Cognitive fatigue can be defined in many ways and an initial distinction is between narrow definitions focusing on a restricted range of phenomena and wider approaches that conceptualise it as a multi-faceted functional state requiring multiple levels of explanation. An example of the narrow approach is the view that cognitive fatigue refers to the decrement in cognitive functioning as a function of time on task. This fatigue is seen as different from endogenous modulation of arousal and alertness. In many real-life situations exogenous and endogenous...
factors both influence cognitive functioning and this leads to the involvement of different mechanisms, a variety of individual differences and a range of potential countermeasures. Indeed, even specific phenomena can be seen to be complex and to argue against a focused approach to cognitive fatigue. This last point can be illustrated by considering the post-lunch dip in alertness and our ability to sustain attention.

A post-lunch dip has been observed both in real-life performance and in the laboratory. Monk (2005) has reviewed research on the post-lunch dip and concluded that it is an increase in the potential for sleepiness that reflects a 12 hour harmonic. Individual differences in this effect have been described with those showing the clearest 12 hour harmonic (morning types) having the biggest post-lunch dip. However, exogenous factors that can induce a sedative effect, for example alcohol, have a larger effect in the post-lunch period than when circadian alertness is high (Horne & Baumber, 1991). Indeed, studies of the ability to sustain attention in the early afternoon have shown that impaired performance reflects the consumption of lunch (Craig et al. 1981; Smith & Miles, 1986, 1987). For example, Smith and Miles (1987) used a cognitive vigilance task involving detection of repeated 3-digit numbers and found that after consuming a meal performance dropped from the pre-meal level of 69% targets detected to a level of 56% detections. In contrast, those who received no meal detected 65% of the targets. Again, individual differences in this effect of lunch have been demonstrated, with stable extraverts (low anxious people) showing the biggest effect of lunch. The mechanisms underlying the effects of lunch on sustained attention are likely to involve CNS effects of cholecystokinin (CCK) and changes in vagal stimulation. There is considerable evidence for effects of the post-lunch dip on performance and safety at work (see Monk, 2005) and it is important to consider countermeasures that can prevent such effects. Smith et al. (1990) showed that caffeine can
prevent the post-lunch dip in sustained attention. In this study performance after lunch in the placebo dropped from a level of 69% detections pre-lunch to 60% post-lunch. In contrast, those who received caffeine detected 71% of the targets in the post-lunch period. Similarly, other research has demonstrated that caffeine is beneficial when alertness is reduced by either endogenous changes (e.g. working at night) or exogenous factors (e.g. prolonged work. See Smith, 2005a, for a review).

Another issue in research on cognitive fatigue is the level of explanation. Traditionally this has been a topic for applied cognitive psychologists and they have discussed this in the context of current psychological theories (e.g. Broadbent, 1958; 1971). Some current approaches suggest that mental fatigue involves adaptive strategies to keep performance at an acceptable level under adverse internal circumstances. Cognitive fatigue often takes the form of declining task engagement, low energy, loss of motivation and increased distractibility. The fatigue process involves motivational control that acts to inhibit activation of current goals and allow competing goals to gain control over behaviour. Such inhibition may be overcome by additional effort. Multi-level explanations based on neuroscience systems are becoming more popular. These approaches examine fatigue in terms of genetics, microbiology, brain structure and function, individual behaviour and the impact on society. Examples of these different approaches will be given in this paper. The main focus will be to take effects demonstrated in the laboratory and consider underlying mechanisms, followed by the impact of such effects in the workplace. The next section of the chapter considers the neurotransmitter basis for lapses of attention. This is followed by a section that considers a peripheral influence on fatigue, namely how gut flora can alter levels of fatigue. The role of gene expression in chronic fatigue syndrome is then used as an example of another approach that has been applied to this area. Different methods of assessing
cognitive fatigue at work are then described and the impact of minor illnesses, such as the common cold, assessed using these approaches. Finally, research on the extreme fatigue experienced by seafarers is described. This research not only covers the variety of research methodologies outlined earlier in the chapter but also addresses the practical issues of preventing and managing fatigue in an industry that is difficult to regulate. The final section of the chapter then draws conclusions from the holistic approach to cognitive fatigue described throughout this article.

Neurotransmitters and lapses of attention.

The first example that I will consider will be our research on neurotransmitters and fatigue. Our interest in neurotransmitter changes underlying fatigue started with a study investigating central noradrenaline and lapses of attention. Many previous studies have shown that sleep deprivation increases lapses of attention (e.g. Williams, Lubin & Goodnow, 1959). Such effects can be reduced by increasing alertness (e.g. by playing loud noise – Wilkinson, 1963). Smith and Nutt (1996) conducted an experiment involving a clonidine challenge which reduces the turnover of central noradrenaline and induces a state resembling a night of sleep deprivation. Administration of clonidine was associated with an a 12-fold increase in lapses of attention (long reaction times) which could be returned to the level of the placebo condition by increasing alertness pharmacologically (with a drug idazoxan that increases the turnover of central noradrenaline) or by playing noise. Other research using the clonidine challenge paradigm has shown that the efficacy of caffeine in restoring function in fatigued individuals is due, at least in part, to changes in central noradrenaline (Smith et al., 2003). For example, when volunteers were given clonidine their simple reaction times were 80msec slower than the placebo group. Those
given clonidine and caffeine (3mg/Kg body weight) had very similar reaction times to the placebo group.

Dietary fibre and fatigue

Interest in this topic developed from an initial study showing that individuals with a high intake of dietary fibre reported levels of fatigue that were about a third lower than those with a low fibre intake (Smith et al., 2001). This was followed by an intervention study (reported in detail in Smith, 2005b) which compared the effects of high fibre (wheat bran) breakfast cereals with low fibre cereals. Volunteers (N=144) in the study were randomly assigned to either the high or low fibre conditions and consumed these cereals for a period of 10 days. Those in the high fibre condition reported a reduction in fatigue (in the region of 8-10%) compared to their baseline measure whereas the low fibre group reported almost identical levels of fatigue as at baseline. Smith (2005b) has put forward plausible mechanisms to account for the effects of dietary fibre on fatigue. The beneficial effects of increasing dietary fibre may be due to a pre-biotic effect (increasing the “good bacteria” in the colon). This may then increase energy in two ways. The first involves improved fermentation which leads to an increase in short-chain fatty acids which lead to an increase in energy. The second involves detoxification (a greater elimination of toxins) which may also lead to a reduction in fatigue. This last point will be returned to in the next section on gene expression and fatigue.

Gene expression in chronic fatigue syndrome

One area of neuroscience that has enormous potential is that of gene expression. We have examined this in chronic fatigue syndrome (CFS) patients, a group whose primary symptoms is fatigue that is made worse by exercise or mental effort (Fukuda et al., 1994). Studies have shown that these patients have cognitive impairments (e.g. Thomas & Smith, 2009) and that these
problems increase with time on task (Smith et al., 1999). Research has demonstrated abnormalities in gene expression in CFS patients (see Kerr et al., 2007). These abnormalities are consistent with what is known about fatigue induced by viral infections and organophosphates. The abnormalities are greater under conditions of acute fatigue and appear to be reduce by therapies that aid recovery in CFS (e.g. pacing).

Cognitive fatigue at work

We have used several methods of assessing cognitive fatigue at work. One approach has been to use standard epidemiological approaches, involving cross-sectional and longitudinal surveys and controlling for potential confounders, to investigate different aspects of the fatigue process. Our conceptualisation of the fatigue process has been based on models of stress. For example, we measure exposure to risk factors for fatigue, perceived fatigue and the symptoms of fatigue. In addition, individual differences such as appraisal and coping must be assessed and associations between fatigue and cognitive failure, minor injuries and accidents examined. We have also examined effects of fatigue on simulations of real-life activities and used the after-effect technique (Broadbent, 1979) to assess effects of fatigue on performance. The after-effect technique involves measuring performance before and starting work. The difference between these two measures is assumed to reflect the demands of the workload and when the workload has been high the post-work measure is impaired relative to when there is a lower workload (see Parkes, 1995). The next section of the paper describes the application of these approaches to the study of the effects of minor illnesses on cognitive fatigue.

Minor illnesses and cognitive fatigue

Fatigue is an integral part of both acute and chronic diseases. Indeed, there are functional disorders where fatigue is the primary symptom (chronic fatigue syndrome) and where objective
testing has demonstrated cognitive difficulties. It has been possible to study experimentally-induced acute minor illness such as the common cold and influenza (see Smith, 1990, for a review) and these studies demonstrate that subjective reports of fatigue and cognitive impairments are associated with these illnesses. The effects of having a cold have typically been in the region of 10-15% impairments. In contrast, having influenza can lead to a 55% slowing of simple reaction time. In addition, impairments may persist after the symptoms have gone and may also occur when the person has a sub-clinical infection or is in the incubation period of the illness. The next stage of the research has been to examine naturally-occurring illnesses (with infection being confirmed by virological assays) and these studies have replicated our earlier findings (Smith et al., 1993; Smith et al., 1998). Results from these studies showed that subjective alertness was 20% lower when the person had a cold and simple reaction time was 10% slower. The research has not only shown that these illnesses are associated with increased fatigue but that they also make the person more sensitive to factors such as alcohol (Smith et al., 1995) or distracting noise (Smith et al., 1993). For example, when healthy volunteers were given a low dose of alcohol their reaction times were not significantly different from the placebo group. When those with a cold were given the alcohol their reaction times were over 200 msec slower than in the colds/placebo condition. Similarly, when noise was played to healthy volunteers no increase in reaction time was observed. However, when the noise was played to those with colds their reaction times were 60 msec slower than in the quiet condition.

The biological mechanisms underlying these effects are likely to be complex but we have identified two possibilities. First, it is well established that anti-viral agents can influence the CNS. Smith et al. (1991) injected volunteers with interferon alpha which produces symptoms resembling influenza. This interferon challenge leads to reduced alertness and impaired cognitive
functioning (a 70 msec slowing of reaction time) and provides a plausible mechanism underlying effects of influenza on behaviour. Our research on the effects of the common cold has largely focused on noradrenergic functioning. The rationale behind this came from the finding that caffeine removed the impaired performance associated with a cold (Smith et al., 1993). In a subsequent study (Smith et al., 1997) volunteers with a cold were given either idazoxan, a drug which increases the turn over of central noradrenaline, or placebo, and their alertness and performance compared with healthy volunteers. The results showed that idazoxan removed the impairments (e.g. an 80 msec slowing of reaction time) seen in the placebo group which suggests that the effects of having a cold on alertness and performance reflect, at least in part, changes in noradrenergic functioning.

One must now ask what are the real-life consequences of these upper respiratory tract infections. Studies using simulations of driving have shown that this is impaired when the driver has a cold (Smith, 2006). Two types of impairment were observed in this study; the first was that those with a cold were about 70 msec slower than healthy volunteers in responding to an unexpected target. Secondly, those with a cold were about 40% more likely to have a collision with the side of the track. Accidents on the road and at work also increase at times when these viral illnesses are prevalent (Tye, 1960), and lost productivity at work due to colds has been estimated at $16.6 billion (Bramley et al., 2002). In two studies (Smith et al., 2000; Smith et al., 2004) we have examined the alertness and performance of workers with colds and healthy workers. The measures have been taken before and after work and both studies showed greater impairments after work in those with colds. In those with colds, reactions time after work were 140 msec slower than at the start of the day. In contrast to this, healthy individuals were 40 msec faster at the end of the day (probably reflecting an increase in circadian alertness).
Overall, these studies provide a good example of the four phases of the research strategy outlined in the introduction – controlled laboratory studies providing a detailed description of cognitive fatigue, neurotransmitter and cytokine challenge studies aimed at identifying underlying mechanisms, studies of the impact in the workplace, and countermeasures to prevent or remove the fatigue.

The next section continues with further coverage of fatigue at work and describes our recent research on seafarers’ fatigue. It extends the research strategy by considering the ways that a culture change can be produced to prevent and manage seafarers’ fatigue.

Seafarers’ fatigue

Global concern with the extent of seafarer fatigue and its potential environmental cost is widely evident across the shipping industry. Maritime regulators, ship owners, trade unions and insurers are all alert to the fact that with certain ship types a combination of minimal manning, sequences of rapid port turnarounds, adverse weather conditions and high levels of traffic may find seafarers working long hours and with insufficient recuperative rest. In these circumstances fatigue and reduced performance may lead to environmental damage, ill-health and reduced life-span among highly skilled seafarers who are in increasingly short supply. A long history of research into working hours and conditions in manufacturing as well as road transport and civil aviation industries has no parallel in commercial shipping. There are huge potential consequences of fatigue at sea in terms of both ship operations (accidents, collision risk, poorer performance, economic cost and environmental damage) and the individual seafarer (injury, poor health and well-being,). Not only has there been relatively little research on seafarers’ fatigue but what there has been has been largely focused on specific jobs (e.g. watchkeeping), specific sectors (e.g. the short sea sector) and specific outcomes (e.g. accidents).
Given the absence of extensive research on seafarers’ fatigue we have carried out a research
programme (Smith, Allen & Wadsworth, 2006) aimed at providing a knowledge base to: predict
worst case scenarios for fatigue, health and injury; develop best practice recommendations
appropriate to ship type and trade; and produce advice packages for seafarers, regulators and policy
makers.

These aims have been met using several different methodologies., some of which are outlined
below. Underlying this research programme is a conceptualisation of fatigue as a process. This
process begins with risk factors for fatigue (i.e. work characteristics and conditions associated
with fatigue), moves on to subjective perceptions of fatigue (i.e. how and when an individual
experiences and reports fatigue), and concludes with the consequences of fatigue both in the
short term (symptoms of fatigue such as loss of concentration; poor performance) and the longer
term (e.g. ill health). This process approach has been suggested elsewhere in relation to work
characteristics, fatigue and ill health, and is analogous to the approach to stress widely used in
studies of the general working population.

Both subjective and objective measures of fatigue were used in the research. The aims of the
programme were achieved through surveys, analysis of existing databases and field research. The
methods involved: a review of the literature; a questionnaire survey of working and rest hours,
physical and mental health; physiological assays assessing fatigue; instrument recordings of sleep,
ship motion, and noise; self-report diaries recording sleep quality and work patterns; objective
assessments and subjective ratings of mental functioning; pre- and post-tour assessments; and
analysis of accident and injury data.

The main results can be summarised as follows. First, the review of the international literature
(Allen, Wadsworth & Smith, 2008) showed that research is increasingly revealing fatigue to be a
significant problem in the seafaring industry. Present reporting systems, however, are often not
designed to record this factor. Evidence shows seafarer shift and working patterns are often
conducive to fatigue with two man watches and excessive working hours areas of particular
concern. Research also suggests that the impact of fatigue on seafarers may be seen in terms of
health, psychosocial consequences, impaired cognition and increased risk of accidents.

A survey of 1856 seafarers was conducted. Most of the respondents were deck (49%) or
engineering (36%) officers. Just over 40% worked on ferries, 25% on offshore support, supply or
standby vessels, and 19% on tankers. Two thirds of the respondents worked on UK flagged
vessels. Results from the survey showed that fatigue was consistently associated with poor sleep
quality, negative environmental factors, high job demands and high stress. Other factors found to
be important included: frequent port visits, physical work hazards, working more than 12 hours a
day, low job support and finding the switch to port work fatiguing. The short-term consequences
of fatigue (reported symptoms of fatigue, and the perception of risk to personal safety) were also
associated with a similar range of factors. Those most at risk of high levels of fatigue and
associated consequences were those who reported the greatest number of fatigue-inducing
factors. It is therefore important to consider the combined impact of negative factors rather than
considering them alone. An association between perceived fatigue, self-reported health status
and cognitive function was also shown (Wadsworth et al., 2007). This association was
independent of work characteristics shown to be risk factors for fatigue. Subjective fatigue may
therefore be a factor which impacts on health independent of other risk factors.

A high proportion of the sample reported having been involved in a collision with another
vessel (most of these incidents were between two moving vessels), or with another object (in
most cases the harbour side). Nearly half of the sample considered fatigue to be a key factor in
reducing collision awareness. One in four watch-keepers (particularly those on longer watches) reported having fallen asleep on watch. Almost all watch-keepers were required to multi-task while on watch, and just under half of these found this to be problematic. Those who found multi-tasking problematic reported higher fatigue levels, and were more likely to have fallen asleep while on watch. A smaller but significant number (17%) were concerned about potential collisions and were again found to have higher fatigue levels and be more likely to have fallen asleep on watch.

Two sub-samples were identified that had very high levels of fatigue. The first group were fishermen. Many fishermen reported that they had worked to the point of collapse and fallen asleep at the wheel and over half of the sample believed that their personal safety was at risk because of fatigue. Comparisons were also made across different sectors of the shipping industry. Seafarers in the short sea and coastal sample were found to report higher levels of fatigue than those from an offshore oil support sample. This may potentially be explained in terms of type of vessel and frequency of port turn-around and data from a mini-bulker crew are shown in a subsequent section.

Diary studies were also carried out. In one study (Wadsworth et al., 2006) the seafarers completed a daily diary over the complete tour-leave cycle (203 respondents completed tour diaries, 197 leave diaries and 182 completed both). Fatigue was found to increase most significantly in the first week of tour. Evidence suggested recovery from tour does not typically occur until the second week of leave. In this study more frequent port calls were associated with greater fatigue among those on shorter tours, and with lower fatigue among those on longer tours. This difference would appear to reflect ship type, as those on shorter tours mainly worked on ferries, while those on longer tours mainly worked on supply, support and container or tanker
vessels. Of methodological significance, the diary study found fatigue on waking to be a more sensitive measure of fatigue than a measurement taken before bed.

Another method involved onboard performance testing. Results showed that fatigue risk factors such as noise, night work and days into tour had an impact on alertness and performance. The next section considers results obtained from a mini-bulker crew, which represented the most extreme case of fatigue we have come across. Mini-bulkers are small ships that carry a variety of dry cargoes around Europe. They typically have a crew of about 8 and only have two watchkeepers who work 6 hours on/6 hours off. They are compared below with bulkers, shuttle tankers and a container ship which operate different watch keeping systems that are better adapted to the fast port turn arounds which now take place. Previous research on accidents at sea (Marine Accident Investigation Branch [MAIB], 2004) had suggested that mini-bulkers were involved in a number of fatigue related incidents. Our results confirm that fatigue is a major problem for the crew of mini-bulkers. This was observed with both subjective reports and objective measures of performance. For example, subjective reports of fatigue were 80% higher for the crews of mini-bulkers than for other types of ship with similar crews but different watch-keeping patterns. The objective performance data revealed that the mini-bulker crew were more impaired than those on the other ships and that the magnitude of this became greater as the tour progressed. For example, after the first day of a voyage the simple reaction times of the mini-bulker crews were about 50 msec slower than other ships and this difference increased to about 70 msecs after 7 days.

The project evaluated the efficacy of methods aimed at preventing or managing fatigue. The results showed that the impact and effectiveness of working time directives appear to be undermined by widespread under recording of working hours. Evidence suggests large numbers
of seafarers are working hours in excess of those allowed by current legislation and that under recording of working hours is associated with higher levels of fatigue. Fatigue guidelines produced by IMO put excessive emphasis on the responsibility of individual crew members to manage fatigue without acknowledging the critical role of corporate and legislative bodies. Fatigue can only be addressed if all levels of the seafaring industry are co-operatively involved and accountable.

Given the diversity of activities undertaken in the maritime sector, and the different profiles of fatigue risk factors in different work groups, it is clear that a range of strategies will be needed to prevent or manage fatigue. Having evaluated current working time directives and a fatigue guidance publication from the International Maritime Organisation, existing approaches seem largely inadequate. Improvement of these approaches is clearly one strategy that could reduce the problem although an awareness campaign approach, as proved successful in other transport sectors, may also have value. Similarly, fatigue management programmes have been developed in other industries and such approaches could form part of a package for dealing with fatigue at sea. Indeed, the general absence of fatigue awareness and management training in the seafaring industry shows that fatigue has not been treated as a health and safety issue. This could be achieved using approaches designed to address other areas of health and safety (risk assessments, audits, training) and would, therefore, involve established procedures rather than development of novel approaches. This holistic approach to fatigue will require all layers of the industry (regulators, companies and seafarers) to be involved. What is crucial is that strategies for prevention and management are evaluated, for without reliable auditing systems the success of any change will be impossible to judge. There are huge potential consequences of fatigue at sea and correspondingly great benefits to be had by addressing it.
As described above, this research programme has provided an evidence base for the development of fatigue recommendations and guidance. These general recommendations for addressing seafarers’ fatigue can be summarised as follows: review how working hours are recorded; establish fatigue management training and information campaigns; develop an industry standard measure of fatigue; and develop a multi-factor auditing tool.

Our analysis has shown that it is the combined effect of a range of factors that is associated with fatigue. The development, implementation, and, crucially, evaluation of strategies to address fatigue must be carried out jointly across all levels of the industry. However, their application must also be tailored, at a local level, to be appropriate and practical. Tackling fatigue at sea must involve the industry as a whole because it has the potential to benefit at an equally universal level. Research on the nature of cognitive fatigue, mechanisms that underlie it, evidence from the field and the efficacy of countermeasures will be crucial steps in taking this forward.

Conclusions

The research described in this paper supports the approach to studying cognitive fatigue outlined in the introduction. The subject matter is very wide and it is essential that phenomena are described appropriately and the area conceptualised clearly to allow validation. The risk factors for fatigue are many and it is argued that one should consider the combined effects of these variables rather than examining them in isolation. Underlying mechanisms need to be considered at many different levels and systems neuroscience provides a framework for doing this in an organised way. Appropriate countermeasures for fatigue have been identified and this knowledge must be incorporated into fatigue policies which aim to prevent and manage fatigue at work and in safety critical activities such as driving. This holistic approach to fatigue requires
involvement of all stakeholders but it is apparent that those who conduct research on the nature of cognitive fatigue, the mechanisms that underlie it, and the practical implications of fatigue, will continue to make an essential contribution to this most important topic.

References


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