Fatigue Levels – An Inside Look

Life by SmartCap provides information to assist equipment operators in the management of fatigue through their shift. This document provides a detailed, inside look at how Life's fatigue levels are calculated, and what they represent.

What Life by SmartCap Measures

Life measures something very specific – an **individual's ability to resist sleep**.

Fatigue as a concept is somewhat grey. Terms such as vigilance, alertness, tiredness and fitness to perform are often used in place of fatigue – often with the same sentiment, but subtly different definitions, and none of which consistently correlate with how a person is feeling.

Microsleeps only occur when we fail to resist sleep; they don't occur when we choose to rest. For people operating equipment, resisting sleep is a natural, sometimes subconscious behaviour. It is when our ability to resist sleep diminishes that we become at risk of a microsleep.

This is why *ability to resist sleep* is the most relevant safety measure for equipment operators.

Interpreting Life Fatigue Levels

Life's fatigue levels are presented on a numerical scale developed at the University of Queensland in 2004. This scale ranges from 1 to 5, with Level 1 representing a hyper alert state and Level 5 representing the involuntary sleep (including microsleep) state.

As with all scales, the numbers themselves are arbitrary; what matters is the meaning of each number, and how we use the information to proactively manage our fitness for work.

The extreme values of 1 & 5 are not incorporated into Life by SmartCap for two reasons. Firstly, the independent validation study only used values 2 through 4; secondly, these values don't provide information that directly assist the user in the real-time management of fatigue.

Life's fatigue levels included in the product can be interpreted as follows:

2	TYPICAL LEVEL OF ALERTNESS	No immediate action required
3	ALERT WITH SOME EARLY INDICATORS	No immediate action required
3+	TRANSITIONING PHASE FROM 3-4 (EARLY WARNING)	You are becoming at risk of fatigue, take action to help manage your fatigue.
4	HEIGHTENED RISK OF MICROSLEEP	You are at heightened risk of microsleep and need to take IMMEDIATE action.

*It's important to note that a Level 4 does not mean a microsleep occurred, nor does it mean that a microsleep was imminent. **A level 4 indicates an increased risk of microsleep**. That risk is further heightened by a low stimulus environment, and is best reduced by operator action and activity.*

A direct measure – our approach to fatigue monitoring

Prior to the SmartCap's technology development, gauging impairment related to fatigue included the measurement of behavioural symptoms such as eye behaviour, gaze direction, micro-corrections in steering and throttle use, and heart rate variability. The measure most commonly used in fatigue monitoring technologies is the percentage of eye closure, or PERCLOS. While studies have shown correlation between PERCLOS and impairment, approaches using this measure suffer from changes in eye behaviour unrelated to changes in alertness. Examples include situations of glare, insufficient lighting, dust and changes in humidity. As such, practical implementation usually suffers from higher rates of false alarms and missed instances of impairment.

The underlying measurement behind the Life levels is brain activity. Often referred to as EEG (or electroencephalogram), brain activity has been the golden standard in sleep and fatigue science for over 30 years. Being a more direct physiological measure, this allows Life's technology to provide greater accuracy by avoiding erroneous measurements related to the external environment. This was made possible by the innovation of the patented EEG technology developed for Life.

Philosophy behind Life Fatigue Levels

The measurement of EEG through practical, wearable technology only solves half the problem of accurate fatigue monitoring in a working environment. What remains is the universal mapping of EEG information to a useful measurement.

While the analysis of EEG is a well-established science, researchers have always found that expert-developed rules to interpret brain activity tend to be effective for a majority and not the entire population. This is a result of natural person-to-person variation based on different physiology. Examples of variations identified include age and gender. Such variation means that a rule-based approach to mapping EEG to a measurement of fatigue would require an expert rule for each physiology, and to know which rule should apply to each person. This is clearly impractical.

In order to produce a practical tool for fatigue monitoring, SmartCap Technologies developed the Universal Fatigue Algorithm based on a data-driven approach. This means that the algorithm is based on real EEG from a large number of individuals, where the multitude of individual relationships are mapped using machine learning (often referred to as Artificial Intelligence) techniques. SmartCap Technologies are experts in this field, and to date the SmartCap Universal Fatigue Algorithm is the only data-driven mapping of EEG to a measure of fatigue in commercial use.

There are a number of specialised techniques we have applied during the training and testing process to ensure that these equations cater for as much person-to-person variability as possible. Our experience is that the more data from a wider range of participants is used, the more universal the result. This also provides the advantage that as more laboratory data is collected, the Universal Fatigue Algorithm can be made to be more accurate and discerning over time.

EEG Processing

EEG analysis usually focuses the frequency content of the neural activity. This is also true for the EEG processing included in the SmartCap Processor Cards.

The sensors in Life's headwear incorporate electronics that apply filtering (low pass) of the signals, so that any signals above 40Hz are significantly diminished. When converted to digital values in the processing card under the brim, we sample at 1280Hz, and then convert this to 256Hz – this allows us to ensure that there is no "aliasing" of high frequency noise in the frequency range of interest.

Once we have the 256Hz signals, we calculate the frequency spectrum of the signal over a 5-second window, which is recalculated each second. The frequency spectrum calculated is from 0-64Hz.

Using the entire frequency spectrum is a plausible approach, however if certain frequencies do not provide information related to an individual's drowsiness, the accuracy would vary significantly from person to person. As such, selective frequency analysis is key to the SmartCap's accuracy. Also, input data is scaled in a way to effectively make it non-dimensional, allowing person-to-person variations in signal strength and frequency content.

After hundreds of combinations of input structure and scaling were tested, our research found the most suitable to be an input of 1 to 13Hz, in 1Hz increments, scaled by the total signal power in the range of 13-30Hz. This was not by design, but by an extensive trial and error process.

Coincidentally, this result is an input that captures the well-known delta, theta and alpha waves, presented in a finer resolution, and scaled by the power of the beta waves. This could be interpreted as effectively a ratio of an individual's drowsiness and wakefulness.

The core of SmartCap Technologies Universal Fatigue Algorithm

The core component of the fatigue algorithm is a series of artificial neural networks that are trained to 'learn' relationships between the frequency content of an individual's EEG and a measure of their drowsiness. This learning is achieved by presenting the networks with large numbers of examples of each drowsiness state, and the corresponding EEG frequency information for numerous participants, and applying mathematical techniques to optimally capture this relationship in a highly non-linear, multidimensional set of equations.

There are two major advantages for taking this learning approach to algorithm development. Firstly, the approach does not require any calibration prior to use. Secondly, the ability for ongoing improvement and refinement.

The drowsiness state is determined by independent, non-EEG measures. The most commonly utilised measures in sleep research are the Oxford Sleep Resistance Test (OSLER test), and the Psychomotor Vigilance Test (PVT). Both tests were used to establish the example dataset used to generate the Universal Fatigue Algorithm.

Confirmation Process

A number of confirmation steps are incorporated into Life's software to ensure the highest level of accuracy possible. Before a fatigue level can be reported, a minimum of 17 seconds of EEG information must be analysed. Within this window of time, 13 separate fatigue calculations have been performed. A measure is only reported if the same measure is calculated in seven consecutive instances. This reported measure is known as the 'confirmed fatigue result'. If no confirmed fatigue result is achieved within 60 seconds, the reported output is "fatigue unknown".

Even more confirmation is required when significant impairment related to fatigue is suspected. Once significant impairment is suspected, the Life system shows a level 3+. Calculations continue, with new levels being determined at more frequent intervals. If strict criteria are met, Life will confirm its highest level; a level 4.

How we test the Universal Fatigue Algorithm

Testing the performance of the Universal Fatigue Algorithm has been at the heart of the development process over the last decade. An unseen-blinded experiment approach is always used, meaning that that brain activity information presented for testing has not been used in the training of the algorithm and that the independent measure of drowsiness is viewed and compared after the calculations are completed.

This approach is useful for developers; however, the true test of an algorithm is to subject it to independent assessment. SmartCap's Universal Fatigue Algorithm was assessed independently by the Monash University Accident Research Centre. This represented the world's first independent, expert assessment of a fatigue monitoring technology. All data used for the assessment was and remains quarantined by the scientists involved in the study, and has never been provided to SmartCap Technologies.

The study involved a number of people (subjects) that volunteered to participate. Each subject participated in a number of tests to determine their ability to resist sleep while also wearing SmartCap's technology. No data was provided to the participants during the experiment – measurements were recorded for later comparison. It is important to note that in the field of sleep and fatigue science, the laboratory setting is considered the most relevant for expert assessment, since the 'controlled' environment ensures that the performance (or lack thereof) of the test device (SmartCap) is accurately assessed.

Once all data was collected, the Fatigue Levels were compared with the expert assessment of fatigue impairment from each of the tests. The researchers found that the SmartCap Universal Fatigue Algorithm was 94.7% accurate in identifying instances of significant impairment related to fatigue. This was based on comparison with OSLER test results, which is a well-accepted evaluation approach for identifying impairment associated with fatigue.

Some of the earlier testing of the Universal Fatigue Algorithm is captured in the peer-reviewed ACARP report C15040, in which an in-field comparison of SmartCap performance against a non-EEG measure of fatigue is documented.

Maintaining Privacy

Although EEG is used to determine an individual's ability to resist sleep, no EEG information is recorded by Life. Once the calculations are performed, all EEG information is discarded. EEG information is never stored by the Life system. Also, no EEG information is ever sent by Bluetooth to the Life Display.

As such, Life cannot determine if you are happy or sad, or anything else. It measures one thing only, your ability to resist sleep.