management that prescribes hours of work and rest, especially for shifts that last more than 12 h. The train companies could use fatigue modelling tools to improve shift-work arrangements (British Health and Safety Executive, 2006; British Rail Safety Standards Board, 2016a). The British Office of Rail Regulation (2011) recommended the use of a comprehensive sleep disorder management tool and promote the tool for fatigue management.

Napping is an effective countermeasure to address task-related fatigue. The British Rail Safety Standards Board (2005) found that napping was used as a coping strategy by one-third of drivers, especially prior to night shifts. Caffeinated drinks were used as a fatigue countermeasure by half of the train drivers in the RSSB survey (2005), and around 5% used caffeine tablets. The employees were informed about the adverse effects of caffeine as well as its benefits, together with advice to use it only when needed at work, as the body gets used to caffeine use and consequently, its effects are reduced. Armed with this information, the drivers would be able to choose whether to use caffeine as a fatigue countermeasure.

The strategy behind the use of these two countermeasures (i.e., napping and caffeine use), and evaluation of them, are not commonly seen in the literature. In addition, the safety bodies of the UK rail industry published several guidelines for train companies' use in managing fatigue and for staff members' use to self-check and deal with fatigue problems (e.g., British Rail Safety Standards and Board, 2012; British Rail Safety Standards Board, 2016 b, c).

3.5 DISCUSSION

Compared to other transport sectors, the amount of research on rail staff fatigue has been much smaller with little relevant literature. The objective of this thesis is to fill the gap in this field and enhance the knowledge on rail staff fatigue. Before conducting further studies, it is important to know about the existing knowledge in this area and where the gap is. The current chapter, therefore, aimed to provide a preliminary description of occupational fatigue in the rail industry.

This chapter reviewed the literature with the research question examining the risk factors associated with train crew fatigue, covering both papers published in referred journals and reports from trade organizations and regulators. It assessed the progress of research on railway fatigue, including research on the main risk factors for railway fatigue, the association between fatigue and railway incidents, and how to better manage fatigue in the railway industry. Systematic searches were performed in both science and industry databases. The searches considered studies published before August 2017. The main exclusion criterion was fatigue not being directly measured through subjective or objective measurements. A total of 31 studies were included in the main review. Ideally, this review should be a systematic review. However, it was done without a meta-analysis due to the very limited literature on this topic found and the different and varied variables used in those different papers.

Fatigue in the rail industry includes most of the features of occupational fatigue, and it is also subject to industry-specific factors. The causes of fatigue included long working hours, heavy workload, early morning or night shifts, and insufficient sleep. A poor working environment, particular job roles, and individual differences also contributed to fatigue. Due to the scarcity of relevant literature on train crew fatigue, the present review might be limited in its conclusions by the samples, parameters, and fatigue measurements in the studies. Currently, the effect of fatigue on well-being and the fatigued population in the railway industry are still not clear. Besides, the majority of the existing studies were conducted with a smaller sample size (e.g., Kibblewhit et al., 2003; Dorrian et al., 2008; Jay et al., 2008) focusing on only one or two job role groups. There was only one study (Dorrian et al., 2011) covering relatively more job groups, but with the limited sample size. A large-scale fatigue study covering all job roles in the rail industry was still lacking. Future studies can consider associations between occupational risk factors and perceived fatigue by examining the prevalence of fatigue and identifying the potential risk factors in staff within the railway industry.

3.5.1 Summary of Main Findings

Occupational fatigue is generally caused by workload, lack of control and support, working time, and individual differences, and it leads to performance impairment and ill health. Fatigue in the rail industry shows most of the features of occupational fatigue and is also subject to industry-specific factors. Previous research had indicated that railway fatigue was associated with workload, working time, shift-work, sleep and rest, and health-related behaviours. These risk factors for fatigue, however, seem to differ between job roles in the railway due to the nature of the duties, and the differences between job roles are still unclear.

Similarly, it is unclear if environmental factors affect fatigue, or if different job roles with different workloads result in different levels of perceived fatigue. Although the effect of fatigue on safety and health has been observed in government reports (British Rail Accident Investigation Branch, 2008; British Office of Rail Regulation, 2011; British Rail Safety Standards and Board, 2014), the evidence on the effects of fatigue on well-being and cognitive performance is less clear in the studies reviewed. Ku and Smith (2010) suggested that fatigue problems are associated with poor social well-being and more health complaints among train conductors and engineers, but there is still a lack of studies covering most of the other job roles.

Most of the existing studies used subjective fatigue ratings or both subjective fatigue ratings and the PVT to assess fatigue, suggesting that in future studies of railway fatigue, fatigue self-assessment and PVT will also likely be used. Although the PVT was broadly used as an objective indicator of fatigue, it is not clear how subjective fatigue is associated with PVT outcomes. Also, the current version of PVT is a portable testing device, but it is costly to use with large samples, which is a motivator for developing a lightweight and more convenient version of PVT (e.g., an online version of PVT). In addition, the diaries have been used to track and assess the changes in fatigue levels before, during and after a shift. Future studies could also try to combine cognitive performance tests with a fatigue diary.

Fatigue has gained attention in the railway industry, as it was one of the main contributing factors in human error-related rail accidents and incidents. Several fatigue management tools and systems have already been developed for use. However, it is commonly noted that there is a lack of systematic evaluations of whether these tools actually reduce fatigue (Anund et al., 2015). The main difficulty is monitoring and detecting fatigue in a timely manner, which would then allow the fatigue management tools to provide support to the fatigued train crew.

3.5.2 Comparison to Other Transport Sectors

As Smith (2007) suggested, the fatigue problems in rail transport are similar to those in other transport sectors. The risk factors for fatigue in rail include long working hours, heavy workload, shift-work, and insufficient sleep and rest, which also predict fatigue in other industries. Zoer et al. (2011) noted that compared with elder crew members, younger staff with a high workload were more likely to report higher levels of fatigue, and a greater risk of mental health complaints. The potential reason for this is because of the culture of the apprenticeship system in railway industry, where younger members may have less voice in choosing personal-preferred work patterns and will be more likely to have the heavier workload.

The Driver's Safety Device on trains is similar to those warning systems equipped on an aircraft, which is used to alert the pilot if the aircraft is in immediate danger (e.g., flying into the ground or having a collision with another aircraft). The shipping industry also has a similar system, the Vessel Traffic Service (VTS), which continuously monitors all ships to ensure the watch-keepers are alert and the ships are on the planned trip with no deviation.

Caffeine and napping are the common and main countermeasures of fatigue for the individual in all these sectors. However, napping during work is allowed in aviation, while staff should stay awake and alert in rail and other sectors. Compared with other transport workers, flight crew often have better rest policies and rest environments (Gregory et al., 2010). On some long-haul flights, pilots even have a room for rest with beds inside. Drivers in road transport often use short breaks during a journey to recover from fatigue, which involves stopping to take a short walk, while train drivers usually do not have enough time stopped at one station to have such a break.

3.6 RATIONALE FOR NEXT STUDIES

Previous research has indicated that high work demand, length of work, and shift-work cause railway fatigue. Individual differences, differences between job roles, and environmental factors may also be involved in the variation in fatigue, but currently there is a lack of evidence showing clear associations between these factors. In particular, very few studies have covered most of the job roles in the railway industry, very few of them were field studies, and limited research had used both subjective and objective fatigue measurement. The effect of fatigue on well-being and the fatigued population in the railway industry are still not clear.

The next study ideally will be a large-scale study among rail staff in the UK. It will first consider associations between occupational risk factors and perceived fatigue by examining the prevalence of fatigue and identifying the potential risk factors in staff from a TOC in the UK railway industry. The study will also build a detailed picture of the relationships between workplace stressors, individual differences, fatigue, and well-being outcomes, covering all job roles in the railway industry. It will cover the fatigue-related issues raised in railway accident reports and provide empirical support for potential organizational interventions to combat fatigue. Based on the knowledge gained from this large-scale fatigue study, further studies can be conducted using the combination of subjective and objective fatigue measurements on rail crew fatigue. A field study investigating occupational fatigue in real-life settings will also provide valuable information in this area.

CHAPTER 4: A SURVEY OF THE RELATIONSHIPS BETWEEN WORK, PERSONALITY AND FATIGUE IN RAIL INDUSTRY STAFF

4.1 INTRODUCTION

ORR (2012) defined fatigue as a state of 'perceived weariness that can result from prolonged working, heavy workload, insufficient rest and inadequate sleep'. This definition implicates potential causes of fatigue. In general, the causes of prolonged work fatigue are varied. First, fatigue is a result of high job demands (Moos, 1988; Hockey & Wiethoff, 1990) and low job control (Karasek, 1979). Job demand refers to workload, while job control refers to the personal ability to control work activities. Secondly, individual differences also play a role in fatigue. Many individual factors have been studied, including personality (Parkes, 1994b), coping type (French et al., 1982; Cox & Ferguson, 1991), and health-related behaviours (Laaksonen et al., 2009). Karasek (1979) noted that individuals can manage their job demands effectively in a controllable situation. In other words, the effect of job demands somehow depends on how individuals appraise and act in response (Hockey & Wiethoff, 1990). Thirdly, fatigue intimately relates to shift work. Shift workers may have little time to recover when working certain shift hours, which makes them more likely to suffer from chronic fatigue. Shift work disrupts the sleep-wake cycle (Ferguson, Lamond, Kandelaars, Jay & Dawson, 2008) and deprives workers of sleep (Åkerstedt, 1991), which in turn reduces performance (Kjellberg, 1977). Lastly, in the railway industry, the working environment and tasks requiring sustained vigilance may increase fatigue (ORR, 2012). Lal and Craig (2001) reviewed the known environmental factors affecting vigilance in the railway industry, which are noise, vibration, environmental pollutants, and a variety of stimuli. For example, exposure to higher levels of noise during driving can lead to driver fatigue, because of the after effect of noise on performance.

The combination of the risk factors listed above has a cumulative effect on occupational fatigue. In a large survey of the general working population (Smith, McNamara, & Wellens, 2004), high demands, low control and support, and exposure to physical hazards, combined with shift-work and long hours, showed significant associations with occupational stress. Moreover, the combined stressor score linearly related to the outcomes. Later, the studies of seafarer fatigue (Smith, Allen & Wadsworth, 2006; McNamara & Smith, 2002) suggested that the combined effect of many risk factors is the strongest predictor associated with fatigue. The combined effect of a range of factors associated with fatigue and its consequences, including reduced personal risk, health and well-being, is more significant than any individual factor.

4.1.1 Fatigue Models

Cameron (1973) suggested that the term fatigue is synonymous with a generalised stress response over time. This provides the rationale for applying stress models, such as the job demand-control (JDC) model (Karasek, 1979) and the expanded demand-control-support (JDCS) model (Johnson & Hall, 1988), in assessing fatigue. However, both JDC and JDCS were too narrow in scope and lacked a role for individual differences. Based on the potential causes of fatigue mentioned above, the demands, resources, and individual effects (DRIVE) model (Mark & Smith, 2008) is more suitable and can be applied to investigate fatigue in the railway industry because it includes not only job demand and job resources (support and control) but also individual differences. This model was one of the most relevant frameworks, as it combined many features of the existing occupational stress models. The simple version (see Figure 4.1) demonstrates the important role of job demand, job resources and individual differences (or coping style) in influencing health outcomes. It also suggests that job resources and individual differences may individually moderate the relationship between job demand and well-being outcomes.

Although the model is useful as a manual in studying occupational fatigue, it is too basic in its representation of the workplace–individual stress process (Mark & Smith, 2008). The process described in the initial model lacks the subjective components of perceived stress, and this subjective appraisal may directly or indirectly affect the relationship between the environment and the outcomes. Therefore, Mark and Smith (2008) designed a more complex DRIVE model (see Figure 4.2) and proposed an added appraisal element (which could be perceived fatigue). This model mainly proposed that perceived stress could mediate the impact of job demand, job resources, and individual characteristics on well-being outcomes. It also proposed that individual differences could moderate the relationship between the environmental factor and perceived stress, and between perceived stress and well-being outcomes. However, subsequent studies (Mark & Smith, 2012a, 2012b; Williams, 2013; Capasso, Zurlo & Smith, 2016) have failed to find such a moderating effect, while the mediating effect was generally more apparent.

Figure 4.1 *Simple DRIVE model*

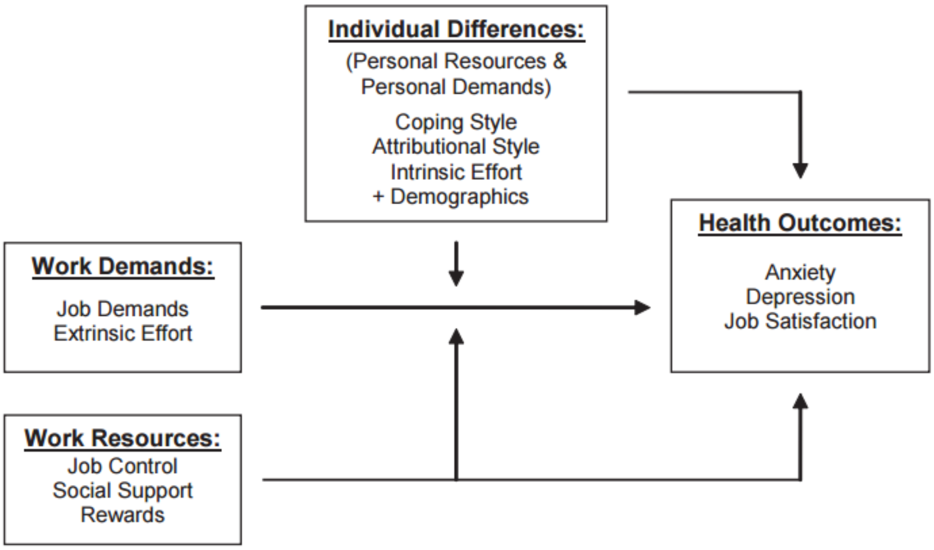
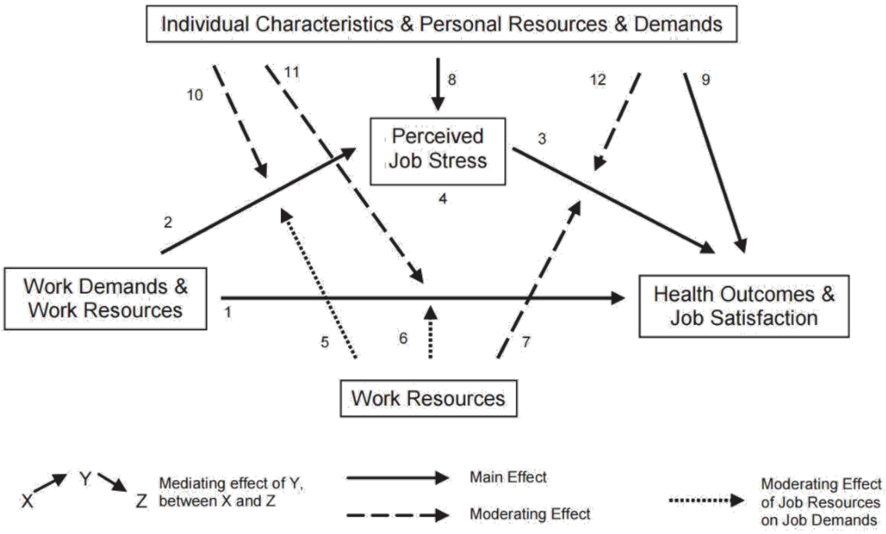


__Figure 4.2__ Enhanced DRIVE model



4.1.2 Rationale of present study

To further manage and monitor fatigue, it is necessary to establish a profile of fatigue among staff members working in the rail industry. The present study first considers associations between occupational risk factors and perceived fatigue and aims to examine the prevalence of fatigue and to identify the potential risk factors in the UK railway industry. The purpose is also to build a detailed picture of the relationship between workplace stressors, individual differences, fatigue, and well-being outcomes using the DRIVE model. This study applies the DRIVE model as the theoretical framework to investigate fatigue and assesses fatigue and well-being. It also investigates the potential risk factors that are included in the DRIVE model, such as job demands, job control and support, work environment, and individual personality and lifestyle. The study aimed to provide empirical support for potential organisational intervention to combat fatigue.

4.2 HYPOTHESES

In this study, there were three main hypotheses.

Hypothesis 1:

High job demands will relate to higher levels of fatigue and poor job support and control will relate to higher levels of fatigue. Staff members who either work shifts or work in an environment where they will encounter a higher level of noise or fumes will be more likely to suffer from fatigue.

Hypothesis 2:

Positive personal characteristics, such as a positive personality and healthy lifestyle, will relate to lower levels of fatigue.

Hypothesis 3:

The combined effects of risk factors will be associated with fatigue, with a higher combined stressor score linearly relating to a higher level of fatigue.

Hypothesis 4:

A high level of fatigue will be associated with low performance efficacy, high presenteeism (working while sick), negative work-life balance and negative well-being outcomes. Also, fatigue will mediate the impacts of work characteristics and individual differences on these outcomes.

4.3 MATERIALS AND METHODS

4.3.1 Participants

Participants were recruited from a train company in the UK, and 1067 of them completed the questionnaires (N = 1067, mean (±SD) age = 44.25±10.763 yr.), which represented a response rate of approximately 50%. The main job types of participants were conductors, drivers, station workers, engineers, administrators, managers, at-seat catering stewards and controllers.

4.3.1.1 Conductors

Conductors (or guards) are responsible for operational and safety duties. They ensure that the train stays on schedule, manage the opening and closing of the train doors, communicate with drivers, manage the passengers on the train and ensure that the train follows applicable safety rules to avoid any incident. They are not involved in the actual operation of the train. The number of passengers, which varies at different times of day and on weekends and special occasions, largely affects the workload of conductors.

4.3.1.2 Drivers

Train drivers are responsible for operating trains between stations. They check equipment and engines before a journey, communicate with control centres, follow signalling instructions, and ensure that passengers and freight get to their destination safely and on time. Many trains are equipped with a vigilance device (based on the ‘dead man's switch’ principle, see Chapter 3) to assist drivers in staying alert when guiding trains safely. However, their work is often repetitive, monotonous in nature, and tiring, especially as they must meet the train at different locations at specific times, adhere to a strict timetable and deal with a broad range of demands.

4.3.1.3 Station workers

Station employees work at the station. They deal with customers and carry out duties on the station platforms, which include selling and checking tickets, helping passengers (and their luggage) get on and off the train safely, signalling the guard or driver to depart, and updating the information on train times and delays.

4.3.1.4 Engineers

The train engineers install, check and repair the rails and mechanical and electrical systems on train engines, passenger carriages and other vehicles. They usually work together in small teams to ensure proper infrastructure maintenance. They work a high proportion of night shifts because some of the work is not possible during normal daytime operations.

4.3.1.5 At-seat catering stewards

At-seat catering crews provide catering on the train, managing the refreshment trolley, counter buffet and restaurant.

4.3.1.6 Controllers

Train controllers (i.e., dispatcher or signalman) are responsible for managing the strategy overview of an area of the rail network and authorising any activities that take place in that area of the railway. They need to manage schedules around station operations and coordinate alternative transport the train services have been disrupted in some emergency situations. Although this type of work is highly safety-critical, some technological safeguards (such as electronic interlocking) are applied to reduce the risk of human factors.

4.3.2 Materials

This survey, shown in Appendix B, ran from 27th April to 18th May, 2015. The questionnaire (the Smith Wellbeing Survey [SWELL]) consisted of 26 single-item questions largely developed from the Wellbeing Process Questionnaire (WPQ; Williams, 2014) and took about 15 minutes to complete. Most of these questions were on a 10-point scale, and the remainder were yes/no answers.

The single-item measure was chosen because previous researchers have confirmed its validity and reliability (Williams & Smith, 2013; Williams, 2015). It allows for identifying the overall risk while saving time in comparison with multi-item measures. In addition to well-being, new single-item measures were also used to record information about the working environment (exposure to noise, vibration and fumes), MSD problems, efficiency at work, and work-life balance. All the items were measured on a scale from 1 (not at all) to 10 (very much so).

Fatigue was the main variable that this survey focused on. Participants rated their physical and mental fatigue from 1 (not at all) to 10 (very tired). Other than fatigue, this survey consisted of the following sections based on the DRIVE model and WPQ:

1. The first section measured respondent’s personal details and individual characteristics. Participants were asked to indicate their age, gender and job role. Also, participants were asked to state to what extent they had a healthy lifestyle (1 = not at all, and 10 = very much so), and how would they describe their personality (1 = very negative, and 10 = very positive).

2. The second section measured the variables that could potentially make unique contributions to the prediction of fatigue. It included questions about job demands and job control and support, which were predictors in the DRIVE model (Mark & Smith, 2008) and derived from the WPQ (Williams & Smith, 2012). Questions about the working environment (levels of noise, vibration and fumes), which were important in the railway industry, and whether or not participants worked shifts or worked at night were included.

3. The third section measured the well-being outcomes that could be the consequence of fatigue. It included eight items derived from the WPQ, and also an item about work-life balance. The well-being items from the WPQ were life satisfaction, job satisfaction, life stress, job stress, life happiness, work happiness, life depression and anxiety, and job depression and anxiety. In the original WPQ, 'depression' and 'anxiety' were two separate measures, while the 'happiness' in this study refers to a 'positive mood'. Here, anxiety and depression were put together within one single-item question since they are similar and have been combined as a new variable in previous studies (for example, Smith et al.,2009). Following Williams (2015), the positive mood score could be translated to a low positive mood group (below the threshold) and a high positive mood group (above the threshold). Then, to evaluate the chronic fatigue and the after-effects of working (i.e. whether participants bring fatigue from work to life), both 'depression and anxiety' and 'happiness' were divided into two measures, one relating to life and the other relating to work. In addition, participants were asked to describe their work-life balance in terms of how often their job interfered with their life outside work or their life interfered with their job (1 = never to 10 = very often).

4. The fourth section also measured items that could be the consequences of fatigue: performance efficiency at work, presenteeism (working while sick), general health, absenteeism and accidents. Participants were asked to state how efficiently they carried out their work and whether they ever came to work when they felt ill, knowing they could not do their job as well as they would like to. Two questions were about general health: to what extent participants suffered from MSDs, and whether work caused their illness or made it worse. Two open questions asked about the number of days absence and the number of accidents/incidents they had experienced in the last 12 months.

4.3.3 Procedure

Participants were given a letter with information about the study and an informed consent form. After the participants had signed and returned the forms, they were asked to answer a paper questionnaire with 26 questions. They were free to withdraw from the survey at any point. Also, they were told that if they felt uncomfortable answering any of the questions, they were free to not respond to those questions. This study was reviewed and approved by the School of Psychology Research Ethics Committee at Cardiff University.

4.3.4 Analyses

Data analyses were carried out using SPSS 23. The independent variables tested were job demands, job control and support, shift work, exposure to noise and vibration, exposure to fumes, health-related behaviours (or health lifestyle) and personality. The dependent variables tested were fatigue and well-being outcomes. The analysis assessed the associations between the following:

1. Fatigue and job demands and resources.

2. Fatigue and job roles, shift-work and work environment.

3. Fatigue and personal characteristics.

4. Fatigue and performance efficacy, presenteeism, general health, work-life balance and well-being outcomes.

The results were analysed using a variety of tests. Pearson correlation was used to compare work and personal characteristics to fatigue and well-being. Then, a chi-square test was carried out to analyse the associations between the high/low fatigue groups and risk factors. Most of the variables used in this analysis were categorised into high/low by using thresholds, while those showing clear bias were categorised by median split. It is not uncommon for researchers to establish cut-off points based on the single items scales, in this study, the thresholds of the 10-point scales were 6 for the negative items and 4 for the positive items. A logistic regression was performed to investigate what factors predict the likelihood that respondents would report that they had a fatigue problem and to test possible interaction effects. The odds ratio (OR) and significance of each independent variable (IVs) was examined more closely in logistic regression when all variables were entered together. Furthermore, the logistic regression was used to examine the combined effect of the risk factors. Hayes' (2013) PROCESS macro (Model 4) was used to examine whether fatigue mediates the effects of job characteristics and individual differences on outcomes.

4.4 RESULTS

4.4.1 Descriptive Statistics

Participant demographics are displayed in Table 4.1 below. Three job types were excluded in Table 4.1 because very few participants had these jobs (N < 15). The most common job types reported were conductors (25.9%), drivers (22.6%) and station workers (21.3%), followed by managers, engineers, administrators and at-seat stewards. There were 57 participants with missing job type data.

Comparing across the variables (in Table 4.2), the sample had generally higher scores on positive personality, control and support, and low scores on exposure to noise, vibration and fumes. In terms of well-being outcomes, the sample showed high life satisfaction, job satisfaction, low job anxiety and depression, both at work and in life, and low job stress. The results indicate high efficiency at work and low frequency of MSDs. Additionally, 71.1% of participants reported presenteeism (they had come to work when they were feeling ill), and 29.5% of participants reported that they had had an illness caused or made worse by work.

Table 4.1 *Demographic characteristics within main job types*

	Conductor	**Driver**	**Station Worker**	**Manager**	**Engineer**	**Administrator**	**At-seat Steward**	**Controller**	**Total**
N	254	222	209	84	76	66	54	17	
(%)	(25.9%)	(22.6%)	(21.3%)	(8.6%)	(7.7%)	(6.7%)	(5.5%)	(1.7%)	982
N Gender	202m, 50f	214m, 8f	145m, 63f	62m, 22f	71m, 4f	26m, 37f	29m, 24f	12m, 5f	761m, 213f
(missing)	(2)		(1)		(1)	(3)	(1)		(8)
Mean Age	44.48	47.10	44.30	41.77	45.09	41.33	36.47	44.26	44.26
(SD)	(10.05)	(7.93)	(12.19)	(10.72)	(11.35)	(11.56)	(11.73)	(10.20)	(10.73)

Table 4.2 *Descriptive statistics for each variable using the single-item measures*

Variables	**N**	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Job Demand	1063	1	10	6.45	2.108
Job Control and Support	1063	1	10	7.04	2.018
Exposure to Noise and Vibration	1065	1	10	5.74	3.020
Exposure to Fumes	1064	1	10	5.00	3.043
Health Behaviours	1064	1	10	6.54	1.874
Personality	1067	1	10	7.38	1.757
Life Satisfaction	1067	1	10	7.44	1.884
Life Stress	1067	1	10	6.05	2.284
Life Happiness	1065	1	10	7.65	1.719
Life Anxious and Depression	1065	1	10	3.73	2.320
Job Satisfaction	1065	1	10	7.55	2.051
Job Stress	1065	1	10	5.46	2.346
Job Happiness	1064	1	10	7.51	1.919
Job Anxious and Depression	1061	1	10	3.65	2.465
Musculo-Skeletal Problem	1062	1	10	4.27	3.022
Performance Efficiency at Work	1060	1	10	8.42	1.354

Work-Life Balance	1062	1	10	6.08	2.787
Absenteeism	990	0	287	5.08	17.102
Accidents at Work	1045	0	10	0.07	0.410

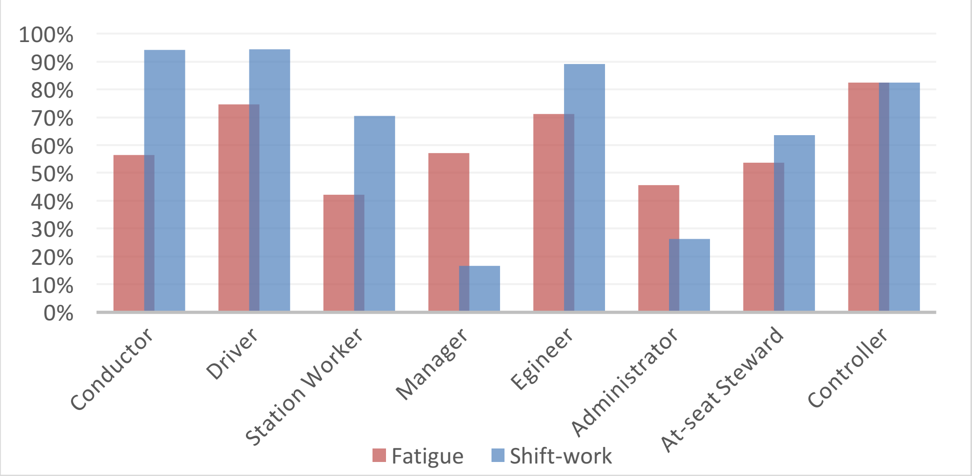
A majority of participants (58.3%) rated their fatigue as high (threshold = 6). The fatigue problem appeared in all the following job roles: by the majority of the drivers (74.7%), engineers (71.1%), controllers (82.4%), more than half of the managers and conductors, and by less than half of the administrators and station workers (see Table 4.3).

In addition, 73.1% of participants did shift work or night shifts in the previous six months, with most of the drivers (92.8%), conductors (91.43%), engineers (85.7%) and controllers (82.4%) doing shift work, whereas only a few of the managers (15.7%) and administers (25.4%) did shift work. The majority of staff whose job roles were more likely to include shift work reported experiencing fatigue (see Table 4.3 and Figure 4.3). Meanwhile, more than half the managers, who were less likely to work night shifts, reported fatigue.

Table 4.3 *Descriptive of fatigue score and shift-work in main job types*

	Conductor	**Driver**	**Station Worker**	**Manager**	**Engineer**	**Administrator**	**At-Seat Steward**	**Controller**	**Total**
Mean Fatigue (SD)	6.51 (2.107)	7.36 (1.937)	5.76 (2.311)	6.49 (1.859)	7.20 (2.046)	5.88 (2.421)	6.26 (1.973)	7.65 (1.835)	6.56 (2.182)
% Fatigue	56.5%	74.7%	42.1%	57.1%	71.1%	45.5%	53.7%	82.4%	58.3%
N Fatigue (missing)	143 (1)	165 (1)	88	48	54	30	29	14	980 (2)
N Shift-work (missing)	233 (7)	206 (4)	142 (8)	14	66 (2)	17 (1)	33 (2)	14	725 (24)

Figure 4.3 *Percentage of participants suffering fatigue problem by job types*



4.4.2 Job type differences

4.4.2.1 Difference in fatigue and risk factors for fatigue

The risk factors for fatigue examined in this study were high job demand, exposure to noise and vibration, low job control and support, taking shift-work, unhealthy lifestyle and negative personality. However, fatigue and the risk factors for it may vary between job types due to different job features. Fatigue was highest among drivers, engineers and controllers, and lowest among administrator and station worker groups, which suggested that the analysis should count in the job differences rather than simply analyse the group as a whole. The next section compared job type differences in the risk factors for fatigue. Figure 4.4 shows the mean scores for each job group on these seven potential predictors (see Figure 4.3 for the percentage of doing shift-work), and there are clear differences between job types.

<u>Driver</u>

The driver group had the most fatigue problems and significantly higher fatigue than the administrator group. The driver position was one of the jobs with the most shift-work, and it had the second highest score for both 'exposure to noise and vibration' and 'exposure' to fumes. Drivers also had the second lowest mean score for having job support and control (the lowest was the engineer group).

Engineer and controller

The engineer group and controller group had the second most fatigue problems (see Figure 4.3, in Section 4.4.1). The engineer group had the lowest score for having job support and control, while it had the highest scores for exposure to noise and vibration and for exposure to fumes. Interestingly, engineers had the highest mean score for healthy lifestyle but the lowest for positive personality.

The controller group had the highest score for job demands and the lowest for healthy lifestyle. This group also frequently took on shift-work.

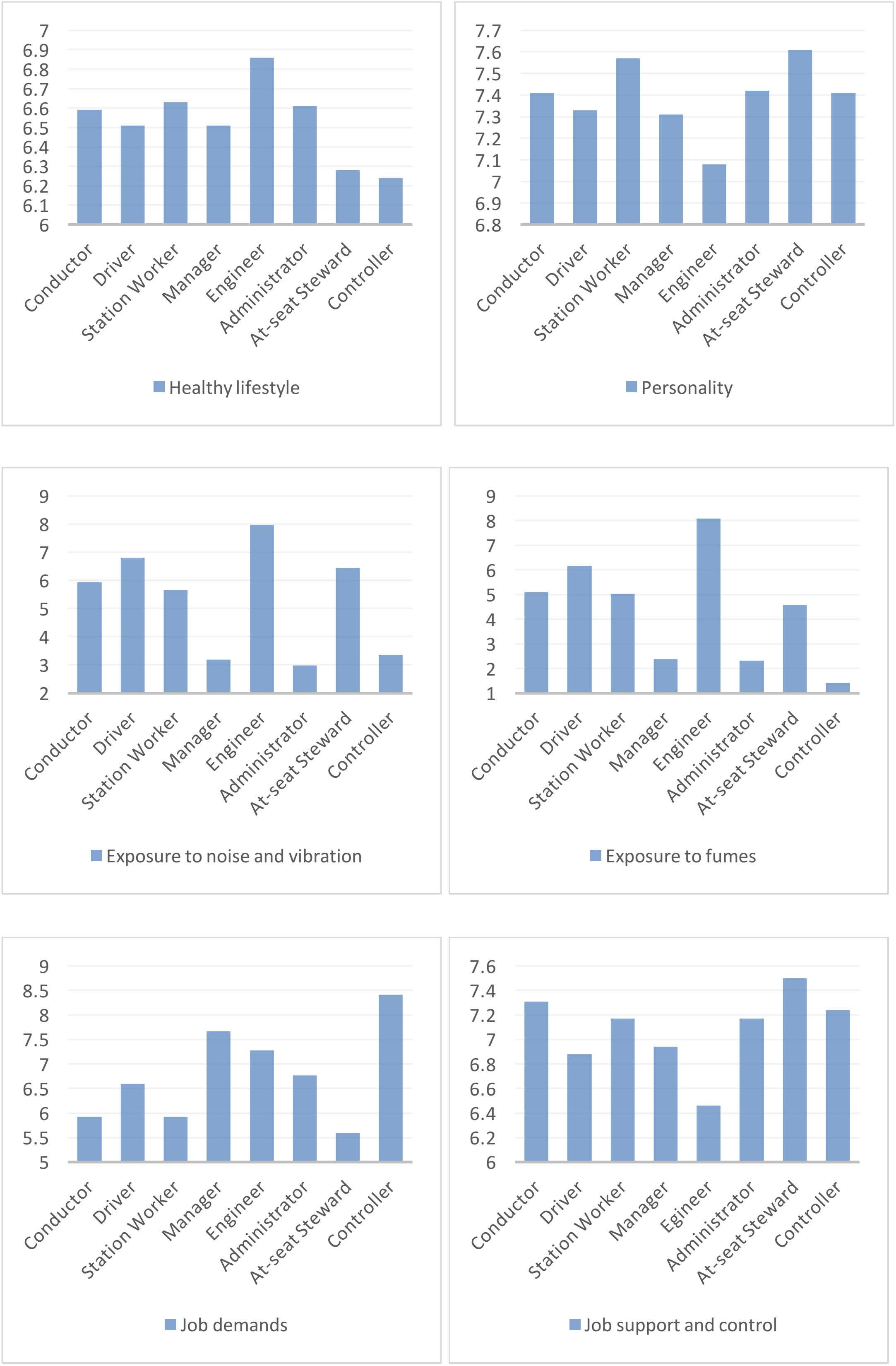
Manager

The manager group had the second highest score for job demands. More than half of them were less likely to work night shifts, but more than half of them reported fatigue (see Figure 4.3).

At-seat catering stewards and conductor

The at-seat catering steward group and the conductor group had the highest scores for 'job support and control' and the second highest for 'exposure to noise and vibration', respectively. These two groups had the lowest scores for job demands. The at-seat catering steward group had the highest score for positive personality but the second lowest for health lifestyle. The conductor group was one of the jobs most often doing shift-work (see Figure 4.3).

Figure 4.4 *Mean scores for fatigue risk factors for different job types*



Administrator and station worker

The administrator group and station worker group had the lowest fatigue scores. The administrator group had the lowest score for exposure to noise and vibration and the third highest mean scores for healthy lifestyle and positive personality. Fewer than half of them did shift-work (for percentage of taking shift-work, please see Figure 4.3) which ranked as the second lowest job type doing shift-work (manager was the lowest).

The station workers had the lowest score for job demand. They also had the second highest mean scores for healthy lifestyle and positive personality.

4.4.2.2 Dichotomous job types

A one-way between-groups analysis of variance was conducted to explore the impact of job role on levels of fatigue. The result showed (in Appendix C) that there was a significant difference in fatigue for the different job role groups: F (7, 972) = 11.79, p = .01. Although issues of fatigue were apparent in all the job roles mentioned, it was reported most frequently in drivers (74.7%), engineers (71.1%), and controllers (82.4%), followed by more than half of the managers and conductors. In the following analysis, these five jobs that reported a high percentage of issues associated with fatigue were categorised as the high fatigue job type, while the rest of them were categorised as the low fatigue job type.

4.4.3 Univariate associations with fatigue

4.4.3.1 Correlations

Appendix C shows the Pearson correlations between all independent variables and fatigue and well-being outcomes.

Job characteristics and fatigue

High job demands showed a significant positive correlation with fatigue, r (1061) = .43, p < .001. Higher levels of job control and support showed a significant negative correlation with higher level of fatigue, r (1062) = -.25, p < .001, while negative job characteristics, such as shift-work, exposure to noise, and exposure to fumes, showed significant correlations with fatigue, with correlation coefficients between .13 and .25 and all significant to *p* < .01.

Individual differences and fatigue

Positive personal characteristics, such as positive personality and healthy lifestyle, showed a small but significant negative correlation with fatigue (r from -.15 to -.12, *p*<.001).

Fatigue and outcomes

Fatigue showed a significant correlation with perceived stress at work, r (1064) =.52, *p* < .01, and negative work-life balance, r (1061) = .48. p < .01, with a high level of fatigue being associated with high levels of work stress and poor work-life balance. Fatigue showed a significant correlation with most of the well-being outcomes (being positively correlated with negative outcomes and negatively correlated with positive ones), both in life and at work, including life satisfaction, job satisfaction, life stress, job stress, life happiness, work happiness, life depression and anxiety, job depression and anxiety, MSDs and work-related ill health (r from.25 to .47, p<.01).

Fatigue was also significantly correlated with low performance efficiency, high presenteeism (both p < .001) and a greater number of days absent (p < 0.05). The correlation between fatigue and the number of accidents at work were close to being statistically significant in a positive direction (p = .057).

4.4.3.2 Chi-square and dichotomous variables

A chi-square test was performed to examine the relations between dichotomised fatigue and risk factor scores (using thresholds). Appendix C shows the results of the chi-square analyse.

The chi-square results were consistent with the Pearson correlation results shown in the previous section, but there were slight differences. Suffering with high fatigue was statistically significantly associated with the majority of the risk factors and well-being outcomes, except for personality, efficiency at work and job satisfaction (summarised in Table 4.4). These exceptions, however, were found to be have highly significant correlations with fatigue before being categorised. Only 1.6% of the participants rated their efficiency at work as low (below threshold), and very few of them rated their job satisfaction (8.9%), personality (6.3%) and health behaviours (14.2%) towards the negative end (all with threshold = 4). These results indicate that the way these variables were stated in the survey may have introduced some bias and possibly encouraged participants to rate these items more positively. Then in the analyses, too much information related to these variables was thrown away by categorising them with thresholds. Therefore, job satisfaction, efficiency and the two individual characteristic factors were re-categorised by using a median split, instead of using thresholds.

A median split was used to recode both personality (M = 8, range = 1 to 10) and health behaviours (M = 7, range = 1 to 10) into positive/negative groups, and efficiency at work (M = 9, range 1 to 10) and job satisfaction (M = 8, range 1 to 10) were recoded into high/low groups. With the median split data, the chi-square results of these variables were all significant (see Table 4.5), which was consistent with the results of the Pearson correlation. In the following analysis, these categorised items were used with others that were categorised by using thresholds.

Table 4.4 *Summary table for chi-square results (variables categorised by using thresholds)*

Variables	Fatigue (p levels)
Job Demand	<0.001
Job Control and Support	<0.001
Shift-work	<0.001
Exposure to Noise and Vibration	<0.001
Exposure to Fumes	<0.001
Health Behaviours (lifestyle)	0.005
Personality	0.169
Life Satisfaction	0.008
Life Stress	<0.001
Life Happiness	0.014
Life Anxious and Depression	<0.001
Job Satisfaction	0.164
Job Stress	<0.001
Job Happiness	<0.001
Job Anxiety and Depression	<0.001
Musculo-Skeletal Problem	<0.001
Performance Efficiency at Work	0.062
Presenteeism	<0.001
Illness Caused by Work	<0.001
Work-life Balance	<0.001

Table 4.5 *Summary table for chi-square results (variable categorised by using a median split)*

Variables	Fatigue (p levels)
Health Behaviours (lifestyle)	<0.005
Personality	<0.001
Job Satisfaction	<0.001
Performance Efficiency at work	<0.005

4.4.4 Analysing predictors of fatigue

4.4.4.1 Multivariate predictors of fatigue

Logistic regressions were run to investigate the predictors of fatigue. The dependent variable used here was categorical fatigue (high/low) and the independent variables were also categorical, re-coded in the previous analysis. The variables included in the model were demographic variables (age, gender and high/low fatigue job types), personal risk factors (lifestyle and personality) and work-related risk factors (job demands, job control and support, shift-work, exposure to noise and vibration at work, and exposure to fumes at work), in which age was continuous and the rest of them were categorical. Interactions between variables were also entered.

The demographics and two individual differences were entered at Step 1, the five work-related predictors were entered at Step 2, and the interactions between job characteristics were entered at Step 3. Then, all the interaction between personal background (job types, lifestyle and personality) and work-related predictors were entered at Step 4.

The results (see Table 4.6.1 and Table 4.6.2) suggested that there were no interaction effects on fatigue, but the personal and job characteristics, especially the job demands, had strong power in significantly predicting whether participants had a fatigue problem. Individuals with high fatigue job types, indeed, were significantly more likely to report a fatigue problem.

Model 1: Demographic, job types and individual differences, and fatigue

The results are presented in Table 4.6.1. Model 1 in this table shows the simple association between social demographics and the fatigue outcome. The indication of the size of the effects can be seen in the odds ratios (OR). Negative personality and high fatigue job types were significantly associated with fatigue problems. High fatigue employees were nearly 3 times more likely to report the fatigue problem ($p<0.001$) than those with low fatigue job types. Overall, staff background explains relativity little (9.5%) of the variance in fatigue. There was no significant associations between age, gender, unhealthy lifestyle and fatigue in this model.

Model 2: Individual differences, Job characteristics and fatigue

Model 2 (Table 4.6.1) shows what happened when the individual differences and work-related risk factors were added to the model. Through adding the five factors, the explanatory power of this model increased twofold, accounting for 23.2% of the variance, and the classification accuracy of it increased to 68.9%. The full model containing all predictors was statistically significant, X^2 (1, N = 914) = 172.353, $p < 0.001$, indicating that the model was able to distinguish between participants who reported and did not report a fatigue problem.

Four work-related predictors made a unique statistically significant contribution to the model: high job demand, exposure to noise and vibration (both $p<0.001$), low job control and support ($p<0.05$), and doing shift-work ($p<0.01$). The strongest predictor of reporting a fatigue problem in this model was high job demands, recording an OR of 3.4, followed by exposure to noise and vibration, recording an OR of 2.2, and doing shift-work, recording an OR of 1.7. No unique statistically significant contributions was made for the factor ‘exposure to fumes’.

Both unhealthy lifestyle ($p<0.05$) and negative personality ($p<0.01$) made a unique statistically significant contribution to the model as well. Unhealthy lifestyle was non-significant in Model 1 but significant in this model. This shows a masking effect on the unhealthy lifestyle that was non-significant in Model 1 due to the variation in the error term, which then became significant in this model because of adding variables which reduced the size of the error term. Negative personality was also significant, recording an OR of 1.5.

The differences between high/low fatigued job types were slightly reduced once the work-related factors were included in the model. This indicates that the work-related factors could not completely account for the differential fatigue of the high fatigue jobs and the low fatigue jobs.

Table 4.6.1 *Logistic regression of social demographic, job and personal characteristics, and fatigue*

	Model 1			**Model 2**		
Variables	Odds Ratio	C.I.	p	Odds Ratio	C.I.	p
Social Demographics						
Age	1.004	[0.991, 1.017]	0.568	1.000	[0.986, 1.014]	0.973
Gender	0.984	[0.732, 1.378]	0.983	0.893	[0.618, 1.288]	0.544
Fatigue Job types (High)	2.930	[2.124, 4.043]	<0.001	2.143	[1.506, 3.049]	<0.001
Personal Characteristics						
Lifestyle (Unhealthy)	1.268	[0.956, 1.682]	0.099	1.477	[1.089, 2.003]	<0.05
Personality (Negative)	1.607	[1.212, 2.132]	<0.01	1.590	[1.174, 2.154]	<0.01
Work Characteristics						
Noise and Vibration (High)				2.211	[1.558, 3.140]	<0.001
Shift-work (Yes)				1.745	[1.207, 2.522]	<0.01
Fumes (High)				0.787	[0.546, 1.135]	0.200
Job Demands (High)				3.447	[2.549, 4.659]	<0.001
Job Control and Support (Low)				1.692	[1.030, 2.780]	<0.05
Nagelkerke R-square	9.5%			23.2%		
Chi square	67.060, df = 5, p<0.001			172.944, df = 10, p<0.001		
Hosmer & Lemeshow test	P = 0.509			P = 0.930		
Classification accuracy	61.4%			68.9%		

Model 3 and 4: Interaction effects of fatigue

Model 3 (in Table 4.6.2) shows the potential interaction that exists between pairs of the work-related risk factors that need to be taken into account. The full model containing all work-related predictors and two-way interactions were statistically significant, X^2 (1, N = 914) = 180.707, p < .001, indicating that the model was able to distinguish between participants who reported and did not report a fatigue problem. However, comparing the results with Model 2, this model did not improve a lot. Through adding the possible work-related interactions, the explanatory power of this model increased slightly, accounting for 24.3% of the variance, but the classification accuracy of it stayed at 68.9%. None of the 10 possible two-way interactions between work-related factors made a unique statistically significant contribution to this model. However, job types, personality, lifestyle, shift-work and job demand were still significant, indicating that it was the direct effect of these variables, rather than moderating effects, that influenced fatigue.

Model 4 (in Table 4.6.2) shows the potential interaction that exists between personal characteristics and job characteristics. The full model containing all predictors and all two-way interactions was statistically significant, X^2 (1, N = 914) = 194.968, $p < .001$, indicating that the model was able to distinguish between participants who reported and did not report a fatigue problem. However, the added block of interactions was non-significant ($p = 0.516$). This model did not improve a lot when compared with Model 3, with its explanatory power increasing slightly, accounting for 25.9% of the variance, but its classification accuracy declining to 68.5%.

No significant interactions were found in this model. Interestingly, the coefficient for job demand was still statistically significant ($p<0.001$) even after adding interaction effects, recording an OR of 4.1. This, again, indicates that the interaction effects could not completely explain the difference in fatigue between high and low job demand groups. The OR indicated that the participants who had high job demands were 4 times more likely to report a fatigue problem than those who had low job demands, controlling for other factors and interactions in the model. The coefficients for high fatigue job types, negative personality, unhealthy lifestyle and shift-work were no longer significant in this model. The robust effect of job demands probably reflects that fact that this variable is relevant to most of the jobs whereas others are job specific.

Table 4.6.2 *Logistic regression of social demographic, job and personal characteristics, and fatigue (contd)*

	Model 3			**Model 4**		
Variables	Odds Ratio	C.I.	p	Odds Ratio	C.I.	p
Social Demographics						
Age	1.000	[0.986, 1.014]	0.956	1.001	[0.987, 1.015]	0.919
Gender	0.869	[0.599, 1.260]	0.457	0.895	[0.615, 1.304]	0.565
Fatigue Job Types (High)	2.143	[1.502, 3.058]	<0.001	0.669	[0.182, 2.451]	0.544
Personal Characteristics						
Lifestyle (Unhealthy)	1.470	[1.080, 2.000]	<0.05	1.173	[0.541, 2.541]	0.686
Personality (Negative)	1.609	[1.184, 2.186]	<0.01	0.832	[0.377, 1.853]	0.648
Work Characteristics						
Noise and Vibration (High)	2.127	[0.844, 5.362]	0.110	2.676	[0.944, 7.581]	0.064
Shift-work (Yes)	2.068	[1.075, 3.977]	<0.05	1.307	[0.581, 2.941]	0.518
Fumes (High)	0.911	[0.289, 2.871]	0.873	1.011	[0.273, 3.746]	0.987
Job Demands (High)	5.168	[2.632, 10.151]	<0.001	4.109	[1.884, 8.959]	<0.001
Job Control and Support (Low)	1.914	[0.440, 8.321]	0.387	3.697	[0.578, 23.633]	0.167
Interactions						
*Noise & Vibration * Shift-work*	1.287	[0.512, 3.236]	0.592	1.097	[0.438, 2.807]	0.848
*Noise & Vibration * Fumes*	0.780	[0.369, 1.651]	0.516	0.767	[0.353, 1.664]	0.501
*Noise & Vibration * Demands*	0.821	[0.401, 1.682]	0.560	0.874	[0.417, 1.841]	0.721
*Noise & Vibration * Support & Control*	1.233	[0.331, 4.590]	0.755	0.929	[0.242, 3.575]	0.915
*Shift-work * Fumes*	1.175	[0.419, 3.297]	0.759	1.185	[0.419, 3.351]	0.750
*Shift-work * Demands*	0.739	[0.347, 1.575]	0.434	0.713	[0.321, 1.584]	0.406
*Shift-work * Support & Control*	0.505	[0.128, 1.993]	0.330	0.307	[0.072, 1.315]	0.112
*Fumes * Demands*	0.731	[0.348, 1.533]	0.407	0.654	[0.301, 1.422]	0.284
*Fumes * Support & Control*	1.699	[0.421, 6.856]	0.456	1.655	[0.382, 7.170]	0.501
*Demands * Support and Control*	1.225	[0.408, 3.677]	0.717	1.029	[0.322, 3.286]	0.962

*Jobs * Noise & Vibration*		1.125	[0.481, 2.632]	0.785
*Jobs * Shift-work*		3.238	[0.979, 10.706]	0.054
*Jobs * Fumes*		0.759	[0.319, 1.808]	0.534
*Jobs * Demands*		1.266	[0.606, 2.645]	0.531
*Jobs * Support & Control*		2.658	[0.709, 9.967]	0.147
*Lifestyle * Noise & Vibration*		0.691	[0.323, 1.481]	0.343
*Lifestyle * Shift-work*		1.509	[0.710, 3.206]	0.285
*Lifestyle * Fumes*		1.098	[0.491, 2.456]	0.821
*Lifestyle * Demands*		1.277	[0.664, 2.457]	0.463
*Lifestyle * Support & Control*		0.443	[0.136, 1.350]	0.152
*Personality * Noise & Vibration*		1.121	[0.522, 2.408]	0.770
*Personality * Shift-work*		1.804	[0.841, 3.871]	0.130
*Personality * Fumes*		0.919	[0.412, 2.054]	0.837
*Personality * Demands*		1.476	[0.768, 2.836]	0.243
*Personality * Support & Control*		1.202	[0.393, 3.675]	0.747
Nagelkerke R-square	24.2%	25.9%		
Chi square	180.845, df = 20, p<0.001	194.968, df = 35, p<0.001		
Hosmer & Lemeshow test	P = 0.734	P = 0.569		
Classification accuracy	68.9%	68.5%		

4.4.4.2 Combined effects

The above analyses showed that multiple risk factors were associated with fatigue problems. The next step was to combine the risk factors into an overall negative occupational factors score (NOF) to test the strength of a combined effects approach. The NOF score was calculated by, firstly, dichotomising each factor to high and low risk groups, including individual differences, work characteristics and fatigue job type. Exposure to fumes was excluded because it did not significantly predict fatigue (see Section 4.4.4.1). Then, the NOF was calculated for each participant by adding the number of high-risk factors together.

The NOF score was treated as a continues variable, and the association between mean fatigue and combined effects are shown in Figure 4.5, indicating that fatigue increased cumulatively with the greater number of risk factors. This relationship was then analysed using logistic regression.

Figure 4.5 *Mean fatigue by combined effects*

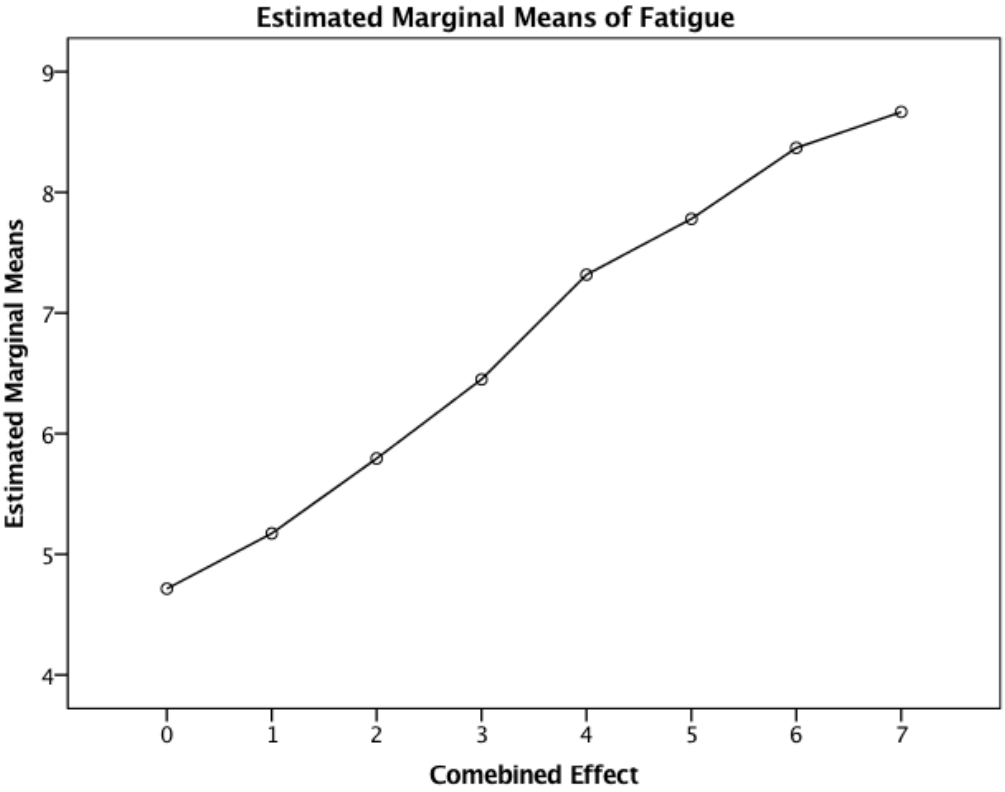


Table 4.7 *Combined effects of exposure to risk and fatigue (logistic regression)*

Variables	**Odd Ratios**	**C.I**	**p**
Combined Effects			
0 to 3 factors	1.000		
4 to 5 factors	3.371	[2.501, 4.545]	<0.001
6 or more factors	22.368	[5.351, 93.493]	<0.001

The dependent variable used in the logistic regression was categorical fatigue (high/low), and the independent variable was the categorised combined effect (three groups: zero to three factors, four to five factors, and six or more factors), in which the participants with 0 to 3 risk factors were treated as the comparison group.

The result shows that the relationship between fatigue and the number of risk factors was not simply additive, but multiplicative (see Table 4.7 above). The OR of 3.371 for four to five factors indicated that participants with four to five risk factors were more than 3 times more likely to report a fatigue problem than those with fewer than three risk factors. Participants with six or more factors (OR = 22.368, p<0.001) were 22 times more likely to report fatigue problems than the comparison group.

4.4.5 Mediation Effect of Fatigue on Outcomes

Hayes Mediation was used to examine whether fatigue mediated the effects of job characteristics and individual differences on outcomes. The variables used in this analysis were original scores, in which shift-work was the categorical variable, and the rest were continuous variables. Fatigue was found to mediate the impacts of these variables on most of the outcomes. The indirect effect was tested using a bootstrap estimation approach with 1000 samples (Shrout & Bolger, 2002).

4.4.5.1 Between personal characteristics and outcomes

Fatigue was found to mediate the impacts of lifestyle and personality on efficiency, work-life balance and most of the well-being outcomes (in Table 4.8 and 4.9). As the confidence interval of these relationships did not contain zero, the indirect effect could be considered significant (Hayes, 2013) as there was a mediation effect of fatigue on them, whereby it fully mediated the impact of lifestyle on job stress and work-life balance. The total effect of lifestyle on job stress was −. 1396 (C.I = -.3530, -.1602, p <.001), with a direct effect of lifestyle on job stress of − .0606 (C.I = -.1261, .0048, p >.05), and the total effect of lifestyle on negative work-life balance was −.1380 (C.I = -.2281, -.0479, p <.001), with a direct effect of lifestyle on it of −.0546 (C.I = .1347, .0254, p >.05). These full mediations suggested that the process by which lifestyle influences either high job stress or negative work-life balance was completely explained, and there was no need to test for further indirect effects. The relationship between personality and MSDs was not significant, as there was no mediation effect of fatigue on it.

Table 4.8 *Summary of the mediation of fatigue on the relationship between lifestyle and outcomes*

Y	**X: Positive lifestyle**				**M: Fatigue**	
	Total Effects		**Direct Effects**		**Indirect Effects**	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Pos. Life Satisfaction	.2727***	[.2145, .3309]	.2477***	[.1903, .3051]	.0250	[.0124, .0412]
Neg. Life Stress	-.2022***	[-.2748, -.1297]	-.1547***	[-.2241, -.0854]	-.0475	[-.0762, -.0198]
Pos. Life Happiness	.2260***	[.1726, .2795]	.2017***	[.1492, .2542]	.0244	[.0113, .0391]
Neg. Life Anxiety and Depression	-.1998***	[-.2735, -.1262]	-.1559***	[-.2270, -.0849]	-.0439	[-.0695, -.0217]
Neg. MSDs	-.2566***	[-.3530, -.1602]	-.2077***	[-.3019, -.1136]	-.0489	[-.0790, -.0222]
Neg. Job Stress	-.1396**	[-.2150, -.0642]	-.0606	[-.1261, .0048]	-.0789	[-.1168, -.0341]
Pos. Job Satisfaction	.1554***	[.0897, .2212]	.1259***	[.0613, .1906]	.0295	[.0140, .0478]
Pos. Efficiency	.1631***	[.1210, .2053]	.1535***	[.1112, .1957]	.0097	[.0036, .0182]
Neg. Work-Life Balance	-.1380*	[-.2281, -.0479]	-.0546	[-.1347, .0254]	-.0834	[-.1311, -.0370]
Pos. Job Happiness	.1816***	[.1207, .2425]	.1457***	[.0869, .2045]	.0359	[.0175, .0545]
Neg. Job Anxiety and Depression	-.2298***	[-.3084, -.1512]	-.1684***	[-.2415, -.0953]	-.0614	[-.0939, -.0286]

Note: * = p<0.05, ** = p<0.01 and *** = p<0.001.

Table 4.9 *Summary of the mediation of fatigue on the relationship between personality and outcomes*

	X: Positive Personality				**M: Fatigue**	
Y	**Total Effects**		**Direct Effects**		**Indirect Effects**	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Pos. Life Satisfaction	.5966***	[.5420, .6502]	.5722***	[.5189, .6255]	.0245	[.0236, .0386]
Neg. Life Stress	-.2756***	[-.3524, -.1988]	-.2175***	[-.2914, -.1436]	-.0581	[-.0861, -.0333]
Pos. Life Happiness	.6041***	[.5579, .6503]	.5816***	[.5358, .6274]	.0225	[.0121, .0356]
Neg. Life Anxiety and Depression	-.4933***	[-.5672, -.4194]	-.4435***	[-.5154, -.3715]	-.0498	[-.0773, -.0287]
Neg. MSDs	-	-	-	-	-	-
Neg. Job Stress	-.2213***	[-.3010, -.1417]	-.1227**	[-.1923, -.0531]	-.0986	[-.1402, -.0574]
Pos. Job Satisfaction	.4679***	[.4031, .5327]	.4374***	[.3731, .5071]	.0305	[.0163, .0481]
Pos. Efficiency	.2640***	[.2208, .3073]	.2543***	[.2107, .2978]	.0098	[.0033, .0194]
Neg. Work-Life Balance	-.2385***	[-.3340, -.1429]	-.1308*	[-.2163, -.0453]	-.1077	[-.1547, -.0617]
Pos. Job Happiness	.4737***	[.4144, .5331]	.4349***	[.3771, .4928]	.0388	[.0223, .0577]
Neg. Job Anxiety and Depression	-.4631***	[-.5433, -.3829]	-.3875***	[-.4628, -.3122]	-.0757	[-.1100, -.0482]

Note: * = p<0.05, ** = p<0.01 and *** = p<0.001.

4.4.5.2 Between work characteristics and outcomes

Job demands, job support and control

The relationships between job demands, job support and control, and outcomes were mediated by fatigue. Fatigue was found to mediate the impact of job demands on life happiness and job satisfaction, with the direct effect reduced to non-significance, indicating full mediation. Fatigue was also found to partially mediate the impacts of these two variables on work-life balance and most of the well-being outcomes (Table 4.10 and 4.11).

The results indicated that the relationship between job demand and positive performance efficiency was mediated by fatigue. The total effect of demand on efficiency was −.0780 (C.I = −.1161, −.0399, P <.001), with a direct effect of demand on efficiency of −.0502 (C.I = −.0922, −.0083, P<.05). The indirect effect was −.0278, and the confidence interval was −.0488 to −.0109, which was significant. Unlike this, results showed that the relationship between job support and control and positive performance efficiency was not mediated by fatigue. A Sobel test was conducted and showed no significance, indicating no partial mediation in this relationship (z = 1.43, p > .05).

Table 4.10 *Summary of the mediation of fatigue on the relationship between job demand and outcomes*

Y	**X: High Job Demands**				**M: Fatigue**	
	Total Effects		**Direct Effects**		**Indirect Effects**	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Pos. Life Satisfaction	-.0751**	[-.1284, -.0218]	.0172	[-.0404, .0748]	-.0923	[-.1219, -.0687]
Neg. Life Stress	.2993***	[.2365, .3622]	.1804***	[.1127, .2480]	.1190	[.0813, .1562]
Pos. Life Happiness	-.0674**	[-.1163, -.0185]	.0213	[-.0313, .0740]	-.0887	[-.1174, -.0664]
Neg. Life Anxiety and Depression	.2212***	[.1561, .2864]	.0950**	[.0251, .1650]	.1262	[.0955, .1632]
Neg. MSDs	.2590***	[.1740, .3440]	.1911*	[.0270, .2113]	.1399	[.0969, .1836]
Neg. Job Stress	.7678***	[.7191, .8165]	.6391***	[.5882, .6899]	.1287	[.1026, .1622]
Pos. Job Satisfaction	-.1458***	[-.2039, -.0876]	-.0604	[-.1237, .0029]	-.0854	[-.1157, -.0546]
Pos. Efficiency	-.0780***	[-.1161, -.0399]	-.0502*	[-.0922, -.0083]	-.0278	[-.0488, -.0109]
Neg. Work-Life Balance	.4112***	[.3353, .4872]	.1728***	[.0956, .2501]	.2384	[.1912, .2964]
Pos. Job Happiness	-.1772***	[-.2309, -.1234]	-.0740*	[-.1317, -.0163]	-.1032	[-.1331, -.0765]
Neg. Job Anxiety and Depression	.3757***	[.3087, .4427]	.2142***	[.1432, .2852]	.1615	[.1280, .1997]

Note: * = p<0.05, ** = p<0.01 and *** = p<0.001.

Table 4.11 *Summary of the mediation of fatigue on the relationship between personality and outcomes*

	X: Positive Job Support and Control				**M: Fatigue**	
Y	**Total Effects**		**Direct Effects**		**Indirect Effects**	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Pos. Life Satisfaction	.3958***	[.3454, .4462]	.3654***	[.3139, .4169]	.0303	[.0169, .0457]
Neg. Life Stress	-.2530***	[-.3193, -.1867]	-.1698***	[-.2353, -.1043]	-.0832	[-.1146, -.0605]
Pos. Life Happiness	.3555***	[.3096, .4015]	.3246***	[.2777 .3716]	.0309	[.0184 .0466]
Neg. Life Anxiety and Depression	-.3656***	[-.4314, -.2998]	-.2965***	[-.3623, -.2306]	-.0692	[-.0963, -.0487]
Neg. MSDs	-.2404***	[-.3296, -.1511]	-.1513**	[-.2409, -.0617]	-.0891	[-.1225, -.0608]
Neg. Job Stress	-.3501***	[-.4169, -.2833]	-.2144***	[-.2750, -.1537]	-.1357	[-.1792, -.1032]
Pos. Job Satisfaction	.5469***	[.4951, .5986]	.5196***	[.4666, .5726]	.0273	[.0127, .0457]
Pos. Efficiency	.2581***	[.2212, .2950]	.2510***	[.2130, .2891]	.0071	[-.0026, .0172]
Neg. Work-Life Balance	-.3718***	[-.4523, -.2914]	-.2226***	[-.2969, -.1484]	-.1492	[-.1981, -.1067]
Pos. Job Happiness	.5268***	[.4793, .5743]	.4855***	[.4375, .5743]	.0413	[.0261, .0596]
Neg. Job Anxiety and Depression	-.5046***	[-.5718, -.4374]	-.4085***	[-.4738, -.3432]	-.0961	[-.1292, -.0699]

Note: * = p<0.05, ** = p<0.01 and ***=p<0.001.

Shift-work and working environment

The results showed that fatigue partially mediated the impact of doing shift work on negative life stress, positive performance efficiency and negative work-life balance (Table 4.12). No mediation was found for shift work and the other outcomes because those relationships were non-significant (p of total effect > 0.5).

Table 4.12 *Summary of the mediation of fatigue on the relationship between shift-work and outcomes*

	X: Shift Work				**M: Fatigue**	
Y	**Total Effects**		**Direct Effects**		**Indirect Effects**	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Neg. Life Stress	-.3886 *	[-.7071, -.0701]	-.6366***	[-.9385, -.3347]	.2480	[.1410, .3776]
Pos. Efficiency	.3346***	[.1505, .5188]	.4025***	[.2191, .5859]	-.0678	[-.1166, -.0312]
Neg. Work-Life Balance	1.5743***	[1.1939, 1.9547]	1.1863***	[.8465, 1.5261]	.3880	[.2161, .5852]

Note: * = p<0.05, ** = p<0.01 and *** = p<0.001.

Fatigue partially mediated the influences of two work environmental factors on negative work-life balance. For noise, the total effect of it on work-life balance was 0.2094 (C.I = .1551, .2636, P <.001), with a direct effect on work-life balance of .1071 (C. I = .0570, .1573, P<.001). The indirect effect was .1022, with a confidence interval of .0758 to .1313, which was considered significant. For fumes, the total effect on work-life balance was .2405 (C.I = .1871, .2939, P <.001), with a direct effect on work-life balance of .1457 (C. I = .0965, .1949, P<.001). The indirect effect was .0947, with a confidence interval of .0704 to .1228, which was considered significant.

The impact of both noise and fumes were fully mediated by fatigue on well-being outcomes (life stress, life anxiety and depression, job stress, job anxiety and depression, job happiness and job satisfaction; see Table 4.13 and 4.14). Fatigue also fully mediated the influence of exposure to fumes on MSD and partially mediated the influence of exposure to fumes on performance efficiency and MSDs. The mediation effects were considered to be significant as the confidence interval of indirect effects did not contain zero. There was a non-significant relationship between fumes and efficiency, with no mediation effect of fatigue.

Table 4.13 *Summary of the mediation of fatigue on the relationship between noise and outcomes*

	X: Exposure to Noise				**M: Fatigue**	
Y	**Total Effects**		**Direct Effects**		**Indirect Effects**	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Neg. Life Stress	.0910 ***	[.0458, .1362]	.0311	[-.0133, .0755]	.0598	[.0425, .0795]
Neg. Life Anxiety and Depression	.0635**	[.0174, .1096]	.0063	[-.0391, .0518]	.0572	[.0412, .0744]
Neg. MSDs	.1354***	[.0757, .1952]	.0736*	[.0137, .1335]	.0618	[.0442, .0846]
Neg. Job Stress	.0797**	[.0332, .1262]	-.0209	[-.0623, .0204]	.1007	[.0752, .1273]
Pos. Job Satisfaction	-.0477*	[-.0886, -.0069]	-.0093	[-.0504, -.0319]	-.0385	[-.0548, -.0253]
Pos. Efficiency	.0285*	[.0018, .0551]	.0460**	[.0189, .0732]	-.0176	[-.0257, -.0102]
Neg. Work-Life Balance	0.2094***	[.1551, .2636]	.1071***	[.0570, .1573]	.1022	[.0758, .1313]
Pos. Job Happiness	-.0561*	[-.0941, -.0181]	-.0095	[-.0470, .0281]	-.0466	[-.0638, -.0332]
Neg. Job Anxiety and Depression	.0919**	[.0430, .1408]	.0116	[-.0350, .0583]	.0803	[.0594, .1037]

Note: * = p<0.05, ** = p<0.01 and *** = p<0.001.

Table 4.14 *Summary of the mediation of fatigue on the relationship between fumes and outcomes*

Y	X: Exposure to Fumes				M: Fatigue	
	Total Effects		Direct Effects		Indirect Effects	
	B	*C.I*	*B*	*C.I*	*B*	*C.I*
Pos. Life Satisfaction	-	-	-	-	-	-
Neg. Life Stress	.0668*	[.0218, .1118]	.0094	[-.0346, .0533]	.0574	[.0409, .0761]
Pos. Life Happiness	-	-	-	-	-	-
Neg. Life Anxiety and Depression	.0592*	[.0135, .1050]	.0054	[-.0396, .0504]	.0538	[.0385, .0725]
Neg. MSDs	.1135**	[.0540, .1729]	.0542	[-.0051, .1136]	.0592	[.0409, .0815]
Neg. Job Stress	.1107***	[.0648, .1566]	.0184	[-.0226, .0593]	.0923	[.0675, .1211]
Pos. Job Satisfaction	-.0561**	[-.0966, -.0156]	-.0207	[-.0614, -.0200]	-.0353	[-.0497, -.0235]
Pos. Efficiency	-	-	-	-	-	-
Neg. Work-Life Balance	.2405***	[.1871, .2939]	.1457***	[.0965, .1949]	.0947	[.0704, .1228]
Pos. Job Happiness	-.0675**	[-.1051, -.0298]	-.0245	[-.0616, .0127]	-.0430	[-.0579, -.0295]
Neg. Job Anxious and Depression	.1027***	[.0542, .1512]	.0284	[-.0178, .0746]	.0743	[.0558, .0965]

Note: * = p<0.05, ** = p<0.01 and *** = p<0.001.

4.5 DISCUSSION

The current study is a large-scale fatigue study covering all job roles in the railway industry. By reviewing existed literature, previous chapters reported the scarcity of relevant literature on train crew fatigue, and found that the studies involving a wide variety of job types or occupational risk factors were very limited. This large-scale study aimed to fill such gap found in the literature reviews and assess current situation on fatigue problem in the rail industry. It examined the prevalence of fatigue and sought to determine the risk factors of it and the outcomes related to fatigue in rail staff. It also built a detailed picture of the associations between workplace stressors, individual differences, fatigue, and well-being outcomes.

The Smith Wellbeing Survey (SWELL) used in the present study showed good psychometric properties and predictive validity. The key features of such subjective measurement included job characteristics, individual differences in personality and lifestyle, fatigue and well-being outcomes. It covered most of the variables mentioned the previous studies reviewed in Chapter 2 and 3, and also reflected the main elements and associations of the DRIVE model. As a short questionnaire, it can be used in future studies, especially field or diary studies.

However, as it involves subjective measurement, SWELL has its limitation in measuring the association between fatigue and performance, with self-reported performance efficiency in the present study showing a bias towards high-efficiency. Although performance impairment had been considered as one of the outcomes of workload (e.g., Parkes, 1995) or fatigue (e.g., Copper, 1992; Beurskens et al., 2000), such associations were still not clear in the present study and needed further investigation. It is suggested that the following studies in this thesis should use objective measures to assess performance.

The results from this survey largely supported the hypotheses and confirmed the effects of job characteristics and personal characteristics on railway fatigue, although a potential risk of such a large-scale study was that some of the effects might be significant by chance.

4.5.1 Hypothesis One

Hypothesis one predicted that high job demands and poor job support and control would relate to higher levels of fatigue. It also predicted that staff members who either work shifts or work in an environment where they encounter a higher level of noise or fumes would be more likely to suffer from fatigue.

The results (see Appendix C) of correlations showed that higher levels of fatigue significantly correlated with high job demands, poor job support and control, shift-work and a negative working environment. Chi-square tests of independence also showed that the relations between fatigue and these risk factors were significant. The results of logistic regression (see Table 4.6.1 and 4.6.2) provided support for this hypothesis and were consistent with prior research that reported that high job demands, low job control and support, doing shift-work, and exposure to noise and vibration were associated with fatigue. The entire model (see Model 2 in Table 4.6.1) predicted 23.2% of the variance in fatigue status and correctly classified 68.9% of the cases. High job demands were found to make the largest contribution to predicting fatigue, controlling for demographics and any potential two-way interaction effects. Also, doing shift-work, exposure to noise and vibration, and low job resources were found to make a unique significant contribution to predicting fatigue, when controlling for demographics.

However, exposure to fumes did not present as one of the significant predictors to fatigue. Although it was significantly associated with fatigue in Pearson correlation and Chi-square analyses, its unique contribution on fatigue was not statistically significant. Overall, the hypothesis that work-related individual variables would contribute significantly to fatigue was supported by the correlational results and the logistic regressions.

4.5.2 Hypothesis Two

Hypothesis two predicted that positive personal characteristics, such as positive personality and healthy lifestyle, would relate to lower levels of fatigue.

Both of the individual differences significantly predicted fatigue, as positive personality and healthy lifestyle were significantly associated with lower levels of fatigue, as we expected. Appendix C shows that positive personality and healthy lifestyle were significantly associated with lower levels of fatigue in the Pearson correlation. However, after categorising by using thresholds, personality had no significant association on fatigue in the chi-square calculations (Appendix C). The non-significant results, indicated that possibly the way we measure personality, produced some bias. The single-item measure of personality was simple and direct with extreme ends (‘very negative’ and ‘very positive’). This question design could have introduced bias and encouraged participants to choose ratings that were more on the positive side. Actually, only 6.3% of the participants rated their personality below the threshold; then, too much information was thrown away by simply categorising it via the threshold. The other personal factor, health-related behaviours, was also at risk of bias. Therefore, both personality and health-related behaviours were then re-calculated through a median split.

After re-categorising personality and lifestyle into high/low groups, a significant contribution was found for both in the logistic regression (Model 2, Table 6-1). The personal factors of negative personality or unhealthy lifestyle are likely to predict fatigue problems in the railway industry, as previous studies have shown (personality: Parkes, 1994b; health-related behaviours: Laaksonen et al., 2009). This also provided a good support for the DRIVE model, showing that individual differences significantly relate to perceived fatigue.

Overall, the more that participants rated their personality as positive or rated their lifestyle as healthy, the less likely they were to report being fatigued. Hypothesis two, therefore, was supported, and the null hypothesis can be rejected.

4.5.3 Hypothesis Three

Hypothesis three predicted that the combined effect of independent variables would be associated with fatigue, with a higher combined stressor score linearly relating to a higher level of fatigue.

The risk factors tended to combine cumulatively to produce negative effects on the railway fatigue, and indeed, this relationship was linear and multiplicative. In logistic regression, the NOF score was categorised into three groups: zero to three factors, four to five factors and six or more factors, as in Smith's seafarer study (2004). The ORs showed that the train crew with four or five risk factors were more than 3 times more likely to report a fatigue problem, while those with more than six risk factors were about 22 times more likely.

There was no 'gold standard' of measuring fatigue that has been used in large populations which allows benchmarking across job types. There is no doubt that highly fatigued train crew work in the industry where a combination of risk factors can be found together. The NOF score comprised the risk dimensions of these potential stressors and their combined effect. The result of analysing NOF scores was consistent with the previous fatigue studies on seafarers, installation workers (Smith, Allen & Wadsworth, 2006; McNamara & Smith, 2002) and nursing professionals (McNamara, 2008). Hypothesis three, therefore, was supported.

4.5.4 Hypothesis Four

Hypothesis four predicted that high levels of fatigue would be associated with low performance efficacy, high presenteeism (work while sick), negative work-life balance and negative well-being outcomes. In addition, fatigue should also mediate the impact of work characteristics and individual differences on these outcomes. This is an important prediction based on the enhanced DRIVE model, which proposes that perceived fatigue is the cognitive mechanism through which psychosocial stressors are transmitted into the well-being outcomes.

The results of univariate analyses showed that fatigue was significantly related to negative work-life balance and negative well-being in both daily life and work life. Fatigue was also significantly associated with less performance efficiency, presenteeism and a greater number of days absent. The correlation between higher levels of fatigue and a greater number of accidents at work were close to being statistically significant.

In the mediation analysis, fatigue was found to mediate the effects of individual differences and work characteristics on efficiency, work-life balance and most of the well-being outcomes. Full mediation effects of fatigue were found between job demands, life happiness, life satisfaction and job satisfaction, lifestyle, job stress, work-life balance, and work environment (noise and fume), well-being at work and the majority of the well-being outcomes in general life. This means that essentially all the relationships between the above variables were via the mediated or indirect pathway.

For shift-work, fatigue only mediated its impact on life stress, performance efficiency and work-life balance. No significant direct effect was found for shift-work on other well-being aspects. Shift-work, noise and fumes did not directly affect life satisfaction and life happiness, while exposure to fumes was also not related to performance efficiency.

Overall, a large number of significant mediating effects of fatigue on the relationships between stressors and well-being outcomes were found, meaning that hypothesis four can be accepted. This result supports the enhanced DRIVE model.

4.5.5 Implications

The four hypotheses presented in this study were partially or fully supported and many of the results were in line with the work of previous researchers. The result supports the DRIVE model framework in the context of railway fatigue research. As expected, job demands, job control and support, job characteristics and personality characteristics individually predicted fatigue. The combined effect of these predictors also predicted fatigue, and individuals who were most at risk of high fatigue reported the greatest number of fatigue risk factors. It is, therefore, important to consider the combined impact of these negative factors to understand the railway fatigue. Meanwhile, fatigue was significantly associated with negative well-being outcomes and mediated the impact of stressors on these outcomes. These cues support the main paths of the DRIVE model (Mark & Smith, 2008), which are relevant in this study. Interactions included in the original DRIVE model were not significant in this study, confirming previous studies that have reported no significant moderation.

Fatigue was significantly related to poor performance efficacy and presenteeism, which can increase the risk of accidents. Also, fatigue was associated with negative work-life balance and negative well-being outcomes in both daily life and work life, including life satisfaction, job satisfaction, life stress, job stress, life happiness, work happiness, life depression and anxiety, and job depression and anxiety. That is, a fatigued worker is more likely to perform poorly and be in a negative mood, than a non-fatigued worker. Then, they are likely to bring their negative mood and other negative after-effects from work to their home life.

This study is the first to include train staff from all job roles in the UK rail industry. The logistic regression results (see Model 1 and 2, Table 6) show that particular job types, especially the driver, engineer and controller, are much more likely to suffer fatigue problems than other job types. These three job types generally involve shift-work and the workers in these positions have poor work-life balance and describe themselves as being unhappy at work more than the other job types. This indicates that fatigue in the railway industry is partially based on job differences. For example, the working environment factors that significantly predicted fatigue in this study were more likely to relate to the work features of train drivers and the engineer team members. It is understandable that these job types suffer problems, such as exposure to noise and vibration at work, more often than other types of workers do. In addition, fatigue can be a vicious circle in particular job types. Around one-third of engineers, drivers, station workers and controllers in this study suffered MSDs problems, while more than one-third of the participants reported a physical or mental illness that had been caused or made worse by work. Fatigue is significantly associated with presenteeism (working while sick), and those who keep on working will have occupational ill health and, in turn, increased risk of suffering with fatigue at work. Absenteeism from sickness is an increasing problem, as supported by the British *Rail Accident Investigation Branch's* (2008) concern that sickness absenteeism is negatively affecting the entire rail industry.

4.5.6 Limitations of the present study

There are several limitations of the current study that should be noted. The study was cross-sectional and a longitudinal study would give a better indication of causality. Secondly, the way personality, performance efficiency and job satisfaction were assessed may have introduced bias towards the positive end of the scale which could be because of the simple design of this general survey. This issue was addressed by using a median split instead of thresholds for the variables in this chapter. Another limitation is that a subjective assessment of performance efficiency may not be able to accurately reflect the effect of fatigue. In the next study, measures of performance were used to try and identify objective indicators of fatigue.

4.6 CONCLUSION

Fatigue is currently a general problem in the railway staff population. Investigating fatigue in railway staff requires the understanding and exploration of many potential risk factors, some of which may be unique to particular job roles. The present study indicated that high job demands, poor job control and support, shift-work, exposure to noise and vibration, unhealthy lifestyle, negative personality and the combined effect of these predictors associated with fatigue. The most at risk of high fatigue were those who reported the greatest number of fatigue risk factors. Fatigue also associate with poor work-life balance, poor performance efficiency and negative well-being outcomes. The rail industry and the public should be aware of these issues and should discuss these findings as they relate to managing and monitoring fatigue. Hopefully, fatigue will be managed in the future through focused research and by the establishment and evaluation of industry standards for fatigue management.

4.7 SUMMARY OF CHAPTER 4 AND LINKS TO CHAPTER 5

The research in chapter 4 found strong relationships between job characteristics, individual differences and fatigue, providing good support for the DRIVE model. Interestingly, the results also found an association between fatigue and performance efficiency, which were both assessed by using subjective measures. Chapter 5, based on the work in chapter 4, used online subjective and objective measures to examine how the effects of fatigue and workload.

CHAPTER 5: EFFECTS OF SUBJECTIVE FATIGUE, TIME OF DAY AND WORKLOAD ON ONLINE COGNITIVE PERFORMANCE TASKS

5.1 INTRODUCTION

5.1.1 Link with Previous Chapter

The results of Chapter 4 revealed strong relationships between job demands, job characteristics, and fatigue, which provided support for the main paths of the DRIVE model. The results also demonstrated that a high level of fatigue contributed to sub-standard work efficiency. The method used to assess these variables, however, was subjective reports, that do not necessarily provide support for associations between the feeling of fatigue at work and objective work performance. The present chapter, therefore, aims to assess performance using objective measures of cognitive function and to examine the association between subjective fatigue and objective performance.

The purpose of this thesis was to investigate fatigue in train crew and to develop an online measure of fatigue. Chapter 2 and 3 presented the findings of previous research that had previously demonstrated the valid results of using either subjective or objective measures in assessing fatigue. In particular, self-assessment of fatigue and the psychomotor vigilance task (PVT) were widely used in the previous studies on railway staff fatigue. The online measure of fatigue developed in the present chapter, therefore, integrates self-assessment, PVT and other two cognitive performance tests. The purpose of this present study was to use online cognitive performance tests to examine whether they are sensitive enough to detect the effects of subjective fatigue, time of day and workload. Based on the results from the previous chapter, this study also examined whether workload (another name for job demand) increases fatigue which then leads to a change in performance, or if there are independent effects of subjective fatigue and workload.

5.1.2 Background

Fatigue refers to the effects or after-effects of diverse activities, such as spending a busy day at work, driving on a long journey or even concentrating for a short duration of time on high demanding physical exercises. Failure to manage occupational fatigue, however, can have disastrous results. Fatigue has been identified as a cause of major incidents, such as the Chernobyl nuclear reactor meltdowns, the Challenger Space Shuttle disaster, and the Bhopal gas explosion (Mitler et al., 1988; Dinges, 1995). The consequences of fatigue can be either short term, such as substandard work performance, or long term, such as ill health (see Chapter 2).

Proactively preventing workplace fatigue will help to minimise mortal consequences and improve staff wellbeing, especially for people involved in safety critical work. Both self-rating of fatigue and cognitive performance tests were used to assess the level of fatigue in previous fatigue research (see Chapter 2). Fatigue can be assessed using performance tests because fatigue impairs people's ability to perform efficiently. A review from Krueger (1989) stated that fatigue appears to result in increased reaction time, decreased vigilance, and perceptual and cognitive distortions.

Several cognitive tasks have been widely used in laboratory studies to investigate fatigue-related performance change, including reaction time (RT) tests, vigilance tasks, logical reasoning tests, memory tests, and the Stroop task (Krueger, 1989; Craig & Cooper, 1992). The RT test assesses motor and mental response speeds, as well as measures of reaction time and response accuracy. RT tests includes simple RT test, and choice RT test, which provides more possible stimuli and optional responses than the simple one. The vigilance tasks measure reaction times when the onsets of stimuli are widely spaced in time (e.g., 12 stimuli per 20 minutes;

Mackworth, 1950), and the Stroop task measures reaction time when the name of a colour is printed in a colour that is not denoted by the name (e.g. "blue" in red ink).

Recently, Ferguson et al. (2016) conducted a study to identify the tests which are sensitive to fatigue outside a controlled laboratory environment. They found that the PVT was the most sensitive objective measure of fatigue compared to other tasks, such as memory tasks, the Stroop task, and the Go-No-Go (a kind of choice RT test). The PVT was also the most used objective fatigue measure in the fatigue research on the train crew (summarised in Chapter 2). The current standard version of PVT, however, is a costly hand-held electronic device developed by Dinges and Powell (Model PVT-192; 1985), enclosed in a plastic case (21 ×11 × 6 cm) and weighing 658 grams. There is also a computerised version of the PVT (PC-PVT; Khitrov et al., 2014), and a palm-based version of the PVT (Walter Reed PDA-PVT; Thorne, Johnson, Redmond, Sing, Belenky, & Shapiro, 2005), both of which are free of charge and have relatively low hardware costs. The validity of these two free versions of PVT was found to be similar to the standard PVT-192, despite small differences in the quality of the data, such as mean RT offset and variability of lapses, being obtained (Lamond, Jay, Dorrian, Ferguson, Roach, & Dawson, 2008; Khitrov et al., 2014). Both of these two versions of PVT, however, are independent package softwares which makes it difficult to integrate with other performance measures or fatigue tests. The inconsistent timing technical issue between measures (or software) can result in a greater margin of timing error in the final data analysis.

5.1.2.1 Online Measures

The convenience and low development cost of online fatigue measures make them a more appropriate tool for detecting fatigue in an occupational setting. Online-based cognitive tests have been developed for two decades, and the interest in online experimentation is growing due to the development of HTML5 and JavaScript. A recent review of online cognitive tests confirmed the main advantage of computerised cognitive evaluation (see Crook, Kay & Larrabee, 2009), which is the ability to provide realistic simulations of cognitive tasks in everyday life. A few tools are now available and are used within the cognitive science community, including PsiTurk (McDonnell et al., 2012), QRTEngine (Barnhoorn, Haasnoot, Bocanegra, & van Steenbergen, 2014), and jsPsych (de Leeuw, 2014).

Reimers and Stewart (2015) examined the response-timing accuracy of running online timing experiments using HTML5 with JavaScript across 19 different computer systems. Their findings suggested that durations of stimuli tended to be slightly longer than specified. This was due to the JavaScript *Date.now()* timer being less precise. Web browsers, like all other applications, take turns for a piece of CPU time, and the time they have to wait will vary depending on the CPU load. For example, a 100 ms timer may actually take 102 ms or 110 ms, and this will gradually send the stopwatch out of time. This also leads to inaccurate reaction time calculations by using less precise time stamps. Evan, Harborne, and Smith (2016) made an attempt to develop an online mobile PVT (m-PVT) using JavaScript, which showed the response time to be significantly slower on a Samsung Galaxy Tab 4 than on an iPhone 6s Plus. This, again, showed that the JavaScript *Date.now()* timer is less precise, and that its accuracy depends on device CPU load and individual device models (or systems).

Although the problem of the timing issue in JavaScript was raised, the authors of QEREngine (Barnhoorn, Haasnoot, Bocanegra & van Steenbergen, 2015) resolved this by using requestAnimationFrame (rAF) to synchronise the onset of stimuli with the refresh rate of the monitor. The rAF is a timing controller for script-based animations specification, with which QEREngine can determine whether the elapsed screen presentation time approaches the intended presentation time. To investigate the accuracy of stimulus presentation timing using the QRTEngine, the authors of the QRTEngine conducted a timing validation study using a method similar to that reported by Simcox and Fiez (2014) to validate the timing accuracy. They presented stimuli under different CPU load conditions and compared the intended durations with the durations as measured by a photosensitive diode (an external chronometry). Chronometry is a term in computer science, meaning the science of the measurement of time, or timekeeping. The internal chronometry is set and applied within the electronic devices (e.g. computer, palm), while the external chronometry is an extra timer located physically outside those devices. The results of Barnhoorn et al. (2015) validated that the QRTEngine timing precision was as accurate as the external photosensitive chronometry. The present study, therefore, developed the online measures based on the QETEngine.

There is no ‘gold standard’ of fatigue measurement, but Broadbent (1979) suggested that an ideal fatigue test would not change people’s normal behaviours, connect a person’s own actions and changes in the outside world, and be applicable in realistic situations. Online measures, therefore, are more convenient to apply in occupational settings compared with offline tests or laboratory experiments. However, before administrating them, one needs to examine whether the online objective performance tests are sensitive enough to detect the effects of subjective fatigue, time of day and workload. Based on the previous literature, it is predicted that both subjective fatigue and workload would be associated with a change in performance. Meanwhile, time of day would possibly also influence performance.

5.1.2.2 Subjective Report of Fatigue

The feeling of fatigue is usually described as feeling tired, sleepy, exhausted and lacking in energy (Shen, Barbera, & Shapiro, 2006; Job & Dalziel, 2001). Some studies have assessed fatigue using self-rated fatigue (e.g. rating from 1-not at all, to 7-very fatigued) instead of using cognitive performance tests. Although in the earlier research, Bartley and Chute (1947) and Cameron (1973), argued that subjective fatigue had no predictive power, self-reported fatigue was found to be strongly associated with fatigue-related performance impairment in later studies. In the 1970s, Japanese ergonomists worked hard on the development of a scale to measure subjective fatigue, and this enhanced the research in fatigue ratings. The fatigue rating scale that Japanese researchers developed and validated consisted of three components: (a) drowsiness and dullness, (b) difficulty concentrating, and (c) feeling of physical disintegration (review by Craig & Cooper, 1992). Many of these subjective fatigue scales have been found reliable in distinguishing between fatigued and non-fatigued staff (Chalder et al., 1993; Kim et al., 2010). They also have reliably distinguished fatigue in different types of job disciplines, both within

(Kishida, 1991) and between industries (Kogi, Saito, & Mitsuhashi, 1970; Beurskens et al., 2000). In short, the subjective feeling of fatigue was associated with fatigue-related performance impairment.

Subjective measures are widely used to assess the level of fatigue, especially the 7 point Samn-Perelli Fatigue Scale and visual analogue scales (VAS) of fatigue, which are used in many railway fatigue studies (summary in Chapter 2). The VAS and Samn-Perelli fatigue scale are two of the well-established single-item subjective measures, and are suitable in practical use because they are quick and easy to administer, whether paper-based or computer-based, and pose minimal disruption to the workers. Williams (2014) suggested that single-item measures are able to identify the broad and fine relationships between predictor variables and outcomes, and can replace the multi-item measures. This present study used a subjective single-item fatigue measure to assess fatigue and examine the association between subjective fatigue and objective performance.

5.1.2.3 Time of Day Effect

Human performance shows temporal changes, known as the time of day effect, which has been studied extensively. A review of time of day effect (Smith, 1992) has identified three important aspects of this effect. First, alertness (body temperature was used as the indicator of alertness) increased over the day until the evening. Research in the 1960s studied time of day and related performance on simple tasks, since Kleitman (1963) suggested parallelism existed between the time of day effects in performance and the circadian clock of body temperature, which consistently showed a peak at 9 p.m. and a trough at 4 a.m.

Subsequent studies revealed that waking time was a key mediating factor in the relationship between performance and temperature. The basis of the body temperature study described how alertness increases over the waking day and reaches its peak in the early evening (Colquhoun, Blake, & Edwards, 1968). Studies of circadian variation in serial visual search performance also supported this view (Hughes & Folkard, 1976; Fort & Mills, 1976; Klein, Herrmann, Kuklinski & Wegman, 1977). Second, subjective ratings of alertness peaked in the late morning (Monk, Leng, Folkard, & Weitzman 1983). Third, fatigue increased over the day due to activity. The result of cumulative fatigue was that performance in perceptual-motor tasks became faster but less accurate in the early evening, compared with the early morning (Monk & Leng, 1982). Later, Smith (1991b) noted that such changes in performance were observed in any strategy used (whatever priority to speed or accuracy, or no priority). Performance was faster but less accurate in the early evening in all above three conditions.

Based on the above reviews, different times of day will result in performance changes. It is expected that the fatigue rating will increase and performance in visual search tests and RT tests will be faster but less accurate in the afternoon than in the morning. There is an argument, however, about the time of day effect on logical reasoning performance. Folkard (1975) suggested that logical reasoning performance peaks in the morning, while Smith and Miles concluded there was no time of day effect for logical reasoning (review in Smith, 1992). The online performance measures used here will assess the effect of time of day, and compare the morning-afternoon differences in objective performance and subjective alertness. The present study, therefore, was a two-period design that measured fatigue and performance, once in the morning and once in the afternoon. This methodology assessed the short-term changes in fatigue in a normal day.

5.1.2.4 Workload Effect

In the domain of occupational fatigue, workload was equated with job demands, which may contribute to the development of fatigue-related reduced performance. High/low workload is a relative concept. The high workload condition, for example in the Driving Examiners study (Parkes, 1995), was taking nine tests a day, while the low workload condition was taking seven or eight tests. Actually, the normal workload for Driving Examiners was nine tests per day, scheduled at 45-minute intervals. In Parkes' study, the two reduced workload levels (seven or eight tests per day with longer intervals) were set and tested as the low workload. Her results demonstrated impaired cognitive performance (e.g. reaction time, searching, memory, and logical reasoning) was associated with the excess demands, extended work time, and other work stressors.

A useful concept to measure workload was also proposed by Jahns (1973). In this concept, Jahns suggested that workload involved three related components: input load, operator effort and performance (or work result). The input load consisted of the external factors, such as work duration and workload, while the operator effort reflected the person’s internal reaction to the input load, such as internal goals, motivation and task criteria adopted. The intensity of effort was probably one of the most important parts of workload (Van Roy, 2008). The performance was the output of the above two components. It was maintained by participants and influenced their tolerated error level (Johannsen, 1979), and involved the probability of error, time to respond, response consistency, response range, response accuracy, etc.

Based on Jahns' concept, two key features of workload could be measured in the tests that were identified, the subjective workload and the performance changes. Subjective workload reflects the personal feelings of the input load and the human effort described above. Subjective workload scores are usually related to the task load. It often increases in proportion to the increase in task complexity scores (Park & Jung, 2006). Performance changes involve reduced functional capacity during the work. The effect of workload could also be measured with the before/after work technique. Broadbent (1979) reviewed a series of fatigue tests, most of which studied task load using the after-effect method, which involved measuring performance before and after work. The difference in performance before and after work reflected the workload effect. In particular, the difference of the before-after performance was greater with a high workload (Parkes, 1995). The after-effect symptoms were usually slower reaction times and less accurate responses. These symptoms were also supported by Parkes' workload study (1995), in which the reaction time, speed and accuracy of search tasks and logical reasoning ability showed clear impairments due to the effect of higher workload.

After-effect measurement of performance was widely used in workload studies, and also in studies of other fatigue-related factors, such as the common cold (Cohen, Tyrrell, & Smith, 1991) and caffeine (Doherty & Smith, 2005; Smith, 2002).

5.1.3 Introduction of Online Measure Development

The online fatigue test developed in this study was a two-part online test, integrated with a single-item fatigue measure and a 10-min PVT, as well as the visual searching and logical reasoning tasks. Based on previous research (see Chapter 2), the single-item fatigue rating and the PVT were used widely to assess fatigue in the transport sectors. The present study examined whether the online version of these tests were as sensitive and validated as the offline versions. The visual search and logical reasoning tests were also selected for their sensitivity to the effects of time of day and workload in the previous studies (Hughes & Folkard, 1976; Fort & Mills, 1976; Klein et al., 1977; Parkes, 1995).

According to Kim et al. (2010), the single-item fatigue rating is an 11-point scale anchored at 0=no fatigue and 10=maximal fatigue. Such a subjective fatigue rating indicated significant changes before and after work (Völker, Kirchner & Bock, 2015). The PVT is a reaction-time test that measures fatigue-related changes in alertness usually associated with sleep loss, extended wakefulness, circadian misalignment and time spent on tasks. A standard PVT is approximately 10 minutes in duration with 2 to 10 seconds random inter-stimulus intervals (ISIs). Although auditory and visual reaction time tests have been used since the late 19th century in sleep research (Patrick & Gilbert, 1896), the current standard PVT version was proposed by Dinges and Powell (1985). Reaction time (RT) is one of the main measures PVT focuses on. Two kinds of errors are also measured, one is the error of omission or lapses (RT>=500ms), the other is the error of commission (responses without a stimulus). Previous studies have shown that when appropriate PVT outcomes are used with precise RT timing, the standard PVT has proven to be very sensitive to the dynamics of both acute total sleep deprivation (TSD) and chronic partial sleep deprivation (PSD; Basner & Dinges, 2011). Unfortunately, although PVT was useful in showing the changes due to sleep deprivation, its effect on fatigue from regular daily work was not identified clearly in a recent fatigue measurement study (Volker et al., 2015).

The online measurement of fatigue in this study was developed in advance using the QRTEngine interface via the Qualtrics Platform. Although the page timing, as an advanced functionality, was already included in the Qualtrics online survey development environment, it was not user-friendly enough for the researcher, who aimed to develop browser-based online reaction time experiments. There was also a timing issue inherent in the JavaScript technologies (Garaizar et al. 2014). Fortunately, these problems were resolved by using the QEREngine (Barnhoorn et al., 2015). The QRTEngine is a user-friendly open-source JavaScript engine that provides a precise reaction time listener at millisecond level for Qualtrics-based JavaScript. The QRTEngine checked presentation and response timings though rAF and resolved the timing issue of using a JavaScript *Date.now* timer. Barnhoorn et al. (2015) validated that the precision of timing with the QRTEngine was as accurate as the external photosensitive chronometry.

Based on the QRTEngine, this study developed three other functionalities in the PVT by using JavaScript. These functionalities were random ISIs setting, minutes controlling and response distinguishing. Lack of control is a problem in online testing. Although PVT can be carried out in noisy surroundings (Elmrnhorst et al., 2012), its 10-minute testing duration may be interrupted due to unknown reasons. This online version of PVT, therefore, defined the responses with RT over 30 seconds as ‘sleep’ that a participant may fall asleep during testing or that the test was interrupted by an unknown risk factor. The data with PVT ‘sleep’ responses were considered invalid data and are excluded in the data analysis. Other than ‘sleep’ responses, there are three other types of responses: too fast (the response before stimulus appears), normal response and lapse responses (RT> = 0.6s, but do not get into the sleeping status).

5.1.4 Rationale Behind The Present Experiments

Fatigue studies can use either subjective measures or objective measures to assess fatigue, and some studies use the combination of both. In the present study, both subjective and objective measures were used. Two experiments were conducted to examine the effects of fatigue on performance, both of which looked at the correlation between subjective fatigue and objective performance. The first experiment focused on the time of day effect and involved testing at two different times of the day. However, no significant effect of time of day was found. This was because some participants were more fatigued in the morning, while others were more fatigued in the afternoon, and the performance was impaired at the time they were more fatigued, not because of time of day effect. Thus, it could not be concluded that fatigue is due to the time of day effect.

The second experiment was performed to examine the effects of the workload at the start and the end of a workday. The high and low workload conditions were defined by the subjective rating of workload. The short and long working hours were used as a reference of workload. In addition, the VAS mood rating was added in the second experiment, and the alertness dimension of this scale was used to validate the single-item fatigue measure.

Four measurements were used in this study: the single-item self-assessment, PVT, visual search and logical reasoning tasks. Use of the single-item methodology for subjective fatigue and online PVT were the central fatigue and workload measures. In addition to these measures of fatigue, online visual search measures and logical reasoning tests were also selected for their previously identified sensitivity to the effects of time of day and workload (Hughes & Folkard, 1976; Fort & Mills, 1976; Klein et al., 1977; Parkes, 1995). This study aimed to examine the associations between subjective fatigue, time of day, workload and objective performance changes by using online cognitive tests. It also examined whether the online measures were sensitive enough to detect fatigue in students. If so, the online measurement tool would later be used to study fatigue in railway staff.

5.1.5 Hypotheses

There were three hypotheses presented below for this study:

Hypothesis 1:

The experimental hypothesis predicted that time of day will relate to a change in objective performance. Reported fatigue will be higher and performance will be less accurate but faster in the afternoon, because of the time of day effect. The ability to reason logically will also decline in the afternoon.

Hypothesis 2:

The experimental hypothesis predicted that the increased feeling of fatigue will be associated with performance reduction, including delayed reaction time, lower accuracy rates and impaired logical reasoning.

Hypothesis 3:

The experimental hypothesis predicted that objective performance will be slower and less accurate at the end of the workday because of workload effect, and the reduction in performance will be greater with a higher workload. Additionally, the workload will increase subjective fatigue, which will then lead to performance changes, and a higher workload will lead to a greater increase in subjective fatigue.

5.2 MATERIALS AND METHODS

5.2.1 Design

Two experiments were carried out to examine the effects of fatigue on performance. Study 1 focused on the time of day effect and Study 2 focused on the workload effect. Both of these studies were two-part designed to compare the changes in performance. All of the participants were full-time undergraduate students.

Study 1 had a within participant design. In this time of day study, the participants' performance was tested twice, in the morning (8 to 11 am) and the afternoon (3 to 6 pm). Although most time of day studies have used a wider range of times, the testing times in this study were chosen based on the weekday schedule of participants (undergraduate students). The students usually had their first lecture at 9 am and had the last lecture at 3.10 pm. The testing times ensured that participants were able to take the online test on time. Participants were randomly allocated, either in the morning-afternoon group (MA group), or the afternoon-morning group (AM group) to avoid time order effects on performance.

Study 2 had a between participant design. Participants were assigned to either a high or low workload group after the experiment, based on their self-rating scores of workload. In this study, the participants' performance was tested twice within one day, at the beginning of work (8 to 11 am) and at the end of the workday (3 to 6 pm). The rationale behind this choice of times was the same as in Study 1.

5.2.2 Recruitment

The sample size was 24 per group so that the power of the test was no less than 0.8 with α of 0.05 when the effect was as expected. Julious (2005) estimated a standard deviation (SD) for a sample size calculation, and recommended 24 participants as an appropriate size. G*Power (Buchner, Erdfelder, & Faul, 1997) was used here for an a priori calculation of sample size, with setting the alpha level at 0.05 and power to 0.8. In this case, a sample of 21 participants per group was required to detect a large effect size of d = 0.5 using a one-tailed test. The one-tailed test was adopted because the effects of time of day and workload have been observed on performance changes in previous research. Therefore, a minimum of 21 participants was needed per group for each study (although the final sample in Study 1 fell slightly below this number).

All of the participants were full-time undergraduate students, recruited in Cardiff University via the Experimental Management System (EMS) participant panel. Both experiments were reviewed and approved by the School of Psychology Research Ethics Committee at Cardiff University. In the time of day experiment, 24 undergraduate students were recruited because of the within participant design. Participants were randomly allocated into the morning-afternoon group (MA group) or the afternoon-morning group (AM group). The test was conducted in the morning and afternoon on different days.

In the workload experiment, 48 undergraduate students were recruited because of the between participant design. Participants were assigned to either a high or low workload group after the experiment, based on their workload self-rating. According to the G*Power result, the appropriate minimum sample size for this experiment was 42. Different from the time of day experiment, both sessions were on the same day, with pre-work in the morning and post-work in the afternoon.

Participants were not permitted to do both experiments. In both experiments, the participants were requested not to engage in any physical activity on test days. Other than this, no other interference with the participant's usual activities of daily living was requested.

5.2.3 Materials

Each session included a single-item self-assessment, a 10-min PVT, a visual search and a logical reasoning task, which was used to measure fatigue and performance in Study 1, as well as workload in Study 2. The fatigue self-assessment was used for measuring subjective fatigue in both sessions, and in Study 2, subjective workload was also measured in the post-work session. The three other cognitive tests were used to assess objective performance. Also, VAS mood rating was used to validate the single-item fatigue measure in Study 2. These online measures required assessment by a computer, and participants would respond by clicking on the keyboard and mouse. All the tasks and data collection were via the Qualtrics online survey platform.

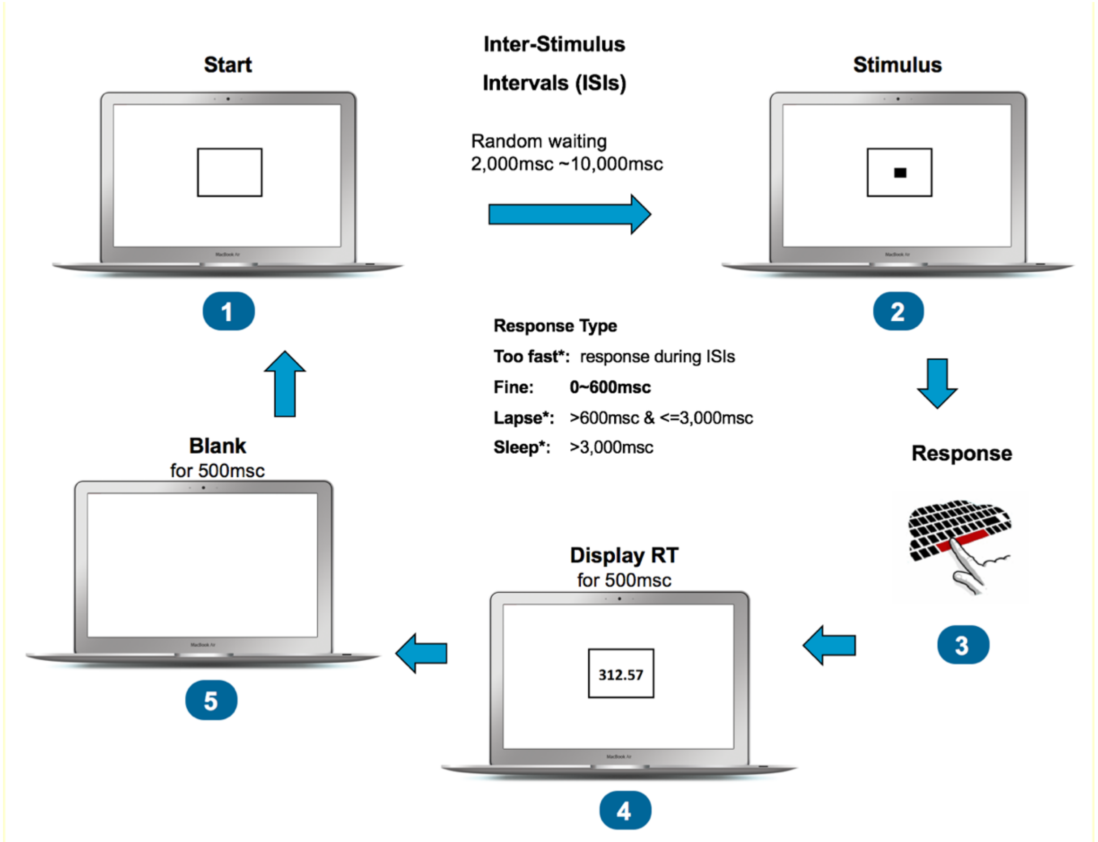
5.2.3.1 Single-item Measures of Fatigue and Workload

Participants rated their fatigue level (measured from 0-no fatigue to 10-maximally possible fatigue) at the beginning of each session. This subjective fatigue rating was used to measure any change before and after work (Volker et al., 2015). In the post-work session in Study 2, participants rated their workload level throughout the day (measured from 0-no workload to 10-extremely high workload). Participants were allocated to either high or low workload condition groups. The allocation of high or low workload conditions was based on the participants' self-rating regarding their workload.

5.2.3.2 Psychomotor Vigilance Task (PVT)

The PVT was 10 minutes in duration, with 2 to 10 seconds of random ISIs in each trial, as proposed by Dinges and Powell (1985). When the PVT started, it was followed by a blank screen. Next, a big empty box appeared on the screen. After the random ISIs, a small square appeared in the middle of the box and timing started until the participant responded by pressing the ‘Space’ key on the keyboard. The RT, type of response, the number of trials in each minute and total were measured. There were four different types of responses which could be recorded; 1. the response was too fast (response before stimulus appears), 2. normal response, 3. lapse (RT >= 0.6s), and 4. sleep (RT >= the 30s). Only the type-2 response (normal response) was marked as correct. If the number of type-1 responses was greater than the sum number of type-2 and type-3 responses, the participant was excluded in the following analysis. Additionally, the meta information of the device and the date and time of task taken were also recorded. At the end of this test, the participants were presented with a hyperlink, which linked them to the next test – a visual search test.

Figure 5.1 *Online PVT used in present study*



5.2.3.3 Visual Search Test

The visual search test consisted of 12 trials, which randomly appeared from a total of 30 trials. In each trial, participants were shown a random 60-letter set and one target letter. They were required to find a set of target letters as quickly and accurately as possible. The response time to find matched letters (the time spent on this page) and the accuracy for each trial was recorded. This task was followed by the logical reasoning test.

5.2.3.4 Logical Reasoning Test

This test was based on Baddeley's (1968) grammatical reasoning test, and it consisted of 24 trials. It required the subjects to make a decision from two options as quickly and accurately as possible. The outcome measures were response time to make the decision and percentage of correct responses. Normally, the percentage of current responses in this test was between 70% and 90%. Data with less than 50% accuracy was less realistic since there were only two options, and the participant had a 50/50 chance to choose the correct one by blind picking. Therefore, such data would be considered as noisy, and would be excluded in the data analysis.

5.2.3.5 Visual Analogue Mood Rating Scale (VAS)

This mood rating scale was added in Study 2 to collect more information on the subjective feeling of fatigue. It was a subjective assessment of mood using the VAS rating system (Bond & Lader 1974). It consisted of 18 items with each ranging in value from 0 (negative end) to 100 (positive end), and measured subjective phenomena on mood. The outcomes consisted of four factors: alertness (eight items), anxiety (6 items), depression (1 item itself) and hedonic tone (3 items). This paper only focuses on alertness, which was used to validate the single-item fatigue measure. The maximum value of alertness was 800. This scale was used in both sessions of Study 2.

5.2.4 Procedure

Before the day(s) in which testing took place, a brief introduction to each cognitive test was emailed to the participants. The introduction included an example of each cognitive test and a familiarisation session to ensure the participants were able to complete the tasks correctly before starting the study. On the testing day(s), participants were asked to complete a series of online tasks via a computer using a strict time frame. They were given two hyperlinks to access the tasks via email (one for each session). The study took approximately 45–60 minutes in total (20–25 minutes for each part). At the end of the experiment, the participants were debriefed.

5.2.5 Analysis

Data analysis was carried out using SPSS 23. Data were analysed using a variety of tests, including Pearson correlation, linear regression and mixed ANOVAs. The independent variables tested were subjective fatigue (for both studies), time of day (for Study 1) and workload (for Study 2). The dependent variables were performance outcomes from each test, including mean reaction time and accuracy (see Table 1 for a list of variables). The analysis assessed the associations between:

1. Time of day, subjective fatigue and performance outcomes
2. Subjective fatigue and workload ratings
3. Workload, subjective fatigue and performance outcomes
4. Subjective fatigue and alertness (to validate single-item fatigue measure).

Table 5.1 *Variables Assessed*

Measures	**Variables**
Single-item Self-assessment	Subjective Fatigue
	Subjective Workload (Study 2 Only)
	Working Hours (Study 2 Only)
PVT	Mean Reaction Time
	Accuracy
	Number of Lapse Responses
	Number of Total Responses
Visual Search	Mean Reaction Time
	Accurate Rate
Logical Reasoning	Mean Reaction Time
	Accurate Rate
Mood	Alertness

5.3 RESULTS — STUDY 1

All of the 24 participants who completed the experiment were full-time undergraduate students. Four data records were excluded due to unacceptable low accuracy (less than 50% correct response) in at least one of the tasks. Such low levels of accuracy were unusual and unacceptable, since participants had already completed a familiarisation session to ensure they understood how to complete the tasks correctly before starting the experiment. These excluded data records that were neither reliable in the PVT nor in the logical reasoning test. In the PVT, if more than half of the responses were rushed (response before stimulus), and the data was considered unreliable. Similarly, in the reasoning task, data with less than 50% accuracy (normal was 70%–90%) would be excluded since there were only two options and the participant had a chance to get 50% correct responses by blind picking. Valid participants (N = 20) came equally from the MA and AM groups.

Data analysis used repeated measures ANOVA to analyse the effects of time of day, and used Pearson correlation and linear regression to analyse the association between subjective fatigue and performance outcome, based on the cross-over experimental design explained above. The independent variables tested were fatigue rating score and time of day (morning, afternoon). The between subject effect was time order (for example, ‘morning -> afternoon’ (MA) versus ‘afternoon -> morning’ (AM)). The hypotheses tested in this experiment were that time of day and subjective fatigue were correlated with objective performance, and objective performance was less accurate but faster in the afternoon because of the time of day effect. The main interests were whether performance across the day was significantly different between morning and afternoon, and whether subjective fatigue was related to objective performance.

5.3.1 Initial Analyses of Time of Day Effect

Table 5.2 below shows the difference in fatigue between the two time sessions. Subjective fatigue scores were categorised into high/low fatigue by using the median. In the morning session, 65% of participants rated their fatigue as high (median = 6, range = 2–9), while in the afternoon session, 60% of them rated their fatigue as high (median = 4, range = 1–8). Table 5.2 also shows the difference in performance outcomes at the two time sessions. A slight reduction in performance was found in both the PVT and the logical reasoning task in the afternoon.

Meanwhile, the reaction time in visual searching was faster, as shown in a previous study.

However, there were no significant effects of time of day on performance outcomes found in the results of repeated measures ANOVA (in Appendix D). Additionally, there was no significant effect of time order (MA or AM group, the between subject variable) in any of the tests.

Table 5.2 *Descriptive Statistics for Time of Day and Mean Fatigue and Mean Cognitive Performances in Study 1*

		Morning		**Afternoon**	
Test		**Mean**	**SD**	**Mean**	**SD**
Self-assessment	Fatigue	6.10	1.997	4.5	2.395
PVT	Reaction Time (msec)	388.73	48.88	389.26	46.94
	Accuracy	89.1%	0.079	88.9%	0.110
	Number of Lapse Responses	5.15	4.32	5.40	7.21
	Number of Total Responses	72.80	3.00	72.2	3.49
Visual Search	Mean Reaction Time (sec)	12.49	3.45	11.24	1.98
	Accuracy	89.6%	0.079	90.4%	0.079
Logical Reasoning	Mean Reaction Time (sec)	4.88	0.89	4.73	1.57
	Accuracy	88.3%	0.097	86.9%	0.090

5.3.2 Associations Between Subjective Fatigue Rating and Performance

The effect of time of day was not found to be significant in the previous analysis. This could be due to the difference in fatigue at the two time sessions between subjects, with some being more fatigued in the morning compared to the afternoon, while some were more fatigued in the afternoon. Therefore, the association can be analysed between fatigue and performance. The variables of difference in fatigue and performance were calculated by using the afternoon score minus the morning score. Pearson correlation and linear regression were used to analyse the associations between subjective fatigue and changes in performance, using continuous variables.

5.3.2.1 Correlation

Table 5.3 and 5.4 show Pearson correlations between the original score of fatigue and performance outcomes in each time session. In the morning session, subjective fatigue did not significantly correlate with any of the performance outcomes. In the afternoon, it significantly correlated with longer reaction time (r (20) =.52, p < .05) and the greater number of lapses (means RT>600ms), r (20) =.51, p < .05) in the PVT. Most of the afternoon scores, however, were not significantly different from the morning scores, indicating no time of day effect observed in the PVT. It could be that other effects (e.g. change in fatigue) might lead to a change in performance scores. Looking at the scores in either morning or afternoon session separately may not be wise, as it is difficult to find their morning-afternoon changes. The correlation between morning-afternoon score changes (see Table 5.6) will be described later in this section.

The greater number of lapse in PVT significantly correlated with the longer mean RT and less accuracy (r from -0.95 to -0.92, p<0.001) in both sessions. These correlations indicated that the greater number of lapse were associated with greater reduction of performance in the PVT. No other correlation was significant in both sessions.

Table 5.3 *Correlation Between Subjective Fatigue and Performance Outcomes in Morning Session*

Morning Session									
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**

Subjective Fatigue (1)	1								
PVT - Mean RT (2)	.264	1							
PVT - Accuracy (3)	-.373	-.759**	1						
PVT - Number of Lapse (4)	.230	.779**	-.933**	1					
PVT – Number of Total Responses (5)	.434	-.071	-.149	-.002	1				
Visual Searching - Mean RT (6)	-.192	.049	-.149	.145	.089	1			
Visual Searching - Accuracy (7)	.297	-.178	-.143	.085	.370	.368	1		
Logical Reasoning – Mean RT (8)	.409	-.042	-.359	.312	.335	-.173	.254	1	
Logical Reasoning - Accuracy (9)	-.231	-.324	.365	-.400	-.152	.082	-.236	-.461*	1

*p<0.05, **p<0.001

Table 5.4 *Correlation Between Subjective Fatigue and Performance Outcomes in Afternoon Session*

Afternoon Session									
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Subjective Fatigue (1)	1								
PVT - Mean RT (2)	.517*	1							
PVT - Accuracy (3)	-.400	-.805**	1						
PVT - Number of Lapse (4)	.505*	.823**	-.951**	1					
PVT – Number of Total Responses (5)	-.359	-.320	.152	-.177	1				
Visual Searching - Mean RT (6)	.323	.417	-.456*	.361	-.379	1			
Visual Searching - Accuracy (7)	.238	.260	-.131	.165	-.073	.208	1		
Logical Reasoning – Mean RT (8)	.288	.116	-.190	.123	-.507*	.413	-.020	1	
Logical Reasoning - Accuracy (9)	-.087	-.261	.295	-.273	.326	-.150	-.430	-.209	1

*p<0.05, **p<0.001

The morning-afternoon difference scores for fatigue and performance were calculated using the afternoon scores minus the morning scores. The positive scores of change in RT indicated a performance impairment in the afternoon, and the negative score of change in accuracy meant that the performance impairment was happening in the morning. The negative score for change in fatigue showed that the participants were less fatigued in the afternoon. Table 5.5 below summarises the mean changes in fatigue and performance, and Table 5.6 shows the correlations between the change in fatigue and the change in performance. The results showed that the changes of subjective fatigue were significantly related to the number of lapse in the PVT (r (20) =.46, p < .05) and reaction time in logical reasoning (r (20) =.57, p < .01). These indicated that the greater the increase in fatigue, the greater number of lapse response in PVT, and the longer the reaction time in logical reasoning. There was no significant correlation found between fatigue and performance in visual searching.

Table 5.5 *Mean Change in Fatigue and in Cognitive Performances*

Test		**Mean Change**	**S. D**
Self-assessment	Subjective Fatigue	-1.60	3.01
PVT	Reaction Time (msec)	0.52	21.44
	Accuracy	-1.5%	0.086
	Number of Lapse Responses	0.25	6.00
	Number of Total Responses	-0.60	4.47
Visual Search	Mean Reaction Time (sec)	-1.24	3.96
	Accuracy	0.8%	0.120
Logical Reasoning	Mean Reaction Time (sec)	-0.15	1.57
	Accuracy	-0.015	0.90

Table 5.6 *Correlations Between Morning-Afternoon Change in Subjective Fatigue and Change in Performance*

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Change in Subjective Fatigue (1)	1								

Change in PVT - Mean RT (2)	.161	1							
Change in PVT - Accuracy (3)	-.361	-.634**	1						
Change in PVT - Number of Lapse (4)	.463*	.605**	-.923**	1					
Change in PVT – Number of Total Responses (5)	-.016	-.282	.194	-.243	1				
Change in Visual Searching - Mean RT (6)	.275	-.126	.190	-.018	-.403	1			
Change in Visual Searching - Accuracy (7)	.370	-.214	.191	-.074	.065	.451*	1		
Change in Logical Reasoning – Mean RT (8)	.568**	.259	-.344	.232	-.095	.202	.249	1	
Change in Logical Reasoning - Accuracy (9)	-.281	-.046	.118	-.057	.080	-.303	-.300	-.609**	1

*p<0.05, **p<0.001

5.3.2.2 Linear Regression

The above results suggest that there was no time of day effect for the group as a whole, but there was a subjective fatigue effect. The change in fatigue was found to correlate with the number of lapse in the PVT and reaction time in logical reasoning. Therefore, a linear regression was used to establish a relationship between the change in fatigue and these two performance outcomes. The result showed that the increase in subjective fatigue was significantly associated with more lapses in the PVT, F (1, 18) = 4.900, $p < .05$, $R^2= 0.214$, and slower reaction time in the logical reasoning task, F (1, 18) = 8.551, $p < .01$, $R^2= 0.322$. Also, the further increases in fatigue were associated with a greater reduction of performance in these two tests.

5.4 SUMMARY — STUDY 1

Hypothesis 1 predicted that time of day would lead to a change in objective performance. Reported fatigue would be higher and performance would be less accurate but faster in the afternoon because of the time of day effect. The logical reasoning would also decline in the afternoon. However, no significant effects of time of day on performance outcomes were found to be significant for the group as a whole. Thus, hypothesis 1 was rejected.

Hypothesis 2 predicted that higher subjective fatigue would result in performance reduction, including slower reaction time, lower accuracy and impaired logical reasoning. As expected, the difference in subjective fatigue significantly predicted change in performance, including increased number of PVT lapse and slower RT in logical reasoning. In addition, the greater feeling of fatigue was associated with a greater reduction in these performance outcomes. In PVT, the increased fatigue predicted the increased number of responses significantly, while the lapse response (RT > 600ms) itself significantly correlated with slower RT and less accuracy. This indicated that PVT performance reduced if subjective fatigue increased, and by contrast, it increased if fatigue decreased. Meanwhile, in the logical reasoning task, reaction time was slower if fatigue increased, and it was faster if fatigue decreased. However, without looking at the subjective fatigue change, there was no significant difference in performance between the different time points. In other words, the effect of time of day did not contribute as much as the influence of subjective fatigue in the above two cognitive tests.

The visual search performance showed a trend to be affected by time of day in that its RT was getting faster in the afternoon in all conditions that were not affected by subjective fatigue. The reason this trend appeared was possibly because the visual search performance has been shown to be highly correlated with body temperature, which increases throughout the day until the evening. Additionally, the RT and accuracy within the same test significantly correlated with each other. There was no influence of the order of different times of day in the experiment.

Overall, increased subjective fatigue led to performance impairment, especially in the PVT and logical reasoning, rather than there being an effect of time of day. Some participants experienced more fatigue in the morning and others experienced more in the afternoon. Their performance was impacted by the period of time in which they experienced fatigue as opposed to the effect of time of day. Subjective fatigue did not show a consistent change with time of day. It could be because of the different activities (e.g. rest, sleep and work) each participant undertook during the period between two test sessions, and this resulted in a different change in fatigue scores. Such activities may have involved different workloads and different periods of work-time. These bring a rationale for the study of the effects of workload on performance in Study 2.

5.5 RESULTS — STUDY 2

Forty-eight participants completed the tests, and two records were excluded in data analyses due to missing data or unacceptably low accuracy (more than 50% incorrect response) in at least one task. These excluded data records were neither reliable in PVT nor in the logical reasoning test. Such low levels of accuracy were unusual and unacceptable since the participants had completed a familiarisation session to ensure they knew how to complete the tasks correctly before starting the experiment. The rule of data exclusion was the same as for the time of day study (see previous session).

Participants (N = 46) were in either the high or low workload condition group. The allocation of a high or low workload condition was based on the participants' self-rating workload.

Pearson product-moment correlation coefficients and mixed MANOVAs were used in this study to analyse the effect of workload on subjective fatigue. The independent variables tested were subjective fatigue, workload, and working duration. The hypotheses being tested in this study were that the effects of workload and subjective fatigue correlated with reduced performance, and higher workload leads to a greater increase in subjective fatigue. The main interests were whether workload increases subjective fatigue, which then leads to performance reduction, or if there is an independent effect of workload on performance, and whether the PVT was sensitive in detecting the effect of workload and the change in fatigue.

5.5.1 Association Between Workload, Working Hours and Fatigue

Workload rating (M = 4.57, range = 0 – 10) showed that this naturally-occurring study of subjective workload does show sufficient variation. The number of hours participants spent on work activities is summarised in Table 5.7 below.

Table 5.7 *Mean Time Spent on Activities*

	Lecture	**Reading**	**Writing**	**Physical Exercises**	**Other Work***
Mean (hour)	2.025	1.565	2.127	1.550	1.712
SD	1.241	0.844	1.687	0.844	1.166
N (%)	20 (43.5%)	31 (67.4%)	15 (32.6%)	30 (54.2%)	33 (71.7%)

*Other work: not related to study and physical exercise.

The workload rating significantly correlated with fatigue ratings at the end of the workday (r (46) =.382, p<0.01), with a higher workload rating being associated with a higher level of fatigue after work. The higher workload also significantly correlated with the greater post-pre changes in fatigue ratings (r (46) =.382, p<0.01), which was calculated by subtracting the pre-work fatigue score from the post-work score (in Table 5.8). Number of work hours had no significant correlation with change in fatigue and performance, thus no further analyses were conducted on work hours.

Table 5.8 *Correlation Between Change in Workload Ratings and Fatigue Ratings*

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Subjective Workload (1)	1			
Working Hour (2)	$.587^{**}$	1		

Post-work Fatigue (3)	.328**	.245	1	
Post-pre Change in Fatigue (4)	.328**	.211	.738**	1

*p<0.05, **p<0.001

5.5.2 Effect of Workload and Fatigue on Performance Changes

Subjective workload scores were categorised into high/low workload by using a median split. Of these, 47.8% of participants rated their workload as high (median = 4, range = 0 – 10). Subjective fatigue scores, again, were categorised into high/low fatigue using the median (Before work: median = 6; At the end of workday: median = 5). In both sessions, 52.2% of partipants rated their fatigue as high. The mean changes in performance are summarised in Table 5.9.

Table 5.9. *Mean Change in Performance Scores by Workload and Fatigue*

Mean (SD)		**High Workload**		**Low Workload**	
	Fatigue	Increased	Decreased	Increased	Decreased
PVT	- RT (ms)	7.10 (28.39)	30.84 (20.56)	16.06 (22.49)	-8.03 (27.57)
	- Accuracy (%)	-4.54 (7.86)	-3.20 (6.67)	-7.80 (8.28)	2.62 (6.96)
	- Lapse	3.25 (5.40)	3.56 (3.32)	4.63 (7.19)	-0.88 (4.84)
	- Total responses	0.42 (4.76)	-2.00 (4.53)	-0.50 (3.89)	0.35 (3.12)
Visual Search	- RT (s)	0.49 (3.98)	0.92 (4.18)	-0.08 (1.98)	1.18 (5.96)
	- Accuracy (%)	-2.83 (9.65)	2.56 (11.11)	-3.37 (19.58)	10.24 (21.87)
Logical Reasoning	-RT(s)	1.27 (1.87)	-2.16 (3.84)	0.50 (2.63)	-0.15 (2.01)
	- Accuracy (%)	-0.42 (13.61)	2.22 (23.95)	-11.13 (21.39)	-5.12 (18.12)
Alertness	- Alertness (% change)	23.33 (78.83)	31.69 (39.65)	-10.51 (27.55)	46.35 (41.60)

5.5.2.1 Correlations

The associations between workload ratings, fatigue ratings and change in performance were investigated by using Pearson correlation (in Table 5.10).

Workload and Performance

There was no significant correlation between the original workload score and performance changes (in Table 5.10). Longer working hours significantly correlated with high workload (r (46) = .59, p < .001), but it did not correlate with changes in fatigue and performance outcomes. There was no significant correlation between the number of working hours spent on each activity (e.g. lecture, reading, physical exercises, etc.) and any of the performance changes (in Appendix D).

Fatigue and Performance

Fatigue showed a significant correlation with accuracy (r (46) = -.37, p < .05) and the number of lapse (r (46) = -.31, p < .05) in the PVT, with greater increases in fatigue being associated with greater reductions in accuracy and increases in PVT lapses. Increasing fatigue also nearly significantly (p = 0.056) correlated with a greater reduction in visual searching accuracy.

Fatigue and Alertness

Fatigue showed a significant negative correlation with alertness (in Table 5.10), r (46) = -.40, p < .001. That is, the greater fatigue was associated with reduced alertness. The eight components of the alertness scale all showed a similar association with fatigue (in Appendix D). It was not a surprise that alertness and fatigue were associated since they represent opposite ends of a continuum. Alertness was also found to significantly correlate with reduced performance in the PVT, with reduced alertness being associated with mean RT (r (46) = -.36, p < .05), accuracy (r (46) = .34, p < .05) and the number of lapse (r (46) = .34, p < .05).

Table 5.10 *Correlation Between Change in Workload, Fatigue and Change in Performance Outcomes*

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Subjective workload (1)	1											

Number of total working hour (2)	.587**	1										
Change in Subjective Fatigue (3)	.328**	.211	1									
Change in PVT – Mean RT (4)	.045	.075	.184	1								
Change in PVT – Accuracy (5)	-.110	-.156	-.367*	-.450**	1							
Change in PVT – Number of Lapse (6)	.141	.115	.310*	.436**	-.874**	1						
Change in PVT –Total Responses (7)	-.091	-.030	.020	-.396**	.133	-.315*	1					
Change in Visual Searching Mean RT (8)	.070	-.166	.003	.037	.036	-.065	.141	1				
Change in Visual Searching Accuracy (9)	-.105	-.130	-.284	-.243	.189	-.109	.129	.479**	1			
Change in Logical Reasoning RT (10)	.043	-.126	.190	-.249	.274	-.303*	.355*	.249	.024	1		
Change in Logical Reasoning Accuracy (11)	.202	-.245	.005	.001	.083	-.067	.080	.082	.218	-.126	1	
Change in Mood – Alertness (12)	.076	.048	-.404**	-.358*	.343*	-.296*	.033	-.196	.068	-.160	-.011	1

$^{*}p<0.05$, $^{**}p<0.001$

5.5.2.2 MANOVAs

MANOVAs were used to analyse the effect of workload and the effect of the changes in fatigue. The variables used in this analysis were categorised into two groups by using a median split. Workload was divided into high/low. The post-pre changes in fatigue were split into increased/decreased fatigue.

Effect of Workload and the Interaction with Fatigue

A two-way MANOVA was conducted to explore the interaction between workload and changes in fatigue. There was no main effect of workload or interaction between workload and fatigue.

Effect of Fatigue on Performance

There was a statistically significant difference between increased fatigue and decreased fatigue on the combined dependent variables, F (8, 37) = 3.699, p<0.01, partial eta squared = 0.44. When the results for the dependent variables were considered separately, the differences that reached statistical significance were accuracy of PVT, accuracy of visual search and the reaction time for logical reasoning (see Table 5.11). In the PVT, response accuracy was significantly affected by fatigue. Increased fatigue not only reduced accuracy, but also resulted in an increase in lapse responses at the end of the workday. Also, the effect of fatigue was found to be significant on the performance of both the visual search and logical reasoning tasks. The accuracy of the visual searches declined more in the fatigue-increased group than in the fatigue-reduced group, while the reaction time for logical reasoning was slower. This, again, confirmed the association between subjective fatigue and the post-pre changes in performance.

Table 5.11 *Significant Univariate Fatigue Effect on Performance*

		df	df error	F	Fatigue	Mean (SD)
PVT	– Accuracy (%)	1	44	8.149	Increased	-5.85 (7.98)
					Decreased	0.60 (7.29)
	- Lapse	1	44	3.873	Increased	3.80 (6.03)
					Decreased	0.65 (4.81)
Visual Search	– Accuracy (%)	1	44	4.423	Increased	-3.05 (13.97)
					Decreased	7.58 (18.96)
Logical Reasoning	- RT(s)	1	44	5.518	Increased	0.96 (2.17)
					Decreased	-0.84 (2.87)

5.6 SUMMARY —STUDY 2

Overall, it was subjective fatigue that predicted the change in objective performance. Fatigue not only was associated with reduced accuracy and an increased number of lapses in the PVT, but it also reduced visual search accuracy and was associated with slower RT in the logistic reasoning task. In the PVT, performance significantly decreased if subjective fatigue increased, and significantly improved if fatigue decreased. Similarly, in the other two cognitive tests, increased fatigue resulted in a greater reduction in performance. If fatigue increased, the response speed in logical reasoning increased, and the accuracy in the visual search further decreased.

The hypothesis predicted that either objective performance or subjective fatigue would be reduced at the end of the workday because of the workload effect, and the reduction would be greater with a higher workload. The result showed that the effect of workload was significantly associated with a greater change in fatigue, but no significant main effect of workload or interaction between workload and fatigue was found. The result also showed longer working hours significantly correlated with high workload, but not with changes in fatigue or any performance outcomes. This indicated that longer working hours increased the perceived workload, but might not necessarily increase the feeling of fatigue.

The alertness dimension of the VAS mood scale was used to validate the single-item fatigue measure. The results showed that the change in alertness and the change in fatigue were strongly correlated with each other, and that increased fatigue was associated with reduced alertness. Also, they correlated with similar changes in performance outcomes, such as PVT accuracy and PVT lapse. These results validated the single-item fatigue measures.

5.7 DISCUSSION

Performance impairment had been considered as one of the outcomes of workload (e.g., Parkes, 1995) or fatigue (e.g., Copper, 1992; Beurskens et al., 2000). However, such associations were still not clear in the large-scale study presented in Chapter 4, which might be limited by the subjective approach to measuring performance. The present chapter, therefore, aimed to assess performance using objective measures of cognitive function and to examine the association between subjective fatigue and objective performance.

This study developed an online fatigue measurement integrating self-assessment and objective performance tests, which includes the psychomotor vigilance task (PVT), visual search task and a logical reasoning task. In particular, self-assessment of fatigue and the PVT were widely used in the previous studies on railway staff fatigue (e.g., Roach et al., 2001; Dorrian et al., 2008; de Araujo Fernandes et al., 2013), while the other two cognitive performance tests were applied broadly in the previous fatigue and workload research (e.g., Bertelson & Joffe, 1963; Parkes, 1995; Charlton & Baas, 2001). The idea of developing such an online fatigue measurement was to apply it outside the laboratory, in the field study. As Chapter 3 stated, very limited existing rail staff fatigue studies had used both subjective and objective fatigue measurement; thus the fatigue test developed in the current study, combining both kinds of measure, would provide a solution to fill this gap. Broadbent's advice for a fatigue test (1978) was largely considered during the design of this online measurement. For example, he suggested that an ideal fatigue test would not change people's normal behaviours, connect a person's own actions and changes in the outside world, and be applicable in realistic situations. Online measures, therefore, are more convenient to apply in occupational settings to investigate occupational fatigue compared with offline tests or laboratory experiments.

The present study examined whether these measures were sensitive enough in a real-life setting to detect the effects of subjective fatigue, time of day and workload. It also examined whether workload (another name for job demand) increases fatigue which then leads to a change in performance, or if there are independent effects of subjective fatigue and workload. The results of these two experiments support the hypothesis that subjective fatigue correlates with objective performance and had an impact on both speed and accuracy. The PVT performance was influenced by subjective fatigue, rather than by the effect of time of day or workload.

5.7.1 Hypothesis 1

Hypothesis 1 predicted that time of day would lead to a change in objective performance. Reported fatigue would be higher and performance would be less accurate but faster in the afternoon because of the time of day effect.

Subjective fatigue did not show a consistent change with time of day. Some participants had higher fatigue scores in the morning, while others had higher scores in the afternoon. Subjective fatigue did not show consistent changes with time of day, this may be because of the different workload participants had during the period between the two test sessions, which resulted in the different changes (increased/decreased) in fatigue.

The visual search performance showed a trend that was affected by time of day. That is, the mean speed in this task got faster in the afternoon, as previous studies have shown (Hughes & Folkard, 1976; Fort & Mills, 1976; Klein et al., 1977) in all conditions, whether fatigue was increased or decreased. This trend of time of day effect can probably be explained by the visual search performance being highly correlated with body temperature, as shown in previous studies, with an increase throughout the day until the evening.

Without looking at changes in fatigue, however, there were no significant differences in performance between the morning and afternoon, in either the PVT or logical reasoning. These indicated that fatigue could be due to exogenous factors. Additionally, it was not surprising that no time of day effect was found on logical reasoning, since this was consistent with Smith and Miles' research (summary in Smith, 1992). Overall, there were no significant effects of time of day on performance outcomes found for the group as a whole. Thus, Hypothesis 1 was rejected.

5.7.2 Hypothesis 2

Hypothesis 2 predicted that higher subjective fatigue would relate to performance reduction, including slower reaction time, lower accuracy rate and impaired logical reasoning.

The two studies indicated a robust effect of fatigue on change in performance. In Study 1, the increase in fatigue led to the increase in the number of lapse responses in PVT and the slower reaction time in logical reasoning. The results of the linear regression showed that the greater feeling of fatigue was associated with a greater reduction in these performance outcomes. Also, the study indicated that the effect of fatigue impaired performance which was independent of the time of day effect, especially in the PVT and logical reasoning. That is, some participants felt more fatigue in the morning, some in the afternoon, and their performance impairment went with the time they were more fatigued, not the time of day.

In Study 2, again, it was the change in subjective fatigue that predicted the change in objective performance. The results showed that the post-pre fatigue significantly influenced the post-pre change in objective performance outcomes in all of the three tasks. In this study, fatigue led to reduced accuracy and increased number of lapses in the PVT, slower RT in logistic reasoning, and reduced accuracy in the visual search.

Overall, the increase in subjective fatigue was associated with performance reduction, and the further increases in fatigue resulted in greater reduction of performance. This supports Hypothesis 2, and the null hypothesis can be rejected.

5.7.3 Hypothesis 3

Hypothesis 3 predicted that objective performance would be slower and less accurate at the end of the workday because of workload effect, and the reduction in performance would be greater with a higher workload. Additionally, the workload would increase subjective fatigue, thus leading to a change in performance, and a higher workload would lead to a greater increase in subjective fatigue.

Workload affected changes in fatigue, but not changes in performance. The results established that the high workload led to an increase in subjective fatigue. However, there was no main effect of workload on performance, or interaction between workload and fatigue. Previous literature has suggested that subjective workload scores increase in proportion to the growth of task complexity (Park & Jung, 2006), which would increase the feeling of fatigue, or would introduce bias in assessing actual workload. The result probably reflects other factors affecting fatigue, and it may be these which then are associated with performance changes.

The result also showed longer working hours significantly correlated with high workload, but not with changes in fatigue and performance outcomes. This indicated that longer working hours increased the perceived workload, but might not increase the feeling of fatigue. The effect of working hours was complex and cannot be simply assessed. It was not only related to the length of working time, but also related to the working activity participants took part in during the time. Although most activities might increase fatigue and impair performance, some of them could even be alerting and improve the outcomes of the cognitive tests (e.g. Dunn & Williamson, 2012).

Overall, the findings provide evidence for the effect of workload on changes in fatigue, but not on changes in performance. Therefore, Hypothesis 3 was partially accepted.

5.7.4 Implications

The hypotheses about subjective fatigue and workload presented in this study were fully or partially supported, while the hypothesis about time of day effect was rejected. Many of the results were in line with the work of previous researchers. As expected, changes in subjective fatigue predicted a reduction in performance, while a high workload increased fatigue. Increased fatigue was associated with a greater reduction in objective performance. This was supported by both studies, in analyses of the original post-pre difference score (Study 1) and increased/decreased fatigue groups (Study 2).

As some participants had to be excluded due to unacceptable low accuracy, the final sample size of Study 1 was somewhat underpowered. However, the use of the differences (i.e., morning-afternoon differences in Study 1 and before-after differences in Study 2) in fatigue scores allowed for individual differences to be controlled for. The findings provide evidence for the effect of workload on subjective fatigue, but no independent effect of workload was found on performance change. The changes in subjective fatigue significantly impaired performance in all of the three cognitive tests. Therefore, it is largely subjective fatigue that predicted the changes in objective performance. This probably indicates other factors affecting fatigue, and it may be these factors which then result in performance changes. Smith and Smith (1988) conducted a factorial study that combined time of day and workload. They found that a high-memory load task was affected by workload, while a low-memory load task was affected by time of day. In the present Study 2, the workload was only recorded once at the end of the workday, which meant a factorial study could not be performed. The main reason for only measuring workload once was that the workload was assessed using self-rating in this study. There was no point in rating the workload before actually undertaking the work activity.

No significant overall effect of time of day was found in this study. Although the findings provide some evidence for the effect of time of day, this is possibly because the particular cognitive test had a high correlation with body temperature which increased over the day. Overall, it was subjective fatigue that predicted the changes in objective performance irrespective of time of day or workload.

The results showed that the online fatigue tests (single-item measure and cognitive tests) did provide indicators of fatigue. The alertness dimension of VAS mood scales was used to validate the single-item fatigue measure. The result of the alertness outcome was consistent with the fatigue outcome, validating the single-item fatigue measure. Meanwhile, the change in PVT performance outcomes were affected by subjective fatigue and workload, indicating that the PVT was sensitive to these changes in state. The outcomes of the three performance tests also showed similar trends related to changes in fatigue. Therefore, the online measures are sensitive enough to study fatigue further, and are potentially applicable to the occupational setting.

The above results suggest that the online fatigue test and logical reasoning task are typically sensitive to detect effects of change in fatigue and workload on performance, while the outcomes of the visual search task might be more sensitive to the time of day effect. Since the next step of this research was to study fatigue in train crew, who have heavier workloads and usually fill shift work on different times of the day, the visual search test could also be used for studying short-term fatigue further.

5.7.5 Limitation

The present studies were conducted from February to April, 2016. Unfortunately, later in July 2016, the developers of QRTEninge decided to maintain it only until February, 2017. This meant that although the online measures used in these two student experiments were validated and fully supported by the QRTEngine team, actions needed to be taken before running the next experiment in railway staff. Such actions could have either been to (1) integrate the QRTEngine code into another open survey platform or an independent website, or (2) contact the QRTEngine team and ask for support, or (3) use other tools (e.g. jsPsych) to develop such online measures. Another limitation was that this study defined high/low workload by median splitting the subjective workload, which might bring bias due to individual differences. Therefore, a symptomatic guide of fatigue and workload rating should be provided in a future study to assist the users in rating their levels of perceived fatigue as accurately as possible.

5.8 CONCLUSION

The present study was designed to examine whether objective fatigue tests were sensitive enough to detect the effects of workload and subjective fatigue. Data analysis showed that fatigue was associated with performance impairments. The results also demonstrated that workload was one of the several predictors of fatigue. High workload is one of the factors increasing fatigue, which then leads to a reduction of performance. Further study is needed of other causes of fatigue and incorporation of these into future studies. No significant effect of time of day was found in this study which may reflect either the limited range of times studies or the different activities carried out at different times.

The two-part online fatigue measure integrating the fatigue self-assessment and PVT did act as indicators of the effects of subjective fatigue and workload. The results from the visual search and logical reasoning tasks were in accordance with results from previous studies. The online fatigue measure appeared valid and sensitive enough to use in further fatigue studies with train crew in the occupational setting. Future research can now examine the application of the online fatigue test in a real life environment, with the addition of self-rated workload and fatigue measures.

5.9 SUMMARY OF CHAPTER 5 AND LINKS TO CHAPTER 6

The research described in this chapter used an undergraduate sample and found that changes in subjective fatigue scores were associated with changes in cognitive performance (PVT, logical reasoning), and that high workload increased fatigue, which was consistent with the findings of Chapter 4. Chapter 5 also highlighted that the visual search test was the only one of the three tasks affected by time of day. Based on the work of the student experiments in Chapter 5, it appeared sensible to conduct a rail staff experiment using the online fatigue measures in the workplace, before and after actual work. Before carrying out such a staff experiment, further exploration of potential risk factors for fatigue among rail staff was necessary.

An online survey about causes of fatigue was run with a staff sample (in Chapter 6). It measured different dimensions of fatigue separately, including physical fatigue, mental fatigue, and emotional fatigue, and investigated the potential causes of each type of fatigue. It was also done to show that the online subjective measurement also works within a staff sample, as the large-scale fatigue survey described in Chapter 4 was a traditional paper-pencil questionnaire and the online studies in Chapter 5 were with a student sample. In order to get an objective view of fatigue, participants were also asked about their colleagues' fatigue. The findings of the online survey in next chapter would provide important information about the format of the online diary study with rail staff (in Chapter 7).

CHAPTER 6: CAUSES OF FATIGUE SURVEY WITH TRAIN CREW

6.1 INTRODUCTION

6.1.1 Link with the Previous Chapter

The results described in Chapter 5 showed a strong relationship between changes in subjective fatigue rating and changes in cognitive performance. The results demonstrated that increased subjective fatigue contributed to substandard performance. The sample used in the study in Chapter 5, however, consisted of undergraduate students that present with risk factors of fatigue in their study life at university, which can be different from those of fatigue in the actual work life of the railway industry. Thus, a further experiment based on a staff sample is needed.

Previous studies identified that job demands (i.e., workload), shift work, working environment, sleep and rest, and individual differences influenced fatigue among train crew. The study described in the present chapter explored the causes of different types of fatigue (i.e., physical, mental, and emotional fatigue) among staff members in a train company using an online survey. It aimed to build a more detailed picture of the relationships regarding job demands, shift-work, and other risk factors of fatigue based on the results of Chapter 4 (i.e., the risk factors of fatigue among rail staff identified in the large-scale fatigue survey). It also examined with an online methodology was appropriate for this sample.

6.1.2 Background

Job demands, in Chapter 4, have been identified as one of the essential stressors of occupational fatigue, with high job demands leading to a greater subjective feeling of fatigue. In the domain of occupational fatigue, workload is often equated with job demands. In the modern railway industry, jobs have placed more emphasis on mental workload, while the traditional physical workload has diminished due to the increasing level of automation in operating systems (Young, Brooklhuis, Wickens, & Hancock, 2015). Mental workload is also complex and multi-dimensional which is frequently described in terms of mental effort or emotional strain (Longo, 2014; Longo, 2015; Reid & Nygren, 1988). It reflects the capacity or resources that are actually required to meet task demands (Eggemeier, Wilson, Kramer, & Damos, 1992), involving the time pressure and the effort exerted for the execution of the task (Hancock & Chignell, 1988). Cain (2007) reviewed the mental workload literature and claimed that it could be summarised as the total cognitive load required to accomplish a task under specific environmental and operational conditions (e.g., in a finite period of time). The majority of jobs in rail transport, such as being a train driver, signaller (i.e., controller), and conductor (i.e., guard), require sustained vigilance. In addition, the engineer may be exposed to heavy time pressure which may result in heavy mental workload and increased feelings of fatigue.

Other than workload, risk factors such as shift work, sleep and rest, and individual differences have also been found to be associated with fatigue. Chapter 3 systematically reviewed previous research on fatigue among rail staff, and found that workload, length of work, timing of the work (i.e., shift work), insufficient rest and sleep, poor sleep quality, job roles, and individual differences were associated with fatigue. The large-scale fatigue survey described in Chapter 4 showed that train crew fatigue was predicted by high job demands, low job control and support, shift work, noisy working environment, unhealthy lifestyle, and negative personality.

Fatigue has generally been discussed as a single entity. However, taking into account the separate energy resources, it is clear that there are different types of fatigue, including physical fatigue, mental fatigue, and emotional fatigue. The physical fatigue resulting from the depletion of muscular energy represents physical tiredness and the incapacity to engage in physical activity, while mental fatigue resulting from the depletion of cognitive energy represents tiredness and the incapacity to engage in mental activity. Recently, in addition to these two types of fatigue, emotional fatigue has received a growing amount of attention (Shirom & Melamed, 2006). This kind of fatigue results from the depletion of emotional energy and represents tiredness and the incapacity to engage in emotional activity. Frone and Tidwell (2015) proposed the Three-Dimensional Work Fatigue Inventory (3D-WFI), suggesting that the measure of work fatigue should be multidimensional, with separate assessments of physical, mental, and emotional fatigue. The psychometric quality and construct of 3D-WFI was then validated in a large-scale national survey in the US (Frone & Tidwell, 2015). In the railway industry, however, research measuring the three different types of work fatigue separately is still lacking, and the causes of different types of fatigue are still unclear.

The Demands, Resources, and Individual Effects (DRIVE) model has been used as a framework for assessing fatigue in previous chapters. In basic terms, this model proposes that high job demands, low job resources (support and control), and individual differences (e.g., negative personality or coping type) predict high levels of fatigue (Mark & Smith, 2008). The DRIVE model was used in the present study to assess different types of fatigue.

The aim of the present study described in this section was to investigate the potential causes of physical fatigue, mental fatigue, and emotional fatigue in a rail company in the UK. It separately measured the different types of fatigue, as well as types of job demands (i.e., physical demands, mental demands, and emotional demands). The study also aimed to build a more detailed picture of the relationships regarding mental workload, other risk factors, and different types of fatigue using the DRIVE model. The survey covered most of the potential risk factors of fatigue which were mentioned in previous literature, such as workload, timing to work, working hours, rest during work, sleep time and quality, and other activities that may influence fatigue. In addition, the current study aimed to determine whether an online version of such subjective measurements was as reliable as the offline one (i.e., the large scale fatigue survey, see Chapter 4), and whether the online version can be used in future research (e.g., an online diary study).

6.2 METHODS

6.2.1 Participants

A total of 246 participants completed an online questionnaire. Most of the participants were male (N = 173, 70.3%), with a mean age of 43.21 years (SD = 10.458, minimum 19.5yr, maximum 65.42yr). There were 66.9% of them who worked in South Wales, UK, while the rest worked in North Wales. Their job roles included train driver, engineer, conductor, manager, administrator, and station worker. The School of Psychology Research Ethics Committee at Cardiff University reviewed and approved this online study.

6.2.2 Materials

This online survey ran in the spring of 2017. The questionnaire consisted of 39 questions, the majority of which were on a 10-point scale and the rest were Yes/No answers (see Appendix E). In addition, there was the opening question, "do you have any comments on your working hours? (e.g., how they could be improved)." Data collection was performed using the Qualtrics online survey platform.

The survey used single-item subjective measures which were valid and reliable (Williams & Smith, 2013) and had been used in previous fatigue studies (e.g., Smith & Smith, 2017). It investigated the details of working hours, shift work, workload, and the potential risk factors outside work (e.g., sleep quality, other activity) and assessed the six predictors of train crew fatigue confirmed in the previous study (in Chapter 4). The survey asked participants not only about the causes of their own fatigue, but also that of their colleagues, which provided relatively objective observation data for assessing the risk factors of fatigue. Frone and Tidwell (2015) claimed that the measure of work fatigue should be multidimensional with separately assessing physical, mental, and emotional fatigue. Given their suggestion, in this questionnaire, work fatigue and job demands were measured alongside physical, mental, and emotional dimensions.

6.2.3 Analysis

Data analysis was carried out using SPSS 23. The quantitative data were analysed using descriptive analysis, exploratory factor analysis, correlation analysis, and regressions, while the qualitative data were analysed using thematic analysis. The approach of exploratory factor analysis used here was principal components analysis (PCA) with Direct Oblimin rotation, with an oblique rotation to extract eigenvalues equalling or exceeding the threshold of 1.

6.3 RESULTS

6.3.1 Descriptive statistics

The primary job types participants reported were managers (21.7%), conductors (20.9%), administrators (20.9%), and train drivers (19.1%), followed by engineers (11.9%) and station workers (5.3%). There were two participants with missing job type data. There were 67.9% of participants doing shift-work. The sample generally reported personality (73.3%), efficiency (91.4%), and effort (95.5%) toward the positive end (all with threshold = 6).

6.3.2 Factor Analysis

Principal components analysis (PCA) with the Direct Oblimin rotation was conducted, and the factor scores (i.e., component scores) were created using the regression method. The components and factor loadings are described in Table 6.1. The factor analysis on the cause of fatigue variables was run separately from other independent variables because they were yes/no questions while others were 10 points questions.

In total, there were 11 components, including 10 predictor factors and one factor covering outcomes. Independent factors included negative work characteristics, positive work and individual characteristics, job demands, length of shift, overtime work, timing of shift, mental workload, effort, positive sleep factor, and other activities. The outcome component was three-dimensional fatigue (3D-fatigue). It should be noted that, based on factor loadings, the contribution of physical demands on three-dimensional work demands (3D-demands, originally component 7) was found to be much smaller than that of either mental or emotional demands; thus, component 7 was renamed as mental workload.

Table 6.1 *Summary of the factor loading of PCA with Oblimin Rotation.*

	Factor Loading	Initial Eigenvalue	Cumulative % Variance
Predictors		**1.657**	**68.1%**
Component 1: Negative Work Characteristics			
Shift-work	.882		
Exposure to Noise and Vibration	.859		
Component 2: Positive Work and Individual Characteristics			
Positive Personality	.811		
Health Behaviours	.667		
Job Control and Support	.580		
Component 3: Job Demands			
Job Demands	.934		
Causes of Fatigue		**3.058**	**68.4%**
Component 4: Length of Shift			
Length of Shift (colleagues)	.808		
Length of Shift	.805		
Component 5: Overtime Work			
Overtime	.829		
Number of Shift before Rest Day (colleagues)	.695		
Overtime (colleagues)	.613		
Number of Shift before Rest Day	.544		
Component 6: Timing of Shift			
Timing of Shift	.828		
Timing of Shift (colleagues)	.822		
Workload		**2.109**	**63.5%**
Component 7: Mental Workload (3D-Demands)			
Hurried or Rushed	.845		
Frustrating	.782		

Mental Demands	.750		
Physical Demands	.462		
Component 8: Effort			
Effort	.960		
Activity Outside Work		**1.585**	**72.4%**
Component 9: Positive Sleep Factor			
Sleep Length (Hours)	.874		
Quality of Sleep	.870		
Component 10: Other Activities			
Activities Outside Work (colleagues)	.826		
Activities Outside Work	.816		
Outcomes		**2.021**	**67.4%**
Component 11: 3D-Fatigue			
Emotional Fatigue	.876		
Mental Fatigue	.859		
Physical Fatigue	.717		

6.3.3 Bivariate Analysis

6.3.3.1 Associations between Fatigue, Efficiency, and Working Hours.

The associations between the three different types of fatigue, efficiency, and six working hours-related variables were investigated using a Pearson correlation (shown in Table 6.2). The three dimensions of fatigue were significantly correlated with each other ($p < .01$). Physical fatigue showed a significant positive correlation with shift length and the frequency of rest and breaks during work (r from .26 to .27, $p < .01$). Mental fatigue showed a significant correlation with the start time of shift work (r (222) = -.20, $p < .01$), with higher levels of mental fatigue associated with earlier shift work start times (i.e., early morning shift work). Mental fatigue, emotional fatigue, and efficiency were significantly correlated with the number of shifts taken before a rest day, with correlation coefficients between .13 and .15, both *p* < .05. In addition, higher efficiency was found to be significantly associated with longer break length, r (219) = .17, *p* < .05).

Table 6.2. *Correlations between three different types of fatigue, efficiency, and working hour-related independent variables (IV).*

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
Physical Fatigue (1)	1									
Mental Fatigue (2)	.40**	1								
Emotional Fatigue (3)	.44**	.67**	1							
Efficiency (4)	-.02	-.09	-.12	1						
Shift Length (5)	.26**	.11	.09	-.12	1					
Number of Shifts Before Rest Day (6)	.02	.13*	.15*	.15*	-.31**	1				
Start Time of Shift-Work (7)	-.10	-.20**	-.08	-.11	.18**	-.27**	1			
Overtime Work (8)	.11	.03	.07	.13	-.09	.15*	-.13	1		
Frequency of Breaks During Work (9)	.27**	.02	.03	.06	.18*	-.09	-.10	-.05	1	
Break Length (hours) (10)	-.06	-.08	-.10	.17*	.09	.01	.03	.04	-.02	1

*p<0.05, **p<0.001

6.3.3.2 *Associations between 3D-Fatigue and Independent Factors.*

The associations between 3D-fatigue and 10 independent components were analysed using their factor scores. The results are summarised in Table 6.3. Fatigue predictors, job demands, and negative work characteristics showed a significant positive correlation with 3D-fatigue, while positive work and individual characteristics showed significant negative correlations with fatigue (all *p* < 0.01).

3D-fatigue was positively correlated with length of shift, overtime work, and timing of shift (r from .20 to .32, *p* < .01). Considering the components of the factor mental workload, 3D-fatigue showed a significant positive correlation with emotional and mental demands, r (217) = .66, *p* < .01, with a higher level of fatigue associated with a higher level of emotional and mental demands. Meanwhile, fatigue showed a negative correlation with effort, indicating that poorer effort was associated with a higher level of fatigue.

In terms of the activities outside of work, fatigue showed a significant correlation with the sleep factor, r (195) = -.260, $p < 0.01$, with a higher level of fatigue associated with a poorer sleep experience. There was no significant association between fatigue and other activities.

Table 6.3 *Correlation between 3D-fatigue and factor IVs.*

Variables (factors)	**3D-Fatigue**
Negative Work Characteristics	.35**
Positive Work and Individual Characteristics	-.24**
Job Demands	.47**
Length of Shift	.32**
Overtime Work	.31**
Timing of Shift	.20**
Mental Workload	.66**
Effort	-.17*
Sleep Factor	- .26**
Other Activity	.02

6.3.4 Regression

Regression analyses were carried out to investigate the associations of multiple independent variables with fatigue. First, a linear regression was run using the factor scores of the independent components and 3D-fatigue. As shown in Table 6.4, mental workload, positive work and individual characteristics, and job demands were the strongest predictors of 3D-fatigue by beta weight, followed by overtime work. The regressions account for 51.3% of the variance in 3D-fatigue.

Table 6.4 *Regression predicting 3D-fatigue.*

	Model					
Variables (factors)	**B**	**S. E**	**β**	**t**	**C.I.**	**p**
Negative Work Characteristics	.099	.071	.100	1.384	[-.042, .239]	0.168
Positive Work and Individual Characteristics	. -.172	.064	-.173	-2.680	[-.299, -.045]	<0.01
Job Demands (High)	.178	.080	.171	2.231	[.020, .335]	<0.05
Length of Shift	.048	.066	.050	.727	[-.082, .178]	.468
Overtime Work	.123	.058	.123	2.109	[.008, .237]	<0.05
Timing of Shift	.079	.065	.080	1.216	[-.050, .209]	.226
Mental Workload (High)	.425	.084	.418	5.042	[.258, .591]	<0.001
Effort	-.047	.067	-.045	-.700	[-.178, .085]	.485
Positive Sleep Factor	-.081	.058	-.083	-1.408	[-.195, .033]	.161
Other Activities	.040	.057	.041	.702	[-.073, .152]	.484
R = .716, R Square = .513						

However, given that the risk factors for different dimensions of fatigue can be different, separate analyses of the physical, mental, and emotional fatigue variables were needed. Therefore, binary logistics regression analyses (using enter method) were run, using the original fatigue variables as the outcomes, and dichotomised factors as the predictors. The dependent variables used here were physical fatigue, mental fatigue, and emotional fatigue, which were dichotomised into high/low groups using median split ($M_{\text{Physical Fatigue}} = 6$, $M_{\text{Mental Fatigue}} = 7$, $M_{\text{Emotional Fatigue}} = 6$). The independent variables were the 10 independent factors, which were dichotomised though median splitting the factor scores. The results are presented in Tables 6.5-1, 6.5-2, and 6.5-3.

6.3.4.1 Analysing Predictors of Physical Fatigue.

In the regression analysis, negative work characteristics, long length of shifts, and overtime work were found to be associated with physical fatigue at a significant level ($p < .05$). The strongest predictor for reporting a physical fatigue problem in this model was the length of shift work, recording an odds ratio (OR) of 4.5, indicating that participants working long shifts were 4.5 times more likely to report physical fatigue problems ($p < 0.001$) than those with shorter shifts. This was followed by overtime work, recording an OR of 3.1, and negative work characteristics, recording an OR of 2.6. High mental workload and high job demands showed a trend toward significance in predicting physical fatigue ($p_{\text{Mental workload}} = 0.069$, $p_{\text{Job Demands}} = 0.084$, both OR = 2.1). There were no significant associations between other factors and physical fatigue in this model. The explanatory power of this model was 39.5% of the variance, and the classification accuracy was 75.0%. The full model containing all predictors, was statistically significant, X^2 (1, N = 172) = 59.972, $p < 0.001$, indicating that the model was able to distinguish between participants who reported and those who did not report a physical fatigue problem.

6.3.4.2 6.3.4.2 Analysing Predictors of Mental Fatigue.

Job demands, mental workload, and overtime work influenced mental fatigue significantly ($p < .01$). The strongest predictor of mental fatigue was job demands, recording an OR of 5.4, indicating that participants working with high job demands were 5.4 times more likely to report a mental fatigue problem ($p < 0.001$) than those with low job demands. This was followed by mental workload (OR = 3.0) and overtime work (OR = 2.9). No significant association between other factors and mental fatigue was found in this model. The model of mental fatigue accounted for 40.0% of the variance and correctly classified 75.7% of cases. The full model containing all predictors was statistically significant (X^2 (1, N = 173) = 61.131, $p < 0.001$), indicating that the model was able to distinguish between participants who reported and those who did not report a mental fatigue problem.

Table 6.5-1. *Odds ratio of each IV on physical fatigue.*

Outcome: Physical Fatigue			
Variables	**Odds Ratio**	**C.I.**	**p**
Negative Work Characteristics (High)	2.630	[1.189, 5.820]	< 0.05
Positive Work and Individual Characteristics (Low)	2.080	[0.907, 4.771]	0.084
Job Demands (High)	1.888	[0.856, 4.165]	0.115
Length of Shift (Long)	4.468	[1.929, 10.347]	<0.001
Overtime Work	3.122	[1.433, 6.804]	<0.01
Timing of Shift (Poor)	0.909	[0.420, 1.969]	0.808
Mental Workload (High)	2.105	[0.943, 4.702]	0.069
Effort (High)	1.239	[0.563, 2.729]	0.594
Positive Sleep Factor (Poor)	1.489	[0.682, 3.250]	0.317
Other Activities	1.769	[0.808, 3.874]	0.154
Nagelkerke R-square	39.5%		
Chi square	59.972, df = 10, p<0.001		
Hosmer & Lemeshow test	P = 0.945		
Classification accuracy	75.0%		

Table 6.5-2 *Odds ratio of each IV on mental fatigue.*

Outcome: Mental Fatigue			
Variables	**Odds Ratio**	**C.I.**	**p**
Negative Work Characteristics	1.658	[0.728, 3.777]	0.229
Positive Work and Individual Characteristics	1.253	[0.549, 2.857]	0.592
Job Demands (High)	5.403	[2.465, 11.840]	<0.001
Length of Shift	0.807	[0.337, 1.932]	0.630
Overtime Work	2.899	[1.324, 6.345]	<0.01
Timing of Shift	1.066	[0.478, 2.378]	0.876
Mental Workload (High)	2.959	[1.311, 6.679]	<0.01
Effort	1.788	[0.808, 3.954]	0.151
Positive Sleep Factor	1.819	[0.817, 4.051]	0.143
Other Activities	0.951	[0.440, 2.058]	0.899
Nagelkerke R-square	40.0%		
Chi square	61.131, df = 10, p<0.001		
Hosmer & Lemeshow test	P = 0.970		
Classification accuracy	75.7%		

6.3.4.3 Analysing Predictors of Emotional Fatigue.

Emotional fatigue was significantly predicted by positive work and individual characteristics, job demands, length of shift, overtime work, timing of shift, and mental workload. Overtime work was the strongest predictor of reporting emotional fatigue, recording an OR of 4.2, $p < 0.001$. This was followed by length of shift (OR = 3.9, $p < .01$), low scores for positive work and individual characteristics (OR = 3.8, $p < .01$), and high job demands (OR = 3.6, $p < .01$). Mental workload and the timing of shift were also the important predictors of emotional fatigue, both recording ORs of 2.7, $p < .05$. The model of emotional fatigue accounted for 42.1% of the variance and correctly classified 76.3% of cases. The full model containing all predictors was statistically significant (X^2 (1, N = 173) = 65.407, $p < 0.001$), indicating that the model was able to distinguish between participants who reported and those who did not report an emotional fatigue problem.

Table 6.5-3 *Odds ratio of each IV on emotional fatigue.*

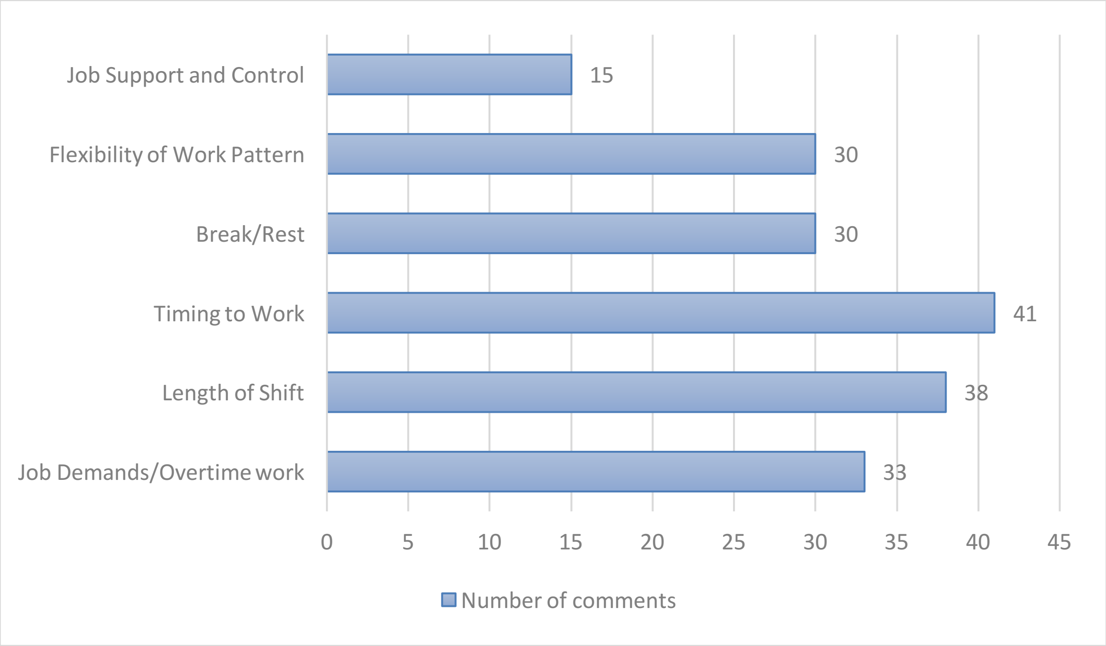
Outcome: Emotional Fatigue			
Variables	**Odds Ratio**	**C.I.**	**p**
Negative Work Characteristics	1.478	[0.636, 3.434]	0.363
Positive Work and Individual Characteristics	3.809	[1.635, 8.875]	<0.01
Job Demands (High)	3.603	[1.604, 8.093]	<0.01
Length of Shift	3.883	[1.591, 9.473]	<0.01
Overtime Work	4.180	[1.851, 9.436]	<0.001
Timing of Shift	2.804	[1.197, 6.568]	<0.05
Mental Workload (High)	2.809	[1.248, 6.323]	<0.05
Effort	1.541	[0.703, 3.381]	0.281
Positive Sleep Factor	1.378	[0.630, 3.014]	0.422
Other Activities	1.776	[0.799, 3.948]	0.159
Nagelkerke R-square	42.1%		
Chi square	65.407, df = 10, p<0.001		
Hosmer & Lemeshow test	P = 0.300		
Classification accuracy	76.3%		

6.3.5 Thematic Analysis (Opening Question)

The thematic analysis strategy (Braun & Clarke, 2006) was employed to analyse the open-ended survey question, “Do you have any comments on your working hours? (e.g. how they could be improved).” The answers were read several times, and the themes listed above were identified and highlighted by coloured pens. Some text involved two or more themes. The answers to this question demonstrated that the factor of working hours is not the only risk factor of fatigue.

There were 133 responses to this question. The main jobs of those who answered this question were train drivers (23.3%, N=31), conductors (21.8%, N=29), administrators (17.3%, N=23), and engineers (15.8%, N=21), followed by managers (15.0%, N=20) and station workers (6.0%, N=8). One participant had missing job type data. The themes of these responses included job demands/overtime work, length of shift, timing to work, break/rest, flexibility of working pattern, and job support and control. Timing to work was the most popular theme, followed by length of shift, job demands/overtime work, break/rest, and flexibility of working pattern. The frequency of these themes is shown in Figure 6.1.

Figure 6.1 *Number of comments on each theme.*



Theme 1. Timing of work

The first topic described was timing of work, the most popular theme being mentioned by 41 comments. Participants generally claimed that less shift-work would decrease fatigue problem.

> Participant 81 (engineer): "*...Shift-work and early shift start times affect me with fatigue.*"
>
> Participant 115 (engineer): "*More day working, shorter night shifts.*"
>
> Participant 90 (train driver): "*If the shifts were better balanced instead of booking on at 03.27 in the morning and working through on night shift, I feel this would help.*"

Participants described how the irregular hours of shift-work affected their work-life balance, and how difficult it was to recover from a series of night shifts when an early morning shift was scheduled immediately after.

> Participant 94 (administrator): "*Too many late shifts, too many weekends, have no enough family time. Work/life balance heavily depends on work and changes on shifts always make things worse never better.*"
>
> Participant 28 (conductor): "*Spare shift which can be moved three hrs either way and it only advised 48hrs before, messing up the healthy lifestyle, sleep and society activities. This should be reduced to an hour.*"
>
> Participant 69 (manager): "*We have to work during the nights. Sometimes working from the day shift on the previous day, then back to a morning start after minimal rest, which can be tiring.*"
>
> Participant 107 (conductor): "*Poor rostering is the main issue. One issue is finishing at 0230 Sunday morning. Having Sunday off then in 0343 starts Monday morning. How am I supposed to prepare my body for that?*"

Participants believed that having a more consistent time to work would reduce fatigue, especially within the same working week. A varied and too changeable start time resulted in their fatigue.

> Participant 19 (train driver): "*I try to regulate my shift pattern by having a permanent swap with one of my colleagues so that I always do early shifts and he always does*

> *late shifts. I find that the change back and forth between early and late (shifts) is the largest contributory factor that influences my fatigue.*"

> Participant 109 (conductor): "*A similar start time all week would help enormously, e.g. if on earlies shifts starting around the same time all day, and not varying between 0343-0701 like one week in my link currently does.*"

This participant mentioned that personal preference of time of day could help with coping with specific shift-work.

> Participant 25 (train driver): "*I try to swap for the late turns as I find they suit me better. On early shift, I would say that I lose about a night sleep over the four shifts. I generally struggle to get to sleep early, even when I'm tired, though I do manage to get up OK.*"

Theme 2. Length of Shift

The second theme highlighted the length of shift-work that the train crew took which was mentioned by 38 comments. Participants reported that current working hours were too long, that the length of each turn should be limited, and that the number of maximum working hours should be reduced.

> Participant 9 (conductor): "*(Working hours) could bring in a maximum 9.5-hour day with having a maximum of 4 hours on a train at any given time.*"

> Participant 76 (engineer): "*Working hour should less 12 hours and average 10-hour shifts throughout the month.*"

> Participant 111 (engineer): "*I think 10 hours should be maximum shift length when working on safety critical work."*

Participants also suggested a reduction in the length of early morning and night shifts.

> Participant 75 (train driver): "*The jobs that start very early in the morning (before 6am) should not be allowed to be much longer than 6-7 hours long in turn length.*"

> Participant 87 (engineer): "*Reduce 12 hours to 10 hours or even 8 hours, especially on nights.*"

Theme 3. Job Demands/Overtime Work

The third theme described the demands that were placed on the train crew and the overtime work that they take. With regards to job demands, participants described how the job demands were high.

> Participant 40 (administrator): "*It's not the length of shifts that make me feel fatigued, but the constant questions, and the concentration needed to check tickets, make sure that people don't get stuck in the ticket barriers etc.*"
>
> Participant 85 (train driver): "*The commitment to covering on-call requirements and being called out in addition to normal daily hours, massively impinges on my fatigue and well-being.*"
>
> Participant 105 (train driver): "*… the problem comes with the intensity of work within the turn.*"

More specifically, participants reported that the nature of their work can be mentally or emotionally demanding and that their fatigue is often more emotional or mental.

> Participant 74 (train driver): "*Repetition of work, i.e. 4 hours of constant driving over the same route multiple times, e.g. City line - mentally exhausting.*"
>
> Participant 128 (manager): "*I have a mentally challenging job.*"
>
> Participant 63 (station worker): "*...it's more emotional and mental fatigue that affect how I feel after a working day.*"

Overtime work was frequently mentioned, and participants described how their overtime work had high demands.

> Participant 84 (manager): "*I work 12 hrs shift. Every shift I work overtime for approximately 40 minutes (20 minutes at the start and 20 minutes after the shift finishes) to allow for a shift handover.* "
>
> Participant 50 (manager): "*The overtime mentioned is event working. It is expected in some departments that staff who volunteer for events complete their full shift before volunteering to work an event for payment. This can lead to staff working in excess of*

> *12 hours. A member of the resources team recently worked a 15-hour shift; this is dangerous given that staff are managing large crowds and have to make safety decisions, which is difficult to do when tired. When finishing evening events, staff can finish as late as 0130 but are expected to return to work for their normal shifts with very little rest.*"
>
> Participant 84 (manager): "*The commitment to covering on-call requirements and being called out in addition to normal daily hours, which massively impinges on my fatigue and well-being.* "

Participants specifically pointed out that the reason for their high job demands and overtime work was insufficient staffing.

> Participant 68 (conductor): "*There are not enough people to complete all the tasks that need completing. Many people within the function are doing two jobs and working in the evenings/weekends.*"
>
> Participant 56 (manager): "*Roster has insufficient staff for the number of hours required (i.e., the roster should have 7 to cover properly but only has 5). Overtime unavoidable at times as job mandatory to cover.*"
>
> Participant 106 (administrator): "*… the biggest issue is the amount of time we spend single manned (i.e. on our own with no backup or support at the station). This has increased in recent months due to staff cuts.*"

Theme 4. Break/Rest

The fourth theme described was breaks during work and rest after work. Insufficient rest and break were reported to lead to fatigue, as well as increase risks to the safety.

> Participant 105 (train driver): "*...the breaks are too infrequent and often too short. Too much time spent without a break leading to fatigue*."
>
> Participant 122 (train driver): "*Breaks are very tight, and if we are late, we feel under pressure to take subsequent trains on time... (Break) sometimes was split into two rushed breaks. This means it is very difficult to eat a hot meal or to shut off for 5 mins, which is not great in a safety critical environment*."

Participants mainly complained that the timing of rest during the shift was poorly placed, either too early or too late, and needed to be more thoughtful.

> Participant 8 (conductor): "*The breaks are in the wrong place. Right at the start or right at the end.*"

> Participant 10 (conductor): "*…Could we please have breaks in the middle of a shift and not after 30 minutes of starting a ten-hour shift or at the end of one?*"

Participants also suggested to have more rest days and arrange them more strategically, especially between opposing shifts.

> Participant 37 (administrator): "*More recovery time. More occasions of consecutive rest days (1 occasion every six weeks at present).*"

> Participant 54 (train driver): "*More rest between opposing shifts. Sometimes there is only 26 hours between late afternoons and early mornings*."

Theme 5. Flexibility of Working Pattern

Flexibility of working pattern was frequently mentioned in the comments. Participants described how a flexible working pattern could benefit their work-life balance and suggested to increase flexibility of working time and working place.

> Participant 5 (administrator): "*Flexible working would assist people to manage their day and improve work-life balance. For example, you can choose to come in at 7 knowing that you can leave at 3 and enjoy time with family or enjoy sunshine etc. Also, you can accrue flexible days.*"

> Participant 86 (manager): "*More flexible approach to start and finish times. I.e., if you work over one day, you should be able to finish early the next day for example. Come in later and go home later on some days or the other way around and more working from home where the job allows.*"

Theme 6. Job Support and Control

Participants reported low levels of job support and control, mainly including lack of support from the manager or other colleagues and unfair arrangement of working time due to their younger age.

> Participant 18 (manager): "*There is little concern from management or unions about the amount of work and length of turn for jobs starting during the late night. The reality of these shifts regardless of attempts to manage those means that almost all drivers working these shifts experience moments and incidents of micro-sleeps and concentration loss during them.*"
>
> Participant 36 (train driver): "*I am in the bottom link (rota) in work as I'm junior. We have ALL the very early starts and ALL the late starts. As you progress (10 years roughly), you move up the links and get easier start times. This should be spread out fairly and not left to the same 35 men*."

6.4 DISCUSSION

The present study aimed to explore the potential causes of physical fatigue, mental fatigue, and emotional fatigue among rail staff, by using both qualitative and quantitative methods. It separately measured the different types of fatigue according to Frone and Tidwell's suggestions (2015) and also measured different types of job demands separately (i.e., physical demands, mental demands, and emotional demands). In particular, the qualitative data adds the details and brings the depth of understanding to the research questions on causes of fatigue.

The DRIVE model was used as a framework for assessing fatigue, although initially it was an occupational stress model developed to overcome earlier models and theories (Mark & Smith, 2008). Cameron (1973) suggested that the term fatigue is synonymous with a generalised stress response over time, which provided the rationale for applying this stress model on fatigue. This model was more conclusive in contrast to other related models by considering context, connectedness, and complexities of a high level. Further, the elements and main paths shown in the DRIVE model reflected some of the causes and predictions of fatigue identified in the previous studies (reviewed in Chapters 2 and 3). Thus, it was appropriate to use the DRIVE model in the current fatigue study.

This study built a more detailed picture of the relationships regarding various risk factors and different types of fatigue based on the DRIVE model. It confirmed that mental workload is an essential cause of fatigue among rail staff. Although other risk factors were also found to be associated with fatigue, only positive work and individual characteristics, job demands, overtime work, and mental workload predicted fatigue as a single outcome, which is consistent with previous studies in Chapter 4 and 5.

The findings provided more specific information on mental workload and other potential causes of different types of fatigue. When different types of fatigue were analysed separately, mental workload, job demands, and overtime work were still found to predict fatigue in all its three dimensions. Physical fatigue was also associated with longer length of shift work, negative work characteristics, and less frequent breaks during work. Moreover, the findings provided evidence that poor shift patterns were associated with mental and emotional fatigue. Both mental and emotional fatigue were associated with poor timing of shifts and a greater number of shifts taken before a day of rest. Emotional fatigue was also predicted by positive work and individual characteristics, which means that high job support and control, healthy lifestyle, and positive personality helped to reduce emotional fatigue. Although the effects of positive work and individual characteristics were in line with a previous large-scale study (see Chapter 4) showing their roles as buffers against fatigue, they only influenced emotional fatigue, not mental fatigue.

These findings support the idea that the jobs of rail staff place greater emphasis on mental workload. In the factor analysis, the contribution of physical job demands to 3D-demands was much smaller than that of mental and emotional demands. This supported the view from previous research (Young, Brooklhuis, Wickens, & Hancock, 2015) that currently, work in the railway industry imposes more cognitive demands than physical demands. Moreover, the predictive ability of job demands was consistent with those of mental workload. It predicted all three different types of fatigue, as well as fatigue as a whole, while the effect of effort was not found to be significant.

It was the mental workload and overtime work that resulted in all three types of fatigue among the train crew. "More work over longer times from fewer people" is a dangerous strategy which can make the train staff more fatigued. Currently, fatigue is conceptualised in terms of working hours in rail transport. This suggests that a future fatigue study of the railway staff should develop an appropriate mental workload measurement. Subjective measures of the mental workload will be sufficient (Longo, 2015; Cain, 2007), despite the fundamental research required to compare subjective and objective workload in the industry.

Based on data gathered through an online survey, the results of the current study are in line with those of previous studies (see chapters 4 and 5). Furthermore, the results showed a bias towards having a positive personality, efficiency, and effort, which also appeared in the offline survey (see Chapter 4). This suggests that the online survey was as reliable as the offline version, and in the future, online studies can be carried out.

In the opening question, participants mainly reported that irregular timing of work and impaired work-life balance led to fatigue and that recovering from opposed shifts was extremely difficult. Participants also reported high job demands, especially mental and emotional demands, overtime work, and long length of shift-work. The amount of rest and break were reported as insufficient, while it was suggested that the timing of breaks during work could be better arranged. A flexible work pattern was believed to improve work-life balance. Participants also raised concerns about lack of job support and control. These comments provided important insight into the nature of jobs in the railway industry and inspired the next study (i.e., a diary study), described in the next chapter.

In future research on occupational fatigue, measuring different types of fatigue separately will be useful to better understand job role differences. Although the high mental workload and overtime work cannot be avoided in many industries, a better understanding of the causes of different types of fatigue among workers could help with fatigue management in the workplace. It is suggested that sufficient opportunities to take breaks during work should be provided to control physical fatigue, and that shift patterns should be better arranged to reduce the risk of mental and emotional fatigue.

6.5 CONCLUSION

This study explored the causes of three dimensions of fatigue among train staff members. The results of it showed that mental workload and overtime work were the essential potential causes of all different types of fatigue among railway staff. Alongside these two factors, physical fatigue also resulted from prolonged shift work, insufficient rest during work, and negative work characteristics, while mental and emotional fatigue resulted from poorly arranged shift patterns, including poor timing of shifts and working more shifts before taking a regular rest day. Positive work and individual characteristics played a buffering role only for emotional fatigue, but not for mental fatigue. Further, the qualitative results found that poor arrangement of the timing of breaks during work, and irregular timing to work which impairs work-life balance also led to fatigue.

6.6 SUMMARY OF CHAPTER 6 AND LINKS TO CHAPTER 7

The study described in the present chapter found that fatigue among rail staff was associated with workload and overtime work, as well as prolonged shift work, insufficient rest during work, and from poorly arranged shift patterns. A longitudinal study was the next logical step in this research where individuals were required to record each day about their fatigue, rest and break, workload, and their shift patterns. It would assess the effects of fatigue closely in the context of participants’ daily work lives, and would be able to assess the effect of cumulative fatigue for a longer period of time than in laboratory experiments. In next chapter, an online diary study with a rail staff sample was conducted to investigate the relationships between fatigue, workload and other potential causes of fatigue found in the present chapter, and objective performance.

CHAPTER 7: A DIARY STUDY WITH RAIL STAFF

7.1 INTRODUCTION

7.1.1 Link with Previous Chapter

The previous survey in Chapter 6 showed that workload and overtime work were the essential causes of all different types of fatigue among rail staff. Fatigue was also associated with prolonged shift work, insufficient rest during work, and from poorly arranged shift patterns. In the previous student sample study (see Chapter 5), occupational fatigue was proved to be affected by workload, and then it resulted in impaired cognitive performance. A diary study was the next logical step in this research in order to closely assess the rail staff's shift patterns and daily work lives. It would be useful to investigate occupational fatigue as it provided a record of subjective feelings and work experiences related to fatigue in context. In the diary, individuals were required to record each day their fatigue before and after work, rest and breaks, their workload, and their shift pattern, as well as to take the online fatigue test developed in Chapter 5.

The present chapter aimed to demonstrate a relationship between workload, working hours, fatigue, and objective performance with a staff sample, which was established in previous fatigue experiments with the student sample. It also aimed to explore other risk factors mentioned in the previous online survey described in Chapter 6, such as shift pattern, overtime work, sleep quality, and breaks during work. The diary used in this study consisted of self-assessment and objective performance tests.

7.1.2 Hypotheses

There were two hypotheses presented below for this study:

Hypothesis 1:

The experimental hypothesis predicted that high workload, long working time, irregular shift time, and insufficient breaks will increase fatigue. Reported fatigue will be higher, and performance will be less accurate and slower at the end of a workday due to the effect of workload.

Hypothesis 2:

The experimental hypothesis predicted that the increased feeling of fatigue will lead to a performance reduction, including delayed reaction time, and lower accuracy rates in both a visual search test and a logical reasoning test.

7.2 METHODS

7.2.1 Participants

Participants were recruited from volunteers from a train company in the UK (N = 19, mean (±SD) age = 41.86±9.89 yr.; 74% male). The main job types reported were managers, conductors, drivers, station workers, engineers and administrators.

7.2.2 Materials

7.2.2.1 The Diary

The diary consisted of 15 questions (shown in Table 7.1), including six questions to be answered before work and nine questions to be answered after work. It was designed based on the material used in Smith and Smith’s (2017) diary studies. The diary was completed immediately before starting work and immediately after finishing work on the first and the last day of a working week (4 days). The questions in the pre-work diary covered sleep duration and quality, time taken to travel to work, fatigue due to the commute, general health status, and alertness before starting work. The questions in the post-work diary recorded workload, effort, fatigue, stress, break duration, work duration, the time they finished work, and level of distraction during work. There were extra questions in the post-work diary on the last day which asked whether participants worked the same time every workday in the working week.

Table 7.1 *Questions in the Diary.*

Befor work Diary

1. How many hours sleep did you get last night?

This question asks about your recent sleep experience, no matter it was at daytime or at night.

________ hours ________ minutes

2. How was the quality of your sleep?

Not at all good Very good

1 2 3 4 5 6 7 8 9 10

3. How long did it take you to travel to work?

________ hours ________ minutes

4. How fatigued did you feel from your commute?

Not at all Very fatigue

1 2 3 4 5 6 7 8 9 10

5. How well are you feeling now?

Not at all well Very well

1 2 3 4 5 6 7 8 9 10

6. How alert do you feel now?

Not at all Very alert

1 2 3 4 5 6 7 8 9 10

After Work Diary

1. How was your workload today?

Very low Very high

1 2 3 4 5 6 7 8 9 10

2. How much effort did you have to put into your job today?

Very little A great deal

1 2 3 4 5 6 7 8 9 10

3. How fatigued do you feel now?

Not at all Very fatigue

1 2 3 4 5 6 7 8 9 10

4. How stressed do you feel now?

Not at all Very stressed

1 2 3 4 5 6 7 8 9 10

5. What was the total length of your breaks today?

________ hours ________ minutes

6. What was the total length of your work today?

________ hours ________ minutes

6.1. What time did you start work today? (e.g. Hour: 23 Minute: 30)

________ hours ________ minutes

6.2. What time did you finish work today?

________ hours ________ minutes

7. During your work today, to what extent were you thinking about other things rather than work?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

8*. Did you work at the same time on other days of this week? (start time, end time, and length)

8.1* If no, which day(s) did you work at a different time? And what was the total length of your work on that day(s)? (hours, minutes)

8.2* What time did you start and finish work on each of those days? For example, Day 2 - 6.30 am

* question only asked in the after work diary on the last day

7.2.2.2 *Objective Performance Tests*

The visual search task and logistic reasoning task, as described in previous student sample study (see Chapter 5), were used to analyse cognitive performance during the online objective performance tests.

7.2.3 Procedure

An invitation e-mail attached with information about the study and an informed consent form was sent to potential participants. After participants signed and returned the forms, they were asked to provide the start date of their next working week. Then, the links of the four test sections and a familiarisation session were sent to them. The familiarisation session included an introduction of the diary and an example of each cognitive test to ensure the participants were able to complete the tasks correctly before starting the study. On the testing day(s), participants were asked to complete the online diary and cognitive tasks immediately before starting work and immediately after finishing work via a computer or mobile phone.

Subjects were free to withdraw from the survey at any point. This study was reviewed and approved by the School of Psychology Research Ethics Committee at Cardiff University.

7.2.4 Analysis

Data analysis was carried out using SPSS 23. Data were analysed using a variety of tests, including Pearson correlation (one-tailed) and mixed ANOVAs. The independent variables tested included subjective fatigue, workload, length of sleep, quality of sleep, time taken to travel to work, alertness, effort, stress, working hours, length of breaks, and level of distraction (see Table 7.2 for the list of variables). The dependent variables consisted of performance outcomes from each test, including mean reaction time and accuracy.

Table 7.2 *Variables Assessed.*

Measures	**Variables**
Diary	Subjective Fatigue
(Before work)	Length of Sleep
	Quality of Sleep
	Time Taken to Travel to Work
	Alertness
	General Health Status
(After work)	Subjective Workload
	Effort
	Stress
	Working Hours
	Time of Starting Work
	Time of Finishing Work
	Length of Breaks
	Distraction during Work
Visual Search	Mean Reaction Time (sec)
	Accurate Rate
Logical Reasoning	Mean Reaction Time (sec)
	Accurate Rate

7.3 RESULTS

7.3.1 Descriptive

19 participants completed the study. 73.7% of them were male. The most common job types reported were managers (26.3%), engineers (15.8%), conductors (15.8%),

drivers (15.8%), and station workers (15.8%), followed by administrators (10.5%). 68.4% of participants did daytime shifts, while 31.6% did night shifts or early morning shifts. 43.1% of participants worked two or more different shift times during the testing week (4 days).

Table 7.3 below shows the difference in fatigue and other variables between the first and last work days. As is shown, fatigue increased after work and over the work week. Quality of sleep and alertness decreased during the week while work stress increased.

Table 7.3 *Descriptive Statistics for Mean of Variables.*

	Variables	**First day**		**Last day**	
		Mean	**S. D**	**Mean**	**S. D**
Before Work	Length of Sleep (hour)	7.18	1.37	7.08	1.31
	Quality of Sleep	6.05	2.12	5.84	2.65
	Time Taken to Travel to Work (hour)	0.50	0.37	0.44	0.26
	Fatigue before Work	2.16	1.21	2.47	1.61
	General Health Status	7.47	1.50	6.58	2.12
	Alertness	7.11	1.52	6.58	2.34
After Work	Subjective Workload	5.79	2.18	5.42	2.43
	Effort	7.16	2.01	6.37	2.63
	Fatigue after Work	6.42	2.12	7.11	2.00
	Stress	3.79	2.30	4.58	2.09
	Length of Breaks (hour)	0.90	0.69	0.87	0.51
	Working Hours (hour)	8.48	1.65	8.75	1.63
	Distraction during Work	5.11	2.58	5.32	2.65

7.3.2 Correlations in Each Diary Session

A one-tailed Pearson correlation was run to investigate the association between fatigue and other risk factors in each diary. There were four diary sessions, before and after work on the first and last days of the work week.

7.3.2.1 Section 1 – First Day Before Work

Fatigue before work was associated with time spent traveling to work (r (19) =.752, $p < .01$), with more time spent on the commute being associated with higher fatigue ratings. Fatigue was also negatively correlated with general health status (r (19) = -.469, $p < .05$), alertness (r (19) = -.430, $p <.05$), and logical reasoning speed (r = -.546, $p < .001$) at a significant level. High sleep quality was significantly associated with longer length of sleep (r (19) = .428), better general health status (r (19) = .601), more alertness (r (19) = .462), and visual searching speed (r (19) = .449), which were all $p < .05$. Logical reasoning speed was associated with not only fatigue, but also general health status (r (19) = .392, $p < .05$) and time spent traveling to work (r (19) = -.501, $p < .05$).

7.3.2.2 Section 2 – First Day After Work

High fatigue after work was associated with lower accuracy on the visual search task (r (19) = -.415, $p < .05$). High workload was found to be associated with more effort (r (19) = .606), high stress (r (19) =.491) but lower distraction (r (19) =-.471), all *p's* < .05. Slower visual searching RT was correlated with its higher accuracy (r=.533, $p < .01$), while slower reasoning RT was associated with its lower accuracy (r=-.454, $p < .05$).

7.3.2.3 Section 3 – Last Day Before Work

Fatigue before work on the last day was significantly correlated with length of sleep (r (19) = .513, $p < .05$). Sleep quality correlated with general health status (r (19) = .750) and alertness (r (19) = .533), both $p < .01$. Slower reasoning RT was associated with its lower accuracy (r (19) =-.442, $p < .05$) and faster visual searching RT (r (19) = -.672, $p < .01$).

7.3.2.4 Section 4 – Last Day After Work

High fatigue after work was associated with high workload, more effort, and longer length of work, r from .400 to .550, all *p* < .05. The higher accuracy of the visual search task was associated with more effort (r (19) =.398), more stress (r (19) = .465), and less distraction (r (19) = -.498), all *p* < .05. Slower logical reasoning RT was associated with lower accuracy (r (19) = -.444, *p* < .05), longer length of breaks during work (r (19) = .485, *p* < .05), and longer visual search RT (r (19) = .405, *p* < .05).

7.3.3 Correlations for Each Day

The before-after work difference scores for fatigue and performance scores were calculated using the post-work scores minus the pre-work scores. The positive scores of change in RT and the negative score of change in accuracy indicated performance impairment after work. The positive score of change in fatigue shows the participants were more fatigued after work. Table 7.4 below summarises the mean changes of fatigue and performance.

7.3.3.1 First Day

The change in reasoning accuracy was associated with high workload (r (19) = -.623, *p* < .01), while the change in visual searching accuracy was associated with high fatigue after work (r (19) = -.417) and a later time finishing work (r (19) = .415), both *p's* < .05. Longer length of sleep was positively associated with a later time starting work (r (19) = .502) and negatively associated with a later time finishing work (r (19) = -.498), both *p's* <.05. No other significant associations were found.

7.3.3.2 Last Day

Change in fatigue showed a significant positive correlation with more distraction during work (r (19) = .485, *p* < .05) and change in reasoning RT (r (19) = .426, *p* < .05). The change in visual search accuracy was positively associated with more alertness (r (19) = .410, *p* < .05) and more stress (r (19) = .474, *p* < .01), while the change in visual search RT was positively associated with more effort (r (19) =.431, *p* < .05) and change in reasoning RT (r (19) =.444, *p* < .05).

Table 7.4 *Mean Change in Fatigue and Cognitive Performance.*

		First Day		Last Day	
Test	**Change in**	**Mean Change**	**S. D**	**Mean Change**	**S. D**
Diary	Subjective Fatigue	4.26	2.56	4.63	2.69
Visual Search	Mean Reaction Time (sec)	0.67	2.76	0.37	1.58
	Accuracy (%)	0.00	7.35	-3.73	7.20
Logical Reasoning	Mean Reaction Time (sec)	0.67	2.20	0.08	0.84
	Accuracy (%)	3.29	15.69	4.61	13.74

7.3.4 Associations Between Change in Fatigue, Workload, and Performance

Changes in fatigue and subjective workload were re-coded into dichotomous variables using a median split. The pre-post changes in fatigue were split into increased/decreased fatigue. (First day: Median $_{\text{Change in Fatigue}}$ = 4; Last day: Median $_{\text{Change in Fatigue}}$ = 5). Subjective workload scores were categorised into high/low workload (First day: Median $_{\text{Workload}}$ = 6; Last day: Median $_{\text{Workload}}$ = 6). The mean changes in performance for each group are summarised in Tables 7.5-1 and 7.5-2.

Table 7.5-1 *Mean Change in Performance Scores by Workload and Fatigue on First Day.*

Mean (SD)		**High Workload**		**Low Workload**	
	Fatigue	**Increased**	**Decreased**	**Increased**	**Decreased**
Visual Search	- RT (s)	1.26 (3.08)	-0.20 (1.83)	.41 (1.89)	1.00 (3.95)
	- Accuracy (%)	0.00 (5.27)	5.00 (7.45)	-8.33 (8.33)	0.00 (0.06)
Logical Reasoning	-RT(s)	1.06 (2.93)	5.91 (6.79)	-0.83 (2.09)	1.16 (2.48)
	- Accuracy (%)	-2.78 (14.35)	-5.83 (16.30)	6.94 (4.81)	17.50 (12.29)

Table 7.5-2 *Mean Change in Performance Scores by Workload and Fatigue on Last Day.*

Mean (SD)		**High Workload**		**Low Workload**	
	Fatigue	**Increased**	**Decreased**	**Increased**	**Decreased**
Visual Search	- RT (s)	0.93 (1.74)	0.81 (1.17)	-0.20 (1.06)	-0.43 (1.81)
	- Accuracy (%)	-4.76 (8.13)	1.04 (7.12)	-4.17 (8.33)	-5.83 (5.59)
Logical Reasoning	-RT(s)	0.32 (0.81)	-0.33 (0.95)	0.50 (0.63)	-0.19 (0.89)
	- Accuracy (%)	4.76 (16.39)	15.63 (11.47)	-4.17 (15.02)	0.83 (6.18)

A two-way, between-groups analysis of variance was conducted to explore the impact of workload and change in fatigue on change in performance. The interaction effect between the workload and fatigue group on the four performance outcome variables was not statistically significant (all $p > 0.05$).

On the first day, there were statistically significant main effects of fatigue on visual search accuracy, F (1, 15) = 4.638, $p < 0.05$, partial eta squared = 0.236, however, the effect size was small. The effect of workload was statistically significant for visual search accuracy, F (1, 15) = 4.638, $p < 0.05$, partial eta squared = 0.236, and reasoning accuracy, F (1, 15) = 6.639, $p <0.05$, partial eta squared = 0.307.

On the last day, no main effect reached at a statistically significant level. The main effect of fatigue approached marginal levels of significance to for reasoning reaction time (F (1, 15) = 2.754, $p = 0.118$, partial eta squared = 0.155), while showing an apparent trend of influencing reasoning accuracy (F (1, 15) = 1.561, $p = 0.231$, partial eta squared = 0.094). The main effect of workload on reasoning accuracy was also close to significance, F (1, 15) = 3.490, *p* = 0.081, partial eta squared = 0.189.

7.4 DISCUSSION

The objective of this thesis is to enhance the knowledge on rail staff fatigue. As reviewed in Chapter 3, very few of the existing studies in this area were field studies, and limited research had used both subjective and objective fatigue measurement. Therefore, a diary study was designed that could be conducted in a real-life setting (in the workplace) and assess rail staff's work experience, based on the knowledge gained in previous chapters in this thesis.

The present study aimed to examine the associations between workload, working hours, fatigue, and objective performance in realistic situations with a staff sample, and also to explore the effects of other risk factors on fatigue mentioned in the previous study described in Chapter 6. It mainly used the online fatigue test integrating both subjective and objective measurements, developed and validated in the student study described in Chapter 5. Subjective measurement of fatigue has been found to be validated and reliable, and widely used in previous research (reviewed in Chapter 3 and 4), but recently Cheng and Hui-Ning (2019) argued that rail staff's abilities to perceive and control their fatigue could be limited (Cheng & Hui-Ning, 2019). Therefore, it is needed for combining objective measurement which can be used in the work situation with subjective measurement.

This diary study used the after-effect method to assess the effect of work-related fatigue on performance by measuring performance before and after work, involving the first and last day of the working week. Broadbent (1979) suggested that using the “After-Effect” technique in fatigue measurement would be applicable in realistic situations, without changing people’s normal behaviours during and after the task. This method has been used with workload (Parkes, 1995), and other factors which change fatigue, such as the common cold (Cohen, Tyrrell, & Smith, 1991; Smith, Thomas, & Whitney, 2000), caffeine (Brice & Smith, 2001; Smith, 2002;

Doherty & Smith, 2005), and night work (Åkerstedt, 1988). The design combining online measures and the after-effect technique would be suitable and convenient to apply in the workplace, especially in the railway industry where wearing extra instruments of objective measures were not allowed for avoiding distractions and other potential safety risks.

Overall, the results of this study on the staff sample were in line with those of the previous study with the student sample (i.e., the workload study in Chapter 5) and the previous research in different industries (road driver: Feyer & Williamson 2001; seafarers: Smith, Allen, & Wadsworth, 2006; train driver: Dunn & Williamson, 2012), finding that performance was impaired by fatigue. Cognitive performance was further impaired when fatigue increased due to work, and this was found with both high or low workload. In addition, subjective fatigue increased, and general well-being outcomes were getting worse at the end of the week, suggesting an effect of cumulative work fatigue on the outcomes during a working week. It was very similar to fatigue among seafarer, that the occupational fatigue increased day by day, and cumulated at work and on leave (Bal, Arslan & Tavacioglu, 2015).

7.4.1 Hypothesis 1

Hypothesis 1 predicted that high workload, long working time, irregular shift time, and insufficient breaks would be associated with increased fatigue. It also predicted that reported fatigue would be higher and performance would be less accurate and slower at the end of the workday due to the workload effect. As expected, the effects of workload and working hours on fatigue were found in this study, with high workload or longer working hours leading to increased feelings of fatigue after work. The results also showed that the subjective feeling of fatigue before work was associated with quality and duration of sleep and time spent on a commute. Due to the limited sample size, the effects of irregular shift time and insufficient breaks on fatigue were not found clearly in this study. However, insufficient breaks during work were clearly associated with slower RT in the logical reasoning task, which is in line with previous studies (e.g., Killgore, Balkin, & Wesensten, 2006).

This could be because rest improves recovery from fatigue and maintains performance, as previous research suggested (e.g., May & Baldwin, 2009; Wadsworth, Allen, McNamara, & Smith, 2008; reviewed in Chapter 2 and 3). Therefore, insufficient breaks might start a chain reaction of increased fatigue resulting in impaired performance. Considering the limitations of the sample size and the method (discussed later in the section 7.6.4) the relationships between breaks, shift pattern, fatigue, and impaired performance can be further studied in the future. Overall, hypothesis 1 was partially accepted.

7.4.2 Hypothesis 2

Hypothesis 2 predicted that the increased occupational fatigue would lead to a performance reduction, including delayed reaction time and lower accuracy rates. Similar to the student sample study, the results here showed that an increased feeling of fatigue was associated with impaired performance, including decreased accuracy in the visual searching task and slower RT in both cognitive tasks, which supports Hypothesis 2. Higher self-reported fatigue showed a clear and strong trend, being associated with a greater reduction in performance, although on the last day this fatigue effect was just outside of the conventional levels of significance. Hypothesis 2 was therefore considered to be accepted.

7.4.3 Limitations

As a method, the online diary study is less controlled than laboratory experiments, although it has the advantage of assessing the effects of fatigue closely in the context of participants’ daily work lives, as well as being able to assess the effect of cumulative fatigue for a longer period of time than in laboratory experiments. One participant commented that he didn't have time to complete the diary immediately after work because he was off very late and caught transport to return home in a hurry. Although this participant completed the post-work diary immediately upon arriving home, his fatigue and performance may have recovered during the commute.

Diary studies are also time-consuming, and participants required reminders and encouragement to fully complete the diaries. In this study, it was difficult to recruit participants and have them fully complete the whole diary study, especially the post-work diary on the last day of the work week. The majority of participants who forgot to fill in the last diary decided to quit the study rather than re-do it. In addition, the online psychomotor vigilance task (PVT) was not used in this study because, as mentioned in the previous chapter, the QRTEninge (i.e., the engine of online PVT) was no longer being updated and supported.

7.4.4 Implications for Future Diary Studies and Applications

Future research requires better control of online diary data collection. While the online diary is an advanced method for assessing fatigue closely in the context of daily work life, reminder texts or e-mails are needed to ensure that participants fill in each diary on time. It can be integrated with the HSE Fatigue and Risk Index (a fatigue prediction tool based on the shift pattern, see Chapter 3, section 4.4) in a future study, although the job demands variable in this index are usually set at a constant level for all staff.

Future research could investigate the timing of rest and breaks during work. This was frequently mentioned and complained about in the causes of fatigue survey (in Chapter 6) but was not assessed in this study. As part of the shift pattern, the record of duration and timing of breaks would be complex, and the required amount of data could be overwhelming. Therefore, to measure and analyse this factor, further data and a larger sample will be needed.

7.5 CONCLUSION

In summary, the findings of this study were in line with those of the previous student sample study described in Chapter 5. Objective performance was impaired due to the effects of fatigue. Negative effects of workload and working hours on fatigue were also found. Fatigue before work was associated with the quality and duration of sleep and the time spent on the commute. Future research using an online diary should consider recruiting a larger sample and mitigating the risks of absence or incomplete diary entries.

7.6 SUMMARY OF CHAPTER 7 AND LINK TO CHAPTER 8

The study described in this chapter investigated effects of fatigue on performance among train staff members. This online diary study included subjective measures of fatigue and its risk factors, and objective measures of cognitive performance. The results were consistent with the previous student study described in Chapter 5, finding that an increased subjective feeling of fatigue was associated with high workload and impaired cognitive performance. With increased fatigue after work, performance was further impaired. High workload and longer working hours also showed negative effects on fatigue. Fatigue before work was associated with the quality and duration of sleep and the time spent on the commute.

Evidence has been provided throughout this thesis to suggest that job demands (i.e., workload), shift-work, job control and supports, overtime work, and individual differences are associated with fatigue among train crew members, while fatigue is associated with poor well-being and impaired performance. The final chapter will, therefore, provide a general discussion of these findings, and suggest some ideas for future directions of research.

CHAPTER 8: GENERAL DISCUSSION

8.1 INTRODUCTION

This chapter summarises and discusses the research described in this thesis. It provides a brief overview of the research undertaken, summarises and evaluates the objectives of this thesis. It discusses the methodological strengths and weaknesses of the present studies and also offers a view to future research.

8.2 SUMMARY AND CRITIQUE

8.2.1 Brief Overview

Human fatigue has been identified as one of the causes in a number of incident or accident reports in the rail industry. As reviewed in Chapter 2, previous research has suggested that occupational fatigue is associated with either task-related risk factors or sleep-related risk factors. The relevant literature for rail staff fatigue, however, was very small because this field of rail crew has historically been smaller than those of other occupations (Anund et al., 2015). Therefore, this thesis plays a role in filling the gap in this field. The present research aimed to investigate fatigue, its risk factors, and the associations between fatigue, well-being outcomes, and performance among staff members in the rail industry by conducting a series of studies. It also aimed to develop a usable online fatigue measure to examine fatigue in a real-life setting. Various methods have been used in this thesis to investigate fatigue, including a general literature review, systematic review, large-scale study, online experiment, survey collecting both qualitative and quantitative data, field study and diary study. It should be noted that this thesis focuses on fatigue from regular daily work, not on that of sleep deprivation, from prolonged or strenuous exertions or from the disease.

The results of the thesis provide overwhelming evidence for the strong relationships between fatigue, job demands, shift-work, job support and control, and individual differences. Job demands, especially mental workload and overtime work were the main predictors of different types of fatigue among train crew, although the risk factors for fatigue appeared to differ between job roles. Positive work and individual characteristics were shown to play a buffering role against fatigue (see Chapter 4), but this only applied to emotional fatigue, not physical or mental fatigue (see Chapter 6). The results also demonstrated that increased subjective fatigue contributed to sub-standard performance (see Chapters 5 and 7) and poor well-being (see Chapter 4).

An online fatigue measure integrating self-assessment of fatigue and workload and cognitive performance tests was developed and validated. The two-part design of the study required it to be applied both before and after a work period. The subjective measure of fatigue was found to be reliable for detecting fatigue and was able to explain the before-after differences in objective performance in both studies of students (see Chapter 5) and of staff members (see Chapter 7). The findings also provide evidence for an effect of high workload on an increase in self-reported fatigue. Such online measurement was considered to be a usable and convenient tool for occupational fatigue research or for future fatigue management in the workplace.

8.2.2 Evaluation of Objectives of the Thesis

This thesis has investigated occupational fatigue along with its risk factors and outcomes in the rail industry. To consider whether the objectives of the thesis have been met, each objective outlined in Chapter 1 is discussed in turn.

1) To review the general literature on occupation fatigue, its risk factors and general outcomes; to review the specific literature on train crew fatigue.

Chapter 2 reviewed the literature on the general area of occupational fatigue, including its causes, effects of it on working performance and physiological problems, fatigue measurement, and fatigue problem in different transport sectors. It was found that the causes of fatigue include generic causes not specific to the workplace (e.g., sleep loss, time on task, time of day) and work-related causes (e.g., job demands, support and control), as well as individual differences and combined effects. Fatigue was found to related to impaired performance, ill health, and incidents. Both subjective and objective measurements have been widely used in fatigue studies and in fatigue prevention in the workplace. It was also found that the literature on fatigue in train crew was very limited and much smaller than that of other transport sectors. The related pieces of literature on fatigue in rail staff were systematically reviewed in Chapter 3.

Chapter 3 presented a systematic literature review of fatigue among train crew focusing on the main risk factors for railway fatigue and also reviewing the association between fatigue and railway incidents and its countermeasures. Ideally, this review should be a proper systematic review. However, it was done without a meta-analysis due to the very limited literature on this topic and the different and varied variables used in those different papers. It was found that fatigue in the rail industry shows most of the features of occupational fatigue, but it was also subject to industry-specific factors such as shift-work and exposure to noise. The risk factors for fatigue in the railway seem to differ between job roles. Fatigue was reported to be one cause of many rail incidents or accidents (reviewed in Chapter 3). However, due to the limited literature, it was difficult to adequately infer causation between fatigue, well-being, and cognitive performance. It found that the majority of existing studies were limited by sample size, and very few of them considered varied job roles in this industry. It also found that the empirical evidence from field studies and the use of both subjective and objective fatigue measurement was still lacking. It is hoped that this literature review of train crew fatigue would have an impact beyond helping determine the direction of this thesis, as it has now been published as a peer-reviewed article in the *Frontiers in Psychology* (see Fan & Smith, 2018a).

2) To examine the prevalence of fatigue and identify the risk factors related to fatigue among railway staffs in general.

Chapter 4 described a large-scale fatigue survey using a staff sample to investigate the association between risk factors, fatigue, and well-being. This study is the first to include rail staff from all job roles in the UK rail industry. Fatigue was apparent in all the job roles, but was mentioned and reported to be highest by drivers, engineers, and controllers. It was found that job demands, job control and support, work environment, and individual differences were the main risk factors predicting fatigue. It was also found that fatigue mediated the effects of risk factors on well-being outcomes. The study provided empirical support for potential organisational interventions to combat fatigue.

3) To develop an online measure of fatigue to examine the effects of time of day and workload on fatigue and to establish the relationship between subjective fatigue and objective performance.

In Chapter 5, a two-part online measure of fatigue was developed, which integrated self-assessment and cognitive performance tests. This measure was found to be valid and sensitive enough to examine the effect of workload on fatigue and the impact of fatigue on performance. It was found that high workload was one of the factors increasing fatigue, and it was increased fatigue which then lead to a reduction of performance. Although the effect of time of day was detected by using a visual search task, its impact on fatigue was not clearly determined in this experiment. This study used a student sample, thus, future research needed to be undertaken in a real-life environment with staff samples to examine the application of the online fatigue measures.

4) To further explore the potential risk factor of fatigue among railway staff.

Chapter 6 investigated fatigue and its potential causes in staff members of a train company, adopting both qualitative and quantitative methods. Many of the reported causes were mentioned in previous studies, such as job demands, work and individual characteristics, and timing of shift work. Further, it was found that job demands, mental workload and overtime work not only predict fatigue as a single outcome, but also predict physical, mental, and emotional fatigue separately. The qualitative data also provided rich information about the causes of train crew fatigue and identified a few potential risk factors of occupational fatigue which were not been systematically examined yet, such as the poor timing of breaks during work and taking opposed shifts within a week.

5) To test the Demands, Resources, and Individual Effects (DRIVE) model.

The studies described in Chapters 4, 5, 6, and 7 used the DRIVE model as a fatigue framework. Support was found for a number of DRIVE model predictions, especially for the predictors and the mediating role of fatigue. The DRIVE model showed its flexibility and reliability by working with more work-related risk factors in occupational fatigue studies. However, it is notable that the moderating effect suggested by the DRIVE model was not found in any of the present studies in this thesis. This issue should be noted when applying the DRIVE model in the future, as such effects were also not found in several previous studies (Mark & Smith, 2012a, 2012b; Williams, 2013; Capasso, Zurlo & Smith, 2016). The general conclusion is that the DRIVE model is a suitable model for fatigue research which focuses on the fatigue process.

6) To investigate the effects of workload and other risk factors on the prediction of fatigue and the impact of fatigue on impairing performance of railway staffs in their work life.

Chapter 7 investigated fatigue in a real-life setting using online diary and performance tests. The findings of this chapter suggested that workload and working hours are associated with increased fatigue after work, while quality and duration of sleep and time spent on commute were associated with fatigue before work. It was found that increased fatigue is associated with impaired performance, which was consistent with the study done in Chapter 5 using a student sample. These two chapters can be a point of reference for researchers who wish to focus on the real-time fatigue processes in the work environment using online fatigue measures (and therefore linking to objective 2).

8.2.3 Mechanisms of Fatigue among Train Crew

8.2.3.1 Predictors of Fatigue

Job demands

Occupational fatigue, in general, is considered to be a result of job demands in the previous research (e.g., Moos, 1988; Hockey & Wiethoff, 1990). In the present research, job demands were identified as the main predictor of fatigue throughout a series of studies in this thesis (see Chapters 4, 5, and 6), which is in line with previous research. Job demands usually refer to physical workload, mental workload, or both together. The results in Chapter 6 indicated that it was the mental workload that results in fatigue among staff members in the modern rail industry, which supports the view of Young et al. (2015) that work in the railway industry currently imposes more cognitive demands than physical demands.

Overtime work and length of work

Overtime work was reported to be one of the causes of different types of fatigue (see Chapter 6), while the length of work was not found to be clearly associated with fatigue. Time spent on work (i.e., time-on-task) is one of the most prominent causes of fatigue and has been studied by a number of previous fatigue studies, for either fatigue in general (Gates, 1916; Huxtable et al., 1945) or occupational fatigue (Chen & Xie, 2014; Kazemi et al., 2016). It is believed that fatigue accumulates over time (e.g., Cameron, 1973). The effect of length of work on fatigue was not evident in this research, which could be because of breaks (e.g., task switching) and rest which provided fatigue recovery from such an effect. Furthermore, the term *overtime* work may not only involve to the length of work, but also relate to the job demands. According to the comments made by the train crew (see Chapter 6), their overtime work often comes with a high workload, such as working on public holidays or after late-night events. Therefore, job demands (or workload), should also be accounted for when discussing the effect of prolonged work time on fatigue.

Shift-work

Evidence in this research showed that shift-work is associated with fatigue, which was generally consistent with previous studies among train crew (reviewed in Chapter 3). Previous studies indicated that shift-work resulted in fatigue (e.g., Dorrian et al., 2011), as well as a cumulative sleep loss (e.g., Darwent et al., 2008) which made it more difficult to recover from fatigue. According to the qualitative data in Chapter 6, workers believed that reduced night shifts and early morning shifts would help reduce the problem of fatigue at work, although these would be difficult to implement due to the 24/7 nature of the industry.

It was found that the length of the shift-work caused both physical and emotional fatigue, while the timing of the shift only caused emotional fatigue. Mental fatigue, however, was not reported to result from shift-work. These differences could relate to current fatigue countermeasures used by railway staff. The main coping strategies for fatigue are breaks, napping, and caffeine use (RSSB, 2012), with napping being commonly used prior to night shifts. The reason why shift-work was not found to lead to mental fatigue could be because napping reduces sleep debt, leads to recovery from fatigue, and increases alertness before work, which then decreases the feeling of mental fatigue during and after work.

Positive work and personal characteristics

Positive work and personal characteristics included job support and control, personality, and health-related behaviours (or healthy lifestyle). These three factors were found to play essential roles in fatigue processes, which were in line with the work of previous researchers (e.g., job support and control: Karasek, 1979; personality: Parkes, 1994; health-related behaviours: Laaksonen et al., 2009). This research indicated that good job control and support, a healthy lifestyle, and positive personality individually predicted low fatigue (see Chapter 4). However, it was then found that these characteristics only played a buffering role for emotional fatigue, but not for physical or mental fatigue (see Chapter 6). These results suggested that physical and mental fatigue were mainly influenced by other risk factors.

Noise and vibration, job roles, and combined effects

Exposure to noise and vibration was found to make a significant contribution to the prediction of fatigue (see Chapter 4), confirming previous research showing that reports of fatigue are more common among workers exposed to high levels of noise (e.g., Landstrom, 1990; Melamed & Bruhis, 1996). As noise and vibration were common work features for train drivers and engineers, they were more likely to report fatigue from these factors than other types of workers. This suggested that the contribution of risk factors on fatigue can be different between job roles.

To offset the effect of job role differences, the combined effect of predictors on fatigue was examined (see Chapter 4). It was found that individuals who were most at risk of high fatigue reported the greatest number of fatigue risk factors. This approach can be applied to the fatigue research involving multiple job roles or cross-industry comparisons.

Rest and sleep

Poor timing and short duration of breaks and rest during work can result in occupational fatigue. Appropriate breaks and rests provide fatigue recovery during prolonged work (e.g., Bergum & Lehr, 1962; Komski, 1967). An ill-timed break, however, would not help fatigue recovery and would waste the limited rest duration. For example, two 20-minute breaks could be taken in a 12-hour shift, but if they were placed at the very beginning and the very end of the shift, it would be worse than taking only one 20-minute break in the middle of the shift. The influence of the timing of breaks was not observed in the diary study (see Chapter 6) due to a limited sample size, which therefore requires future fatigue research to examine such effect.

Poor sleep quality and short sleep duration were reported to be associated with fatigue before work (see Chapter 7), but not with fatigue after work. Many of the previous fatigue studies confirmed that sleep-related risk factors lead to fatigue, which including sleep quality and duration (e.g., Parkes, 1994; Wadsworth, Allen, McNamara, & Smith, 2008). The results here provide support for the findings from previous research.

8.2.3.2 Outcomes of Fatigue

<u>*Performance*</u>

Fatigue was associated with poor performance efficiency when measured with either single-item self-assessment (see Chapter 4) or objective cognitive performance tasks (see Chapters 5 and 7). In which, increased subjective fatigue predicted impaired objective performance, including slower response time and more errors, for both the student and staff samples. These were in line with the previous studies conducted in different industries (road driver: Feyer & Williamson 2001; seafarer: Smith, Allen, & Wadsworth, 2006; train driver: Dunn & Williamson, 2012). The speed-error trade-off was also observed in some cases as Rabbitt (1981) suggested. It was found in the current research that high workload increased fatigue, and then the increased fatigue resulted in impaired performance. In other words, the impact of workload was not found to directly impact performance changes, which was inconsistent with Parkes' workload study (1994). One possible reason is that, in the present research, workload was measured through a self-reporting score, while in Parkes's study, the workload was set by a high-demand driving examination load and a low-demand driving examination load. The perceived workload, other than the input load, was also involved with the operator effort and performance (or results) (Jahns, 1973), which therefore led to a different result from the well-controlled task loads of the previous laboratory studies.

<u>*Work–life balance and well-being outcomes*</u>

Fatigue was associated with negative work–life balance (i.e., work–life conflict) and poor well-being in both daily life and work life (see Chapter 4). Meanwhile, fatigue was found to mediate the effects of job demands, job support and control, and individual differences on work–life balance and well-being outcomes. Fatigue fully mediated the effects of job demands on life happiness and job satisfaction, the effect of lifestyle on job stress and work–life balance, and the impact of the work environment (i.e., noise and fumes) on well-being at work and the majority of the well-being outcomes in general life. This means that essentially all of the relationships between the above variables can be explained by the fatigue pathway. This effect of fatigue was found to support the mediation path in the DRIVE model. It should be noted that either work influences life, or life influences work. The present study focused more on the effect of work fatigue influencing life, thus, the association between life fatigue influencing work experience needs to be further investigated in the future.

8.3 RESEARCH STRENGTHS AND LIMITATIONS

8.3.1 Strengths

The major strength of this research is its holistic approach. It systematically reviewed previous fatigue studies among rail staff (see Chapter 3), conducted a large-scale survey which was the first to include train staff from all job roles in the UK rail industry (see Chapter 4), and further explored the potential risk factors for fatigue using both qualitative and quantitative methods (see Chapter 6). The stressors of fatigue mainly included job demands, job support and control, time of day effect, shift-work, overtime work, work environment, sleep and rest, and individual differences. It not only investigated the predictors of fatigue, but also studied the effect of fatigue on outcomes including work–life balance, well-being outcomes both at work and outside work, and cognitive performance. It provided a relatively comprehensive blueprint for understanding the processes of railway staff fatigue based on the DRIVE model.

Another strength was that the approaches used in this research were flexible and convenient. Single-item subjective measures (used in Chapters 4, 5, 6, and 7) allow multiple factors to be examined in a relatively short questionnaire, and help improve both participant understanding and the clarity of the construct being measured. The two-part online fatigue measure developed (used in Chapter 5 and

7) integrated single-item self-assessment and cognitive performance tests. It was a tool, which can be used flexibly in the occupational setting via mobile devices, and is sensitive enough to study fatigue. The core of the self-assessment in this tool is the subjective measures of fatigue and workload, and it is flexible enough to allow for other questions which are important for the specific population to be included being investigated.

8.3.2 Limitations

The limitations of the current research should be taken into consideration when interpreting the findings. First, the staff sample used was based in the UK railway industry. Thus, caution should be taken in generalising the results of this research to the rail population in other countries due to the differences in factors such as shift systems, policies, or automation levels. Furthermore, although the self-report measures used in the research were found to be reliable, they may be open to biases in reporting items such as personality or performance efficiency. It is suggested that self-reporting be used carefully and, ideally, in combination with objective measures, as was done in latter Chapters of the present research (i.e., Chapter 5 and 7). In addition, due to the limited sample size and having less control than a laboratory experiment would, the effects of factors on fatigue, such as irregular shift time and insufficient breaks, were not clearly determined from the online diary study. One has to be careful to avoid such issues when applying these methods in future research.

8.4 RECOMMENDATIONS

This thesis has investigated the occupational fatigue and well-being in railway staff using quantitative and qualitative research methods. Based on the findings of this research, there were a few suggestions for the railway industry. In general, either the organisation or individual should raise concerns on fatigue and the after-effect of it, and take actions to prevent it in the workplace.

The primary prevention is fighting risks of fatigue at the source. The current research provided more specific information on the causes of fatigue, indicating that job demands (i.e., mental workload), shift work and insufficient rest were the main risk factors of fatigue. Considering the nature of the jobs in the railway industry, however, it will be not easy to control or reduce the workload, especially as there could be unpredictable train issues and unplanned overtime work. Thus, companies and organisations can focus on improving the shift pattern and better arranging rest. For those staff who have a particular circadian preference (e.g., night preference), it is suggested to allow them often working at the time of day they prefer. For other staff, it is recommended to arrange more extended rest between opposing shifts which will help on adjusting biological rhythms and also allowing them to recover from fatigue. Besides, policies and guidelines for rest and breaks are needed, regulating not only the duration of rest but also the timing of the breaks during work. For example, two breaks should be taken generally in a 10-hour shift, the breaks are ideally placed in the midway of the whole turn, and that the adequate break time is 30 minutes. Additionally, it is suggested to provide a better work environment with less exposure to noise and vibration, and a comfort staff lounge.

The secondary prevention is providing support for coping with fatigue. Such support could be holding training on fatigue prevention and management or events on health. Duty-holders should be aware of the costs on ill-health and report their fatigue problem, especially before and during safety-critical work. Also, companies should consider collaborating with trade unions on improving their engagement on health and fatigue management.

Fatigue management is a topic for not only the individual and the organisation but also the society. Although significant progress has been made in terms of understanding the causes of, the outcomes of, and countermeasures for occupational fatigue, a great deal of complexity remains. It is both an opportunity and potential threat for society to manage fatigue, especially under the technology revolution on automation and fatigue-monitors. Therefore, if the society could raise concerns on fatigue, communicate knowledge on fatigue to the public, and work together to manage fatigue, the improvements in safety, compliance, worker's well-being, and other relevant metricises could be delivered.

8.5 FUTURE RESEARCH

The research presented in this thesis can inspire future fatigue studies among rail staff. As Anund et al. (2015) claimed that the relevant literature of train crew fatigue was very small, the research presented in this thesis, thus, plays a role in filling the gap in this field. The present research has highlighted the risk factors of occupational fatigue for staff members in the railway industry, the effect of fatigue on well-being and on performance, as well as the mediation effect of fatigue. The findings of the present research supported a number of the DRIVE model predictions, therefore, it is safe to suggest that future research use the DRIVE model as one of the frameworks to investigate stress and fatigue in other occupations.

The completion of this thesis is not the end of studying fatigue among rail staff. There is a plan to conduct more staff experiments to further investigate the effects of shift-work, sleep, and breaks and rest during work on fatigue. Although these effects were already claimed as the causes of fatigue, their contributions to affecting fatigue are needed to be examined in more detail to develop the strategy for fatigue management. In the future study, the diary study can be integrated with the HSE Fatigue and Risk Index (a fatigue prediction tool based on the shift pattern, reviewed in Chapter 3) to better measure the risks of fatigue coming from the shift pattern and break arrangement. Although the job demands variable in this index is usually set at a constant level for all staff, it can be measured through the single-item self-assessment in the diary.

There is another possibility to compare and generalise the results of this research to rail staff in other countries by conducting cross-national and cross-cultural studies. For example, it would be interesting to compare fatigue and the work of train drivers in the UK and Australia, as Australia is vast country, and train drivers there are more likely to drive for longer distances and continued work for a longer duration of time than those in the UK. Likewise, to compare fatigue in rail staff in the UK and China would also be valuable, as China has more complex and longer rail lines with relatively poor job support and control.

In addition, the writer of this thesis suggested that future occupational fatigue research measure different dimensions of fatigue (i.e., 3D-Fatigue), as well as job demands (i.e., 3D-Demands). Investigating risk factors of different types of fatigue separately will help improve the understanding of fatigue in specific populations and improve the follow-up fatigue management. It also suggested that researchers continue to explore potential factors of fatigue using qualitative methods in future research, as was done briefly in the present research (see Chapter 6), as this can provide extra valuable information.

8.6 CONCLUSION

In summary, the research presented in this thesis fills the gap in the field of rail staff fatigue. The research has investigated fatigue, its risk factors, and the associations between fatigue, well-being outcomes, and performance among staff members in the rail industry by conducting a series of studies. The findings of it indicated that high job demands, high mental workload, overtime work, and shift-work individually cause fatigue, while positive work and personal characteristics play a buffering role against fatigue. Fatigue was found to predict impaired objective performance and also mediate the effect of the above predictors on well-being outcomes. The DRIVE model provided a flexible and comprehensive framework to conceptualise the fatigue process, and a number of the DRIVE model predictions were supported by the findings of present research. Moreover, a two-part online measure of fatigue integrating self-assessment and cognitive performance tests was developed and validated. It has the benefits of flexibility and convenience to aid in examining the impact of fatigue on performance. As demonstrated in the research, the development of train crew fatigue is determined by a complex system of variables. Thus, carefully taking each risk factor of fatigue into account is likely to produce success in fatigue management in the railway industry.

CHAPTER 9: REFERENCES

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CHAPTER 10: APPENDICS

10.1 APPENDIX A: CHARACTERISTICS OF INVESTIGATION REPORTS OF FATIGUE-RELATED TRAIN INCIDENT OR ACCIDENT

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Report 01/2007	9 February 2006	UK: Derailment of a freight train at Brentingby Junction, near Melton Mowbray	Causal factors: Fatigue, time of day	The driver was suffering from fatigue because he had not slept for about 22 hours. Also, the time of the day the accident happened coincides with the period when levels of alertness are naturally low.
RAIB Report 06/2007	21 February 2006	UK: Dispatch of a train with an unsecured load, Basford Hall Yard, Crewe	Causal factors: Human errors Contributory factors: Fatigue	This staff had a high fatigue index and a very high risk index on the accident date. The shifts that he had previously worked, together with his off-duty activities may have increased his susceptibility to fatigue, and to having an accident or incident.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Report 24/2007	28 June 2006	UK: Derailment of a freight train at Maltby North	Causal factors: Human errors Contributory factors: Fatigue	The length of the shifts being worked by the signallers at Maltby made them prone to fatigue during the night shift. The driver of train 6C51 may have been suffering the effects of fatigue following events associated with the locomotive failure earlier in his shift.
RAIB Report 27/2007	18 August 2006	Signal T172 passed at danger at Purley station, Surrey	Causal factors: Human errors Contributory factors: Fatigue	The freight driver was fatigued and his sleep had been disturbed on the previous night. The driver's hours of duty and shift patterns were also approaching the level at which his performance might be affected. Fatigue was identified as a contributory factor to the error made.
RAIB Report 30/2007	31 October 2006	UK: Collision at Badminton	Causal factors: Fatigue	The fatigue experienced by the driver, which may have made it difficult for him to remain alert.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Report 24/2009	26 April 2008	UK: Freight train collision at Leigh-on-Sea	Causal factors: Fatigue	The driver was in a state of fatigue caused by: a) the base roster pattern; b) not obtaining sufficient rest prior to his shift commencing; and c) the main driving task within the work site being in the second half of the shift when fatigue was most likely to occur.
RAIB Report 28/2009	10 November 2008	UK: Derailment of two locomotives at East Somerset Junction	Causal factors: Human errors, fatigue	It is probable that the signaller's actions were affected by fatigue because of the number of hours and the nature of the shifts that he had worked in the period leading up to the accident. Besides, the absence of a suitable framework of controls to manage fatigue was a risk factor.
RAIB Report 15/2011	17 August 2010	UK: Uncontrolled freight train run-back between Shap and Tebay, Cumbria	Causal factors: Insufficient alertness Contributory factors: Fatigue	The causes that the driver was insufficiently alert at the time of the incident was because he was fatigued. It also found that the driver had been exposed to a work pattern that was likely to induce high levels of fatigue.
RAIB Report 03/2012	8 March 2011	UK: Two incidents involving track workers between	Causal factors: Human errors	Staff has been fatigued as it was the end of the first night shift of the week. Also, the staff felt under pressure to complete the work.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
		Clapham Junction and Earlsfield	Contributory factors: Fatigue	
RAIB Report 03/2012	21 July 2013	UK: Passenger train collision at Norwich	Causal factors: Human errors Contributory factors: Fatigue, noise	The driver was tired and this might have affected his performance. He was also possibly distracted by the noise made by the passengers immediately behind his cab.
RAIB Report 12/2015	26 October 2014	Train struck and damaged by equipment cabinet door in Watford Tunnel	Causal factors: Human errors Contributory factors: Fatigue	The testers may have been suffering from fatigue, increasing the probability of an error being made. A possible underlying factor was that Siemens had not fully implemented its policy on managing the risk from fatigue.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Rail Investigation Summary – July 2015	7 September 2014	Latvia: Fatal shunting accident at Skirotava	Causal factors: Human errors Contributory factors: Fatigue	The investigation concluded the immediate cause of the accident to be that the shunter did not check that the wagons were moving and walked on to the line just in front of them before he was run over. The report added that fatigue – as a result of his increased workload – may have caused his 'temporary loss of concentration'.
RAIB Report 14/2016	11 September 2015	UK: Overspeed at Fletton Junction, Peterborough	Causal factors: Fatigue Contributory factors: Support and control	The driver did not reduce the train's speed to comply with the speed restriction, probably because of distraction and fatigue due to home-related stress. Neither the management system nor the driver had recognised that home-related distraction and fatigue were likely to be affecting the safety of his driving. This involved both the line management system and the investigation process.
RAIB Report 18/2016	28 March 2015	UK: Signal passed at danger incident at Reading Westbury Line Junction	Causal factors: Fatigue	The driver was too fatigued to control the train properly. He did not report as unfit for duty.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Report 18/2016	3 November 2015	UK: Signal passed at danger incident at Ruscombe Junction	Causal factors: Fatigue	The fatigued driver was not sufficiently rested and fell asleep on the approach to the signals concerned. Besides, the drivers were nearing the end of a long night shift.
National Transportation Safety Board (NTSB) Accident Report NTSB/RAR-16/03	17 August 2014	US: Fatal collision between two Union Pacific freight trains in Arkansas	Causal factors: Fatigue	Federal investigators have ruled that this accident resulted from a fatigued driver and guard, both of whom probably fell asleep on board one of the trains.
RAIB Report 04/2017	10 April 2016	UK: Collision between a train and tractor at Hockham Road user worked crossing, near Thetford	Causal factors: Human error, fatigue Underlying factor: Lack of fatigue management	The signaller's competence to operate the workstation safely and effectively was not adequately monitored and the signaller's concentration levels have decreased due to fatigue.
RAIB Report 05/2017	24 June 2016	UK: Near miss between a train and a track worker at Shawford	Causal factors: Human errors, fatigue	There was a breakdown in safety discipline and vigilance when the COSS and track worker went onto the railway at Shawford. The track worker's alertness and decision making were probably affected by fatigue.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Report 16/2017	28 February 2017	UK: Track worker near miss incidents at Camden Junction South, London	Causal factors: Human errors, fatigue Underlying factor: Lack of fatigue management	The signaller was affected by fatigue. Additionally, the RAIB observes that the management of fatigue risk for signallers does not reflect current good practice.
RAIB Report 18/2017	9 November 2016	Overturning of a tram at Sandilands junction, Croydon	Causal factors: Human error, fatigue Underlying factor: Lack of fatigue management	The driver had become fatigued due to insufficient sleep when working very early turns of duty. Although some doubt remains as to the reasons for the driver not applying sufficient braking, the RAIB has concluded that the most likely cause was a temporary loss of awareness of the driving task during a period of low workload, which possibly caused him to microsleep. It is also possible that, when regaining awareness, the driver became confused about his location and direction of travel.
NTSB Accident Report NTSB/RAR-18/04	28 April 2015	US: Collision between two freight trains at Roswell	Causal factors: Fatigue, human errors	The NTSB determined the cause of the accident to be that the conductor of the Roswell Local failed to return the points for the Main Line because he was fatigued. The fact that the crew of the moving train did not perceive the misaligned points in time to avoid the collision was a contributory factor.

Reference	Date	Accident	Fatigue-Related Factors	Fatigue Factor Description
RAIB Rail Investigation Summary – April 2018	8 April 2017	Romania: Freight train derailment between Băniţa and Merişo	Causal factors: Human errors, fatigue	Contributing to this was the fact that the first wagon’s angle cock was off, which interrupted the air pipe and rendered the continuous braking ineffective. Furthermore, the driver was suffering from fatigue and the crew had been impaired by the consumption of alcohol.
RAIB Report 07/2018	1 June 2017	UK: Fatal accident at Trenos footpath crossing near Llanharan, Rhondda Cynon Taf, South Wales	Causal factors: Human errors, fatigue	It is likely that the signaller was fatigued due to insufficient sleep, and that it is possible that this influenced his decision making when he removed the protection without being sure that the line was clear.

10.2 APPENDIX B: QUESTIONNAIRE OF THE LARGE-SCALE FATIGUE SURVEY

10.2.1 Train Crew Working Well Survey

Informed Consent

I understand that my participation in this project will involve completing a questionnaire on aspects of my well-being in relation to my work experiences, self-perception, and mental and physical health, which will take approximately 15 minutes of my time.

I understand that participation in this study is entirely voluntary and that I can withdraw from the study at any time without giving a reason.

I understand that I am free to avoid responding to any questions that I feel uncomfortable answering and that I can discuss my concerns with Professor Andy Smith at the email address below.

I understand that the information provided by me will be held totally anonymously, so that it is impossible to trace my responses back to me individually. I understand that this information may be retained indefinitely.

I also understand that at the end of the study I will be provided with additional information and feedback about the purpose of the study.

By checking the box below and continuing, I consent to participate in the study conducted by Professor Andy Smith, School of Psychology, Cardiff University.

I have read and understood the above statement and consent to participate.

Contact Details

Researcher	**Supervisor**
Jialin Fan	Prof Andy Smith
School of Psychology	School of Psychology
Cardiff University	Cardiff University
63 Park Place	63 Park Place
Cardiff	Cardiff
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10.2.2 Train Crew Fatigue Survey

1. **Age (years):**

2. **Gender: M/F**

3. **Job description:**

4. **Health-related behaviours**

   A healthy lifestyle involves taking exercise, eating a balanced diet, not smoking, not drinking excessive amounts of alcohol, and not being overweight. To what extent do you have a healthy life style?

   Not at all Very much so

   1 2 3 4 5 6 7 8 9 10

5. **Personality**

   People often describe themselves as being positive ("seeing" the glass as half full) or negative ("seeing the glass as half empty"). How would you describe yourself?

   Very negative Very positive

   1 2 3 4 5 6 7 8 9 10

Thinking about the last 6 months:

6. **Life satisfaction**

   How satisfied are you with life in general?

   Not at all Very much so

   1 2 3 4 5 6 7 8 9 10

7. **Life stress**

   How much stress have you had in your life in general?

   Very little A great deal

---

1 2 3 4 5 6 7 8 9 10

8. Happiness

Would you say you are generally happy?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

9. Anxious/Depressed

Would you say that you generally feel anxious or depressed?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

10. Musculo-skeletal problems

Do you suffer from musculo-skeletal disorders (e.g. arthritis; back pain; sciatica; repetitive strain injury)?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

11. Noise and vibration

Are you exposed to noise or vibration at work?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

12. Shift work/Night work

Do you work shifts or work at night?

Yes/No

13. Fumes

Are you exposed to fumes, dust or solvents at work?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

14. Job demands

How demanding do you find your job (e.g. do you have constant pressure, have to work fast, have to put in great effort)?

Not at all demanding Very demanding

1 2 3 4 5 6 7 8 9 10

15. Job control and support

Do you feel you have control over your job and support from fellow workers?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

16. Perceived stress at work

How much stress do you have at work?

Very little A great deal

1 2 3 4 5 6 7 8 9 10

17. Job satisfaction

Are you satisfied with your job?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

18. Physical and mental fatigue

How physically or mentally tired do you get at work?

Not at all tired Very tired

1 2 3 4 5 6 7 8 9 10

19. Illness caused or made worse by work

Have you had an illness (either physical or mental) caused or made worse by work?

Yes/No

20. Presenteeism

Do you ever come to work when you are feeling ill and knowing you can’t do your job as well as you would like to?

Yes/No

21. Efficiency at work

How efficiently do you carry out your work?

Not very efficiently Very efficiently

1 2 3 4 5 6 7 8 9 10

22. Work-life balance

Do you find your job interferes with your life outside work or your life outside of work interferes with your job?

Never Very often

1 2 3 4 5 6 7 8 9 10

23. Happy at Work

Are you happy at work?

Never Very often

1 2 3 4 5 6 7 8 9 10

24. Anxious/Depressed because of work

Are you anxious or depressed because of work?

Never Very often

1 2 3 4 5 6 7 8 9 10

25. Absenteeism

Approximately how many days sick leave have you had in the last 12 months? _______

26. Accidents at work

How many accidents requiring medical attention have you had in the last 12 months? ______

10.2.3 Measuring well-being in train crew – Debriefing

Thank you for completing the questionnaire. As stated in the introduction, the aim of the questionnaire is to identify the important elements of well-being.

The questionnaire you have just completed is part of a larger project which aims to research and develop mental health and well-being assessment tools for supporting employers and employees in Wales. The traditional method of assessing well-being in the workplace involves identification of negative job characteristics that the employee may be exposed to (e.g. time pressure), however this largely ignores the role of the individual in appraisal of those characteristics (e.g. coping style or optimism), and how positive appraisal may negate any effect on health outcomes such as depression.

The data you have provided for the questionnaire will therefore be used to:

- Identify the relationship between stimuli (e.g. job demands), individual characteristics (e.g. optimism), and outcomes (e.g. depression) as a way of defining well-being;
- Determine whether short-form or single item questions related to these elements can be combined as a short measure for overall well-being.

Your responses to the questionnaire will be held totally anonymously, with no questionnaire being traceable to an individual.

If answering the questions has made you think about certain problems (e.g. being anxious, depressed or stressed) then contact your line manager or HR to find out about available support services in your company.

If you have any queries or concerns about the research, please contact the researchers using the details below.

Thank you again for your participation.

Researcher	**Supervisor**
Jialin Fan	Prof Andy Smith
School of Psychology	School of Psychology
Cardiff University	Cardiff University
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Cardiff	Cardiff
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10.3 APPENDIX C: CORRELATION AND CHI-SQUARE ANALYSES FROM THE LARGE-SCALE FATIGUE SURVEY (STUDY 1)

10.3.1 Correlation

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**	**(19)**	**(20)**	**(21)**	**(22)**	**(23)**
Fatigue (1)	1																						
Job demands (2)	.430**	1																					
Job control and support (3)	-.249**	-.145**	1																				
Noise and vibration (4)	.248**	.124**	-.042	1																			
Fumes (5)	.236**	.172**	-.067*	.698**	1																		
Shift-work (6)	.136**	-.065*	-.005	.293**	.342**	1																	
Health behaviours (7)	-.123**	.010	.164**	.052	-.008	.017	1																

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Personality (8)	-.146**	.004	.358**	.012	-.030	-.027	.326**	1															
Life satisfaction (9)	-.234**	-.076*	.420**	-.007	-.034	-.044	.276**	.559**	1														
Life stress (10)	.329**	.271**	-.221**	.118**	.083**	-.074*	-.167**	-.209**	-.313**	1													
General happiness (11)	-.245**	-.072*	.414**	-.026	-.039	-.027	.261**	.625**	.782**	-.312**	1												
General Anxious/ depressed (12)	.306**	.193**	-.313**	.091**	.085**	-.058	-.158**	-.378**	-.524**	.481**	-.556**	1											
MSDs (13)	.261**	.175**	-.157**	.140**	.120**	-.002	-.160**	-.061*	-.115**	.198**	-.123**	.217**	1										
Perceived stress at work (14)	.516**	.690**	-.303**	.100**	.140**	-.053	-.105**	-.157**	-.245**	.451**	-.253**	.383**	.271**	1									
Job satisfaction (15)	-.232**	-.152**	.538**	-.069*	-.081**	.009	.137**	.392**	.492**	-.248**	.481**	-.369**	-.157**	-.329**	1								
Illness caused by work (16)	.253**	.105**	-.245**	.169**	.162**	.103**	-.149**	-.120**	-.225**	.232**	-.197**	.323**	.366**	.254**	-.303**	1							
Presenteeism (17)	.247**	.156**	-.214**	.047	.016	-.064*	-.097**	-.117**	-.157**	.190**	-.166**	.150**	.187**	.249**	-.244**	.240**	1						
Efficiency at work (18)	-.136**	-.108**	.376**	.057	.021	.118**	.239**	.358**	.350**	-.131**	.351**	-.237**	-.072*	-.239**	.348**	-.132**	-.093**	1					
Work-life balance (19)	.477**	.306**	-.266**	.228**	.264**	.242**	-.096**	-.153**	-.225**	.191**	-.221**	.219**	.187**	.328**	-.298**	.240**	.222**	-.172**	1				

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
Happy at work (20)	-.301**	-.185**	.548**	-.092**	-.112**	-.044	.185**	.440**	.554**	-.298**	.585**	-.435**	-.194**	-.369**	.772**	-.326**	-.216**	.430**	-.360**	1			
Work-related Anxious/ depressed (21)	.398**	.313**	-.408**	.115**	.130**	-.031	-.180**	-.335**	-.444**	.397**	-.445**	.591**	.256**	.526**	-.482**	.371**	.239**	-.278**	.361**	-.556**	1		
Absenteeism (22)	.065*	-.011	-.007	.060	.072*	-.023	-.076*	-.064*	-.092**	.153**	-.113**	.128**	.118**	.023	-.014	.165**	.041	-.106**	.050	-.116**	.141**	1	
Accidents at work (23)	.059	.060	-.084**	.060	.119**	.078*	-.097**	-.077*	-.065*	.075*	-.098**	.078*	.083**	.077*	-.099**	.195**	-.015	-.153**	.039	-.132**	.029	.139**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

10.3.2 Chi-square Results by Fatigue

Variables			Low Fatigue	High Fatigue
Job Demand	Low	Count	276	203
		Expected count	198.2	280.8
		Row %	57.6%	42.4%
		Adjusted residual	9.7	-9.7
	High	Count	163	419
		Expected count	204.8	341.2
		Row %	28.0%	72.0%
		Adjusted residual	-9.7	9.7
	χ2	94.992, *p*<0.001		
Job Control and Support	Low	Count	411	529
		Expected count	389.5	550.5
		Row %	43.7%	56.3%
		Adjusted residual	4.2	-4.2
	High	Count	29	93
		Expected count	50.5	71.5
		Row %	23.8%	76.2%
		Adjusted residual	-4.2	4.2
	χ2	17.717, *p*<0.001		
Shift-work	No	Count	135	126
		Expected count	108.7	152.3
		Row %	51.7%	48.3%
		Adjusted residual	3.8	-3.8
	Yes	Count	298	481
		Expected count	324.3	454.7
		Row %	38.3%	61.7%
		Adjusted residual	-3.8	3.8
	χ2	14.597, *p*<0.001		
Exposure to Noise and Vibration	Low	Count	283	283
		Expected count	234.3	331.7
		Row %	50.0%	50.0%
		Adjusted residual	6.1	-6.1
	High	Count	157	340
		Expected count	205.7	291.3
		Row %	31.6%	68.4%
		Adjusted residual	-6.1	6.1
	χ2	26.974, *p*<0.001		
Exposure to Fumes	Low	Count	308	345
		Expected count	270.3	382.7
		Row %	47.2%	52.8%
		Adjusted residual	4.8	-4.8
	High	Count	132	278
		Expected count	169.7	240.3
		Row %	32.2%	67.8%
		Adjusted residual	-4.8	4.8
	χ2	23.272, *p*<0.001		
Positive Health Behaviours (lifestyle)*	Low	Count	269	329
		Expected count	247.2	350.8
		Row %	45.0%	55.0%
		Adjusted residual	2.7	-2.7
	High	Count	170	294
		Expected count	191.8	272.2
		Row %	36.6%	63.4%
		Adjusted residual	-2.7	2.7
	χ2	7.504, *p*<0.01		
Positive Personality*	Low	Count	276	308
		Expected count	241.8	342.2
		Row %	47.3%	52.7%
		Adjusted residual	4.3	-4.3

Variables			Low Fatigue	High Fatigue
	High	Count	165	316
		Expected count	199.2	281.8
		Row %	34.3%	65.7%
		Adjusted residual	-4.3	4.3
	χ2	18.251, *p*<0.001		
Life Satisfaction	Low	Count	416	560
		Expected count	404.1	571.9
		Row %	42.6%	57.4%
		Adjusted residual	2.7	-2.7
	High	Count	25	64
		Expected count	36.9	52.1
		Row %	28.1%	71.9%
		Adjusted residual	-2.7	2.7
	χ2	7.100, *p*<0.01		
Life Stress	Low	Count	302	275
		Expected count	238.9	338.1
		Row %	52.3%	47.7%
		Adjusted residual	7.9	-7.9
	High	Count	139	349
		Expected count	202.1	285.9
		Row %	28.5%	71.5%
		Adjusted residual	-7.9	7.9
	χ2	62.018, *p*<0.001		
Life Happiness	Low	Count	425	583
		Expected count	416.3	591.7
		Row %	42.2%	57.8%
		Adjusted residual	2.5	-2.5
	High	Count	14	41
		Expected count	22.7	32.3
		Row %	25.5%	74.5%
		Adjusted residual	-2.5	2.5
	χ2	6.006, *p*<0.05		
Life Anxious and Depression	Low	Count	398	502
		Expected count	372.5	527.5
		Row %	44.2%	55.8%
		Adjusted residual	4.4	-4.4
	High	Count	42	121
		Expected count	67.5	95.5
		Row %	25.8%	74.2%
		Adjusted residual	-4.4	4.4
	χ2	19.376, *p*<0.001		
Job Satisfaction*	Low	Count	304	336
		Expected count	265.3	374.7
		Row %	47.5%	52.5%
		Adjusted residual	4.9	-4.9
	High	Count	137	287
		Expected count	175.7	248.3
		Row %	32.3%	67.7%
		Adjusted residual	-4.9	4.9
	χ2	24.244, *p*<0.001		
Job Stress	Low	Count	369	281
		Expected count	269.4	380.6
		Row %	56.8%	43.2%
		Adjusted residual	12.7	-12.7
	High	Count	72	342
		Expected count	171.6	242.4
		Row %	17.4%	82.6%
		Adjusted residual	-12.7	12.7
	χ2	161.597, *p*<0.001		
Job Happiness	Low	Count	423	561
		Expected count	406.8	577.2
		Row %	43.0%	57.0%
		Adjusted residual	3.9	-3.9

Variables			Low Fatigue	High Fatigue
	High	Count	16	62
		Expected count	32.2	45.8
		Row %	20.5%	79.5%
		Adjusted residual	-3.9	3.9
	χ2	15.054, *p*<0.001		
Job Anxiety and Depression	Low	Count	412	474
		Expected count	365.6	520.4
		Row %	46.5%	53.5%
		Adjusted residual	7.8	-7.8
	High	Count	25	148
		Expected count	71.4	101.6
		Row %	14.5%	85.5%
		Adjusted residual	-7.8	7.8
	χ2	61.343, *p*<0.001		
Musculo-Skeletal Problem	Low	Count	354	385
		Expected count	305.8	433.2
		Row %	47.9%	52.1%
		Adjusted residual	6.5	-6.5
	High	Count	85	237
		Expected count	133.2	188.8
		Row %	26.4%	73.6%
		Adjusted residual	-6.5	6.5
	χ2	42.760, *p*<0.001		
Performance Efficiency at Work*	Low	Count	248	289
		Expected count	223.3	313.7
		Row %	46.2%	53.8%
		Adjusted residual	3.1	-3.1
	High	Count	192	329
		Expected count	216.7	304.3
		Row %	36.9%	63.1%
		Adjusted residual	-3.1	3.1
	χ2	9.476, *p*<0.01		
Presenteeism	Low	Count	170	121
		Expected count	120.2	170.8
		Row %	58.4%	41.6%
		Adjusted residual	7.0	-7.0
	High	Count	264	496
		Expected count	313.8	446.2
		Row %	34.7%	65.3%
		Adjusted residual	-7.0	7.0
	χ2	48.684, *p*<0.001		
Illness Caused by Work	Low	Count	326	339
		Expected count	279.6	385.4
		Row %	49.0%	51.0%
		Adjusted residual	6.4	-6.4
	High	Count	86	229
		Expected count	132.4	182.6
		Row %	27.3%	72.7%
		Adjusted residual	-6.4	6.4
	χ2	41.388, *p*<0.001		
Negative Work-life Balance	Low	Count	322	208
		Expected count	219.8	310.2
		Row %	60.8%	39.2%
		Adjusted residual	12.7	-12.7
	High	Count	118	413
		Expected count	220.2	310.8
		Row %	22.2%	77.8%
		Adjusted residual	-12.7	12.7
	χ2	162.254, *p*<0.001		

⁎ Categorising by using Median Split

10.4 APPENDIX D: ANOVA (STUDY 1) AND CORRELATION (STUDY 2) ANALYSES FROM THE ONLINE FATIGUE EXPERIMENTS

10.4.1 Repeated Measures ANOVA (Study 1)

Comparisons: Afternoon vs. Morning

Measure	Mean Difference	Std. Error	Sig.	95% CI Lower Bound	95% CI Upper Bound
PVT - Reaction Time (msec)	.521	4.492	.909	-8.916	9.959
PVT - Accuracy	-.001	.019	.930	-.031	.038
PVT - Number of Lapse Responses	.250	1.335	.854	-2.555	3.055
PVT - Number of Total Responses	-.600	.995	.554	-2.691	1.491
Visual Search - Mean Reaction Time (sec)	-1.241	.906	.187	-3.144	.661
Visual Search - Accuracy	.008	.027	.774	-.066	.050
Logical Reasoning - Mean Reaction Time (sec)	-.151	.362	.681	-.911	.609
Logical Reasoning - Accuracy	-.015	.021	.493	-.058	.029

Adjustment for multiple comparisons: Bonferroni

10.4.2 Correlation (Study 2)

Correlation between workload, time spent on actives and performance changes

Variables	**Workload**	**Total working time**	**Lecture**	**Reading**	**Writing**	**Physical Exercises**	**Other Activities**
Workload	1	.587**	.096	-.071	.180	.361	.398*
Post-pre change in fatigue	.382**	.211	.018	.131	.041	.302	.177
Post-pre change in PVT - Reaction Time (msec)	.045	.075	.422	-.208	.043	-.182	-.020
Post-pre change in PVT - Accuracy	-.110	-.156	-.394	.147	.102	.170	-.033
Post-pre change in PVT - Number of Lapse Responses	.141	.115	.274	-.036	.053	-.264	-.007
Post-pre change in PVT - Number of Total Responses	-.091	-.030	-.343	.119	-.247	.239	-.078
Post-pre change in Visual Search - Mean Reaction Time (sec)	.070	-.166	.210	-.219	-.336	-.090	-.066
Post-pre change in Visual Search - Accuracy	-.105	-.130	.350	-.178	.073	-.258	-.167
Post-pre change in Logical Reasoning - Mean Reaction Time (sec)	.043	-.126	-.495*	.184	-.353	.085	-.091
Post-pre change in Logical Reasoning - Accuracy	.202	.245	.199	.070	.183	.035	.272

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Correlation between fatigue and the eight components of alertness scale

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post-pre change in fatigue (1)	1								
Post-pre change in alert (2)	.216	1							
Post-pre change in energetic (3)	-.526**	-.143	1						
Post-pre change in quick-witted (4)	-.311*	-.183	.851**	1					
Post-pre change in attentive (5)	-.376*	-.096	.710**	.683**	1				
Post-pre change in strong (6)	-.192	-.094	.570*	.489**	.577**	1			
Post-pre change in proficient (7)	-.324*	-.160	.681**	.714**	.564**	.220	1		
Post-pre change in clear-Headed (8)	-.265*	-.138	.806**	.783**	.678**	.677**	.638**	1	
Post-pre change in co-ordinated (9)	-.138	.136	.564**	.539**	.609**	.574**	.425**	.696**	1

[a]: Sum of eight alertness components.

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

10.5 APPENDIX E: QUESTIONNAIRE OF THE CAUSES OF FATIGUE SURVEY

10.5.1 Causes of Fatigue Survey

1. **Age (years):**
2. **Gender: M/F**
3. **Job description:**
4. **Health-related behaviours**

   A healthy lifestyle involves taking exercise, eating a balanced diet, not smoking, not drinking excessive amounts of alcohol, and not being overweight. To what extent do you have a healthy life style?

   Not at all Very much so

   1 2 3 4 5 6 7 8 9 10

5. **Personality**

   People often describe themselves as being positive ("seeing" the glass as half full) or negative ("seeing the glass as half empty"). How would you describe yourself?

   Very negative Very positive

   1 2 3 4 5 6 7 8 9 10

6. **Noise and vibration**

   Are you exposed to noise or vibration at work?

   Not at all Very much so

   1 2 3 4 5 6 7 8 9 10

7. **Shift work/Night work**

   Do you work shifts or work at night?

Yes/No

8. Fumes

Are you exposed to fumes, dust or solvents at work?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

9. Job demands

How demanding do you find your job (e.g. do you have constant pressure, have to work fast, have to put in great effort)?

Not at all demanding Very demanding

1 2 3 4 5 6 7 8 9 10

10. Job control and support

Do you feel you have control over your job and support from fellow workers?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

11. Physical fatigue

How physically tired do you get at work?

Not at all tired Very tired

1 2 3 4 5 6 7 8 9 10

12. Mental fatigue

How mentally tired do you get at work?

Not at all tired Very tired

1 2 3 4 5 6 7 8 9 10

13. Emotional fatigue

How emotional tired do you get at work?

Not at all tired Very tired

____

1 2 3 4 5 6 7 8 9 10

Working hours and fatigue

14. What is the normal length of your shift in hours?

____

15. How many shifts do you work before you have rest days?

____

16. What times(s) do you normally start your shifts? (if you work several shift patternswrite down all the start times)

____

____

____

17. Do you do overtime? Yes/No

What makes you fatigued?

18. Length of shift? Yes/No

19. Timing of shift? Yes/No

20. Number of shifts before rest day? Yes/No

21. Overtime? Yes/No

What makes your colleagues fatigued?

22. Length of shift? Yes/No

23. Timing of shift? Yes/No

24. Number of shifts before rest day? Yes/No

25. Overtime? Yes/No

26. Do you have any comments on your working hours? (e.g. how they could be improved)

____

____

____

Workload and fatigue

27. How physically demanding is your job?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

28. How mentally demanding is your job?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

29. How hurried or rushed do you feel during your job?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

30. How efficiently do you perform your job?

Not very efficiently Very efficiently

1 2 3 4 5 6 7 8 9 10

31. How frustrating is your job?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

32. How often do you get a rest break?

____

33. How long does the break last for?

____

34. Do you think that your colleagues' workload makes them fatigued?

Not at all Very much so

1 2 3 4 5 6 7 8 9 10

Factors outside work that make you fatigued

35. How long do you sleep for? (Hours)

____

36. How good is the quality of your sleep?

Not good Very good

1 2 3 4 5 6 7 8 9 10

37. Do you do things that reduce the amount of sleep you would like (e.g. playing computer games; watching TV)?

Not at all Very often

1 2 3 4 5 6 7 8 9 10

38. Do you think that activities outside work influence the level of fatigue of your colleagues at work?

Not at all Very often

1 2 3 4 5 6 7 8 9 10

10.5.2 Debrief

Thank you for completing the questionnaire.

As stated in the introduction, the aim of the questionnaire is to identify what causes fatigue. Your responses to the questionnaire will be held totally anonymously, with no questionnaire being traceable to an individual. If answering the questions has made you think about certain problems (e.g. being anxious, depressed or stressed) then contact your line manager or HR to find out about available support services in your company.

If you have any queries or concerns about the research, please contact the researchers using the details below.

Thank you again for your participation.

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