Summary:

What is fatigue and how does it affect the safety performance of human transport operators?

TØI Report 1351/2014
Author: Ross Owen Phillips
Oslo 2014, 103 pages English language

The ability to manage human fatigue in transport operations would be improved by a shared understanding of what fatigue is, how it should be measured, and how it affects safety performance. This may be achieved by a broader operationalization of fatigue, which would allow commonly studied aspects of fatigue to be considered alongside each other, and make explicit those aspects of fatigue that individual studies do and do not account for. According to such an operationalization, fatigue should be measured in terms of experience, physiological state and performance. In studying the effects of fatigue on operators, there would be a need for greater consideration of its longer-term effects, and its motivational aspects. To understand its performance effects would require that we attend to the systematic interaction of sleep history, time of day, time at work, and time on task, in the context of factors describing various aspects of work and non-work life.

There is a long-standing lack of consensus about what fatigue is or how it should be measured. The literature is peppered with divergent attempts to operationalize the term, and unless the reader understands precisely how fatigue has been operationalized by the different studies, a comparison of prevalence rates is almost meaningless. Convergence on the operationalization of fatigue is required for improved consistency of measurement, to allow comparisons across findings and increase the priority of fatigue as a transport safety risk in relation to those that are more easily measured. Convergence would also help managers understand the effects of fatigue as more demands are placed on workers in a 24-hour society increasing in complexity and efficiency. This report seeks to evolve the literature towards convergence on operationalizing fatigue for study in human transport operators. This is achieved in two main ways. Firstly, a consensus definition is generated for the study of the effect of fatigue on safety-related functions of human transport operators through reviewing existing attempts at definition. Secondly, explicit links are drawn between the effects of fatigue and the safety functions of human transport operators.

What is fatigue?

An important issue to address when operationalizing fatigue, is whether or not the concept should be treated as synonymous with sleepiness. Sleepiness is a clear and serious threat to transport safety. We understand sleepiness a lot more than we understand other components of fatigue, at operational, theoretical and physiological levels. Based on homeostatic and circadian influences, we can make reasonably successful predictions of average sleepiness for a groups of operators at varying times of the day, after they have followed a given work schedule, or have been given a certain series of sleep opportunities. An obvious question then is why not focus on sleepiness as a safety risk for human transport operators, and ignore the confusing concept of fatigue altogether? There are several answers. Firstly, we wish to understand the effects of sustained work and working while tired on performance, and sleepiness models say little about this. Secondly, even though they may not be sleepy, human operators may still be fatigued such that performance or latent performance is affected. Thirdly, vigilance is a central task for all transport operators, and task-related fatigue can have strong effects on vigilance. And fourthly, we are interested in accounting for how cumulative fatigue related to stress and other energetic constructs may lead to performance reductions. We therefore wish to operationalise fatigue as a broad concept that can capture not only the effects of sleepiness on safety in human transport operators, but those of task- and job-related effects, in addition to the longer term interactive effects of health and safety.

A review of existing attempts at definition finds that the broader concept of fatigue cannot be distilled to a single dimension, but has multidimensional aspects, which are dynamically interdependent and do not fully correlate. These aspects describe how fatigue manifests itself in subjective experience, physiology and performance. The impact of these multiple components of fatigue on the operator must be considered together within a systems perspective. From our review we have evolved a broad multidimensional definition of fatigue that is useful for the study of fatigue in human transport operators, and other researchers may wish to converge on this. It is meant as a contextual definition that can be used as the basis for narrower operational definitions to be used for specific studies of aspects of fatigue. The definition is as follows.

Fatigue is a suboptimal psychophysiological condition caused by exertion. The degree and dimensional character of the condition depends 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.

The definition implies that psychological (experiential) and physiological aspects of fatigue need to be measured in order to understand the state of fatigue. In order to understand the fatigue *process*, we need in addition to characterise the form, dynamics and context of exertion, in addition to performance. The definition also accounts for sleepiness as a component of fatigue. The inclusion of exertion as a cause of increased homeostatic pressure in models of sleepiness explains the overlap between fatigue and sleepiness. Exertion in the face of homeostatic and circadian sleep pressure may also increase sleep propensity, and exacerbate the sleepiness component of fatigue. In fact fatigued states may be revealed in terms of performance decrements in circadian lows, as fatigue becomes too great for the operator to be able to compensate.

How to think about fatigue

Given that we wish to employ the broader concept of fatigue, how should we think about components that are not directly related to sleep drives, in particular those that are related to exertion, sustained activity, time at work and time on task? In particular, our thinking must be structured in a way that accounts for the large variation in time-on-task effects on performance. Two main models explain variation in time-on-task effects on performance by accounting for the nature of the task and/or the motivational influences on fatigue: the compensatory control model and the dynamic model of stress and attention. These models disagree fundamentally about whether the experience of fatigue is an indicator forecasting a future lack of energetic resources (mental or physical), or a discrepancy between the direction of actual behaviour and desired goals. We note that the latter makes it difficult to distinguish fatigue from stress, but it may be beneficial to consider that concerns about one's own physiological state *and* concerns about misalignment of behaviour and desires may contribute to the fatigued state and thus be limiting for performance. This approach can be assimilated into a new heuristic for the *process* of fatigue in human transport operators. This heuristic also accounts for sleep drives as an integral component of fatigue; the role of lower order (subconscious) and higher order (conscious) processes in determining performance; and the role of emotions and feelings linked to fatigue in determining fatigue effects on performance.

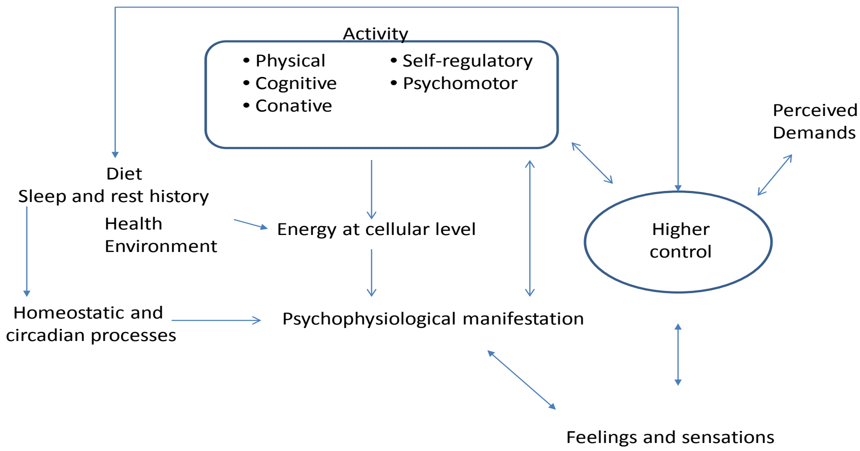

Figure S1. A holistic model of fatigue that accounts for the role of sleep. Here fatigue is not one step in the process, but is described by indices that map the system e.g. the collective state of experiential, physiological and performance/activity (physical, cognitive or psychomotor) indices.

Regardless of stance on the origin of the experience of fatigue, most authors agree that energetic limitations are not directly linked to performance decrements. In other words, when considering how fatigue affects performance, we must attend to the human transport operator's attitude and motivation he or she brings to the task. He or she will be adept at adapting to maintain performance, but that this has certain costs which any survey of fatigue should attempt to account for. These costs may be in terms of latent performance decrements and personal health or quality of life costs. When compensating for performance, we should also consider changes in strategy that an operator chooses to perform the task, and how these subtle changes may have implications for safety. Any survey should consider that some tasks, especially vigilance, may be inherently fatiguing in terms of performance.

Measuring fatigue

If fatigue is multidimensional, each dimension should ideally be surveyed when assessing fatigue in a sample, as far as this is practical. Self-reports are the most pragmatic way of gathering data, and this is important to consider when surveying human transport operators. Self-reports can be used not only to collect a measure of subjective fatigue states, but as a means of collecting performance data, or data on compensatory strategies, latent performance decrements or health effects. In assessing performance, it is important that reports relate specifically to performance of the task in question.

Most instruments have been developed to collect self-reports on acute subjective fatigue. A taxonomy of fatigue measures strongly suggests that chronic fatigue has been overlooked in the development of survey measures. Some instruments measuring acute fatigue measure exclusively sleepiness, while others tap into various aspects of the broader construct. After review, we conclude that instruments employing several items to assess each of several aspects of fatigue are preferable, and it is important that the instrument defines the period of interest for the respondent. Several popular scales are available, with good psychometric properties. Several scales analyse the experience of fatigue along several dimensions, the most common of which are physical, cognitive and emotional fatigue, and sleepiness. Each subdimension may map on to a general or overarching fatigue dimension. In addition to fatigue scales, scales developed independently to measure alertness should also be considered. Overall, we regard the Swedish Occupational Fatigue Index (SOFI) as promising for the measurement of fatigue experience in human transport operators. The SOFI is probably the most well developed scale for occupational fatigue, and different human transport operators may have characteristic subscale profiles, depending on the nature of their job. When assessing different workers we should remember that fatigue that is specifically task-related may be experienced along dimensions that are different from fatigue due to general tiredness and work, and it may be important to capture the task-specific fatigue experience in order to understand the most safety-relevant aspects of fatigue.

Objective measures tapping into the physiological state of fatigue have not yet been used to survey of large numbers of human transport operators. However, methods such as palmtop reaction time tests or actigraphy are becoming increasingly accessible, and may be worth considering. Alternatively it may be possible to survey representative subsamples of operators using objective methods. Again, measures of performance should be matched to safety-related performance of interest.

Safety performance effects of fatigue

Sleep deprivation has been found to affect a range of cognitive functions, most notably reaction time and lapses. Slowed and more variable reaction times are found in computer tests and real world driving. Functions affected by sleep deprivation that may be particularly relevant to human transport operators are reaction time, alertness, perceptual skills, decision making, judgments and cognitive slowing. Increased attention deficits and accelerated vigilance decrements may be particularly important. The implications of these functional decrements caused by sleep deprivation for performance will depend on the task or job activities in question. Monotonous, unstimulating tasks are more likely to make performance vulnerable to functional decrements. Time of day will also influence the extent of functional decrements and related performance outcomes. Importantly, sleep deprivation may produce impairments that reduces the ability of operators to handle unexpected, challenging situations, and make them more likely to rely on ingrained and inappropriate schemas. The fact that sleep deprived workers may also be more susceptible to distractions increases the likelihood of this happening.

Links have been established between recent sleep deprivation, circadian lows and accidents, implying the involvement of sleepiness. However, little is known about how chronic partial sleep deprivation, typical of real world working, affects performance, although we know that there are strong effects on attention and vigilance.

Isolating the effects of task fatigue on performance from the effects of homeostatic and circadian influences is often difficult and rarely achieved. However, there is good evidence that sustained task performance results in decrements to sustained attention and functions involved in vigilance, especially where the task is continuous, perceived as boring, is demanding or taxes attentional resources. In terms of real world settings, the following may induce task fatigue for human transport operators: driving on unstimulating, long straight roads; sailing a quiet ship on uneventful, open seas while following the same course; long straight, unstimulating rail stretches. These effects will of course be exacerbated by circadian nadirs and sleep deprivation. The job of human transport operator may also involve physically or other mentally demanding tasks that exacerbate vigilance performance decrements. Costs of attempting to maintain main task performance, include attentional narrowing, less use of memory, strain and effort, post-task preference for low effort, subjective fatigue and risky decision making. Thus the effects of fatigue on performance of the whole job may be important, as are interactions of other job characteristics, such as supervision levels, on performance. The effect of task-related fatigue on accidents and injuries is unresolved due to lack of suitable studies.

Specific effects on safety performance in human transport operators

Combined challenges of fatigue due to poor sleep history (especially irregular shift patterns and fragmented sleep), work at all times of day and sustained task performance appear to be the main influences on fatigue in human transport operators in the rail, road and sea sectors. In particular, all operators can be challenged by task underload, i.e. having to perform a vigilance task under unstimulating, monotonous conditions. This can occur at times of day when sleep drives are at their highest. Task overload may also be a particular problem for some operator roles. Thus a system of factors may interact to cause fatigue, and this system and the dynamic interaction of its elements that must be surveyed and managed to ensure that the performance and wellbeing of operators is not influenced unduly by fatigue.

The most serious effects of fatigue on transport operators are in terms of sleepiness and maintenance of cognitive task performance. For any operator, fatigue may pose a particular threat to skill-based task performance, in terms of increase risk of slips, lapses and mode errors. Fatigue-induced mode errors may be an overlooked threat and cause operators to persist with inappropriate strategies in unforeseen, deviant, demanding or distracting situations. Many fatigue-related safety problems may be caused by the influence of fatigue on complex faculties that allow operators to be mindful about emerging situations, assess a range of possibilities and act on emerging situations. In such cases fatigue will not only influence simple attention, but immediate priorities, expectations and the current world model, and access to and salience of knowledge and previous experience. Effects of fatigue on reaction time, decision-making and memory may also be important in this regard.

Implications for studying human transport operators

There are several implications for the study of fatigue in human transport operators:

- Fatigue should be operationalized using the provided definition, and thought about using the heuristic provided.
- Fatigue should ideally be measured in terms of the experience, physiological state and performance.
- The experience of fatigue itself should be measured along several dimensions, and supplemented with a measure of alertness.
- SOFI may be particularly useful, i.e. it is well developed and would allow for useful comparisons among different operators, and with other occupational samples.
- Cumulative chronic fatigue should not be ignored.
- Performance should be measured in a way that is specific to task-related safety.
- Motivational aspects surrounding the task or job should also be measured, and related to compensatory strategies, costs to the operator and latent performance decrements.
- Where there is a main safety-relevant task, the nature of the task itself should be considered.
- The physiological and behavioural methods of fatigue measurement may be difficult to apply in routine operations. In this regard, rapidly advancing handheld technology available to all (especially mobile phone apps) could be considered and/or study of a representative subsample.
- In regarding performance effects, the systemic interaction of sleep history, time of day and time at work or on task should be considered in the context of factors describing the operator's job and non-work/off-duty life.
- For operators that may be sleep deprived, a range of cognitive functions may be challenged, and these may lead to reduced attention, poor detection abilities, vigilance problems, delayed response times, cognitive slowing, poor judgements and lapses; in particular there may be overreliance on ingrained schemas in deviant situations.
- For underloaded operators with task fatigue and little control, there may be problems with attention and vigilance.
- Job fatigue will also be associated with slips, lapses, mode errors and, again, the ability to assess and act appropriately in emerging situations that are non-routine.

Finally, when considering how to survey fatigue in human transport operators, we should consider that life outside work (or life off-duty) may also play an important role on fatigue while on duty. Constructs such as psychological detachment from work or work-life balance may be useful in this regard.