PERSPECTIVES ON COGNITIVE SCIENCE

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CogSpeed: A Proposed Technology for Instantly Measuring Cognitive Performance in a Laboratory or a Real World Setting

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Abstract

CogSpeed, a computer-adaptive web-based application that can instantly test human cognitive performance objectively and also collect scores on the Samn-Perelli Subjective Fatigue Scale, is described in detail. A theory of cognitive performance based on levels of consciousness is described and applied to the development of the *CogSpeed* test. The speed at which a person can process information is a key variable of this measurement approach. *CogSpeed* aims to analyze a worker's ability to perform their job safely, especially in hazardous environments, providing a universal measuring tool to compare cognitive functioning in the laboratory and the field. Special *CogSpeed* design features enable rapid and reliable assessment of cognitive ability anywhere, among all populations, across all cultures. *CogSpeed* can identify individuals whose thinking and behavior may be impaired due to short-term factors such as cognitive fatigue, drug use, or, traumatic brain injury, or long-term factors such as dementia. *CogSpeed* use can provide a valuable service by identifying severe cognitive impairment, potentially saving lives. Initial development, theoretical underpinnings, and recommendations for further research and commercial applications are discussed.

Introduction

The objective measurement of physical phenomena is crucial to the advancement of all sciences. To date, modern psychology, while subjective measures of cognitive decline have been relatively successful, there is no unified technology to empirically and objectively determine the speed and quality of a person's cognitive functioning at any given moment or to evaluate cognitive decline over time, either in a laboratory, or while engaged in common, everyday behavior in the field. The ultimate goal of *CogSpeed* technology is to be able to accurately and objectively predict in real time when an individual's cognitive processing ability has declined to the point that his behavior is a danger to himself or others.

Objective Cognitive Performance Measurement Needed in the Laboratory

There are currently many shortcomings in research trying to measure short-term cognitive performance decline in a laboratory setting due to cognitive fatigue, sleep deprivation, circadian rhythms, and work-rest cycles. The sample sizes are often inadequate, the range of conditions is limited, and the populations studied are too narrow. Additionally, the experimental situations rarely cover a long enough time period to establish a well-defined cognitive performance baseline, inject the test conditions, objectively measure cognitive processing over time, and then measure complete cognitive processing recovery. Typical measurement techniques are often subjective paper and pencil questionnaires. Currently employed objective measures are often time consuming, open to learning effects, faking or expensive. They have responses prone to high variability, making it difficult to discern statistical differences among groups. They are often impractical, making it problematic to repeat theses tests as often as needed or test large numbers of subjects. The limited objective measurement equipment and methodologies are not standardized.

Medical research and clinical treatment lack efficient and effective objective measurement devices for evaluation of long-term cognitive decline involving dementia. While memory deficit is a major factor, little emphasis is placed on other behavioral impairments that impact daily living, such as the cognitive requirements for driving. Objective measures are needed to evaluate the benefits of various treatments, medications, and rehabilitation techniques, along with the capability to monitor and track a patient's recovery.

Inexpensive, objective, and portable tools that can provide rapid results are also needed to identify and track cognitive deficits caused by factors such as drug side effects or concussion.

Currently, one of the most widely used objective laboratory tests is the Psychomotor Vigilance test (PVT) (Basner, M. and Dinges, D. 2011). It is a simple reaction time test that normally requires ten minutes to administer to get reliable results. It has been used in many studies of fatigue and sleep deprivation. However, the PVT is used to develop group averages for statistical analyses, not to try to predict the cognitive processing ability of a single individual. Hand-held PVT devices that took three minutes to administer were not found to be highly reliable. (Antler, C. A. Yamazaki, E. M. Casale, C. E. & Brieva Namni Goel, T. E. 2022). There have been further attempts to develop smart phone versions of the PVT. But the PVT has been criticized for not being well-standardized and it does not yet meet the stringent criteria outlined in this report for measuring cognitive processing ability under all conditions. This paper proposes the use of *Cogspeed,* an entirely different type of measuring device with more wide-ranging applications.

Research Applications

There are many research studies which could benefit from being able to accurately and efficiently measure objective cognitive processing deficit as a dependent variable. *CogSpeed* is a standardized test that can be used to determine cognitive performance decrements in many different circumstances caused by fatigue, drugs, alcohol, brain trauma, and senility. *CogSpeed* provides a universal measurement tool for comparison of cognitive functioning in both the laboratory and the work place. *CogSpeed* is culture-free and has no language barrier. Data can be collected and downloaded anywhere, anytime, and instantly shared with any researcher, the moment the testing is complete.

One thing that has become apparent in recent research is that there is a wide range of individual differences in response to specific levels of variables affecting cognitive ability, such as time awake, work-rest cycles or alcohol or drug consumption that must be taken into account. For example, when a researcher is studying fatigue, they must be able to measure sure that the fatiguing protocol being investigated is robust enough to both subjectively and objectively fatigue the subject,. Otherwise, they may not be studying a truly fatigued subject.

As mentioned earlier, for researchers who want to collect subjective fatigue data, *CogSpeed* also includes the Samn-Perelli Fatigue Scale. It can be assumed that when a truthful individual reports the lowest score on the Samn-Perelli Fatigue Scale, they are in all likelihood not fit for duty. But a primary goal of the *CogSpeed* test is to be able to objectively predict a significant, reliable decline in an individual's level of cognitive performance capability in a real-world setting, regardless of whether they want to admit it.

An especially interesting line of neurological research would involve the use of *CogSpeed* to create various levels of degraded cognitive activity in the brain over time by causes such as fatigue, drugs, alcohol, senility or brain trauma. One of its advantages is that it is a highly repeatable yet relatively complex standardized test that can be easily used in laboratories throughout the world. *CogSpeed* generates a set of high-speed time-stamped, rigorous response demands and produces a cognitive impairment score. Once the *CogSpeed* test begins it requires complete uninterrupted attention until finished, which takes about two minutes. All brain activity is focused on meeting the test requirements. Every display and correct and incorrect response are trackable down to the millisecond. They can then be precisely synchronized and correlated with brain scans and EEG results.

One question to explore is whether degraded cognitive ability is due to actually slowing brain speed, ie neural transmission speed, or is the processing degradation simply observed as a slower *CogSpeed* score, but really due to disruption of pathways and functioning of specific areas of the brain? Or might the observed cognitive degradation be a combination of both slower speed and disruption, depending on the effect of the specific cause of impairment?

Would EEGs or brain scans, be able to tell the difference among the various causes of cognitive slowdown to the test, even though the result on *CogSpeed* would would manifest itself in a simply lower cognitive processing score? If so, it should be determined how these various degrading causes affect different parts of the brain and neural pathways, and in what ways? If fatigue, alcohol, drugs, and senility affects different parts of the brain in different ways, would it be possible to identify unique response patterns to the test itself for these different causes of impairment?

Would EEGs, or brain scans, be able to identify when a person believed their physical (motor) response to the complex reaction time test was either correct, incorrect, or missed?

And finally, if individual differences can be detected in specific brain areas and neural transmission pathways in response to *CogSpeed* testing, would it be then be possible to identify genetic differences in fatigue tolerance?

An adjunct use for *CogSpeed* is as a quick, inexpensive pre-screening tool for most psychological research involving human subjects. Prior to the start of an investigation, *CogSpeed* can verify whether every test subject is alert, well-rested, unimpaired due to drugs or alcohol, and ready to begin the experimental protocol.

Customized data reports can be developed for statistical analysis. Investigators can create specific test displays or target formats for unique research requirements. *CogSpeed* algorithms controlling such variables can be easily modified for experimental analysis.

Possible research topics include:

Laboratory and on-the-job fatigue studies for any occupation
Sleep deprivation studies
Sleep and circadian rhythm research
Work-rest cycle studies
Work-load analyses
Data inputs for Fatigue Modeling,
Fatigue Risk Management Analysis
Individual differences research
Gerontology research
Dementia impairment level evaluation
Psychopharmacological research
Comparison of drug drowsiness effects by dosage

Future Research Needed for *CogSpeed* Development

As it is hypothesized that the decline in response to *CogSpeed*, is also a valid analogue for expected decline in performance for real-world tasks requiring cognitive ability, research is needed to demonstrate that decline in scores on this complex reaction-time test correlate significantly with the decline of performance measures for a number of real-world tasks representing a wide range of work-related behaviors. In my dissertation, the original *DIPT* was validated for a specific set of subjects and conditions, and shown to be highly correlated with declines in simulator flying performance. Future research is needed to validate the new *CogSpeed* test against other types of behavioral performance for all factors that influence cognitive ability. For example, *CogSpeed* scores should be compared to other traditional subjective and objective cognitive and behavioral performance tasks in a range of controlled sleep deprivation, alcohol, drug, and traumatic brain injury research. Research is needed to determine if the extent of individual differences in cognitive impairment are due to fatigue, drugs, alcohol, brain trauma, and senility are task-dependent

Baseline scores should be developed for the general population. Population norms for age and various physical conditions should be created. The normative lower and upper age limit at which people can successfully complete the test should be determined. Very young children may not be able to respond adequately. Declining cognitive performance is to be expected with increasing age, up to the point where the test can no longer be successfully completed. The typical age at which this occurs would be an important data point for evaluating senility. Inability to complete the test may also be an indiction of a previously undetected medical problem.

CogSpeed is not an IQ test, and scores are not expected to be influenced by intelligence. Likewise, sex, perceptual-motor skills, and education level should not have a significant influence on the scores. However, varying baseline scores due to individual differences may be uncovered and should be researched.

Baseline scores for gender or physical prowess are expected to be minimal, but decrements due to the five influencing factors may be significantly different among various individuals. For example, individual tolerance to alcohol, sleep deprivation, or certain drugs may significantly effect scores.

What Does *CogSpeed* Really Measure? - A Proposed Theory Of Cognitive Performance Decrement Based On Levels Of Consciousness

It is hypothesized that human consciousness results from the activation of a broad set of neural networks in the brain. It is further hypothesized that the cognitive performance decrement due to "fatigue" is caused by the reduction in this neural networking that maintains consciousness.

It is proposed that the feeling of cognitive fatigue is a perception caused by sensors in the brain monitoring the increasing effort to maintain consciousness by keeping certain of these neuronal network connections functioning. This perception of fatigue is what is reported with the subjective measurement of fatigue such as the Samn-Perelli Fatigue Scale. It should follow that fatigue receptors would eventually be discovered in the brain.

When one is sleep-deprived or their time awake increases much past their normal bedtime, prior to the onset of sleep, there is a progressive reduction of these neural network connections. During this period as a person perceives their effort to maintain consciousness, ie, to maintain these connections, they report feeling fatigued. However, unlike changes in muscle due to physical fatigue, there is no actual "fatigue" of the brain.

So cognitive fatigue is argued to only be a perception in the brain, just like pain or color is a perception. The receptors for color wave lengths are in the eye and its signals are processed in the occipital lobes to give a perception of color. But the objects viewed don't have a "color" themselves as we perceive color. There is no "color" to be found inside the brain. Similarly, the receptors for pain are located through out the body, but the signals are processed in the brain to give a perception of pain. However, there is no physical "pain" in the body. In like manner, signals from cognitive fatigue receptors detecting the struggle to maintain consciousness would be processed in the brain to provide the perception of fatigue without actual "fatigue" in the Brain.

To repeat: the cognitive performance decline due to cognitive fatigue is proposed to be actually caused by the reduction in the neural networking that maintains consciousness. At some point during waking, the continued reduction of neural network connections causes sleep. Sleep is not a state of being "unconscious." It is just very low level of consciousness, a state of lack of awareness and an inability to perform basic cognitive behaviors.

There are also levels of consciousness below sleep, for example, coma. Loss of consciousness is considered to be a severe reduction of these neural network connections. Complete irreversible loss of these neural networks, ie, complete unconsciousness, is brain death.

The perception of cognitive fatigue varies from zero, when one is wide awake and the neural consciousness network is fully activated, to an increasingly uncomfortable perception when the network is trying to shut down but one is being forced to try to maintain these connections and remain active.
With increasing time awake, perception of fatigue is episodic, not strictly linear. ie, the perception of fatigue will vary progressively in intensity over time, as the robustness of the level of neural network connections varies. In most sleep deprivation experiments, the reported perception of cognitive fatigue precedes measurable cognitive performance decrement. That is, a person perceives they are trying to maintain declining neural connections before the neural network connections have declined sufficiently to impact cognitive performance.

The increasing drop in cognitive performance along with the perception of cognitive fatigue is primarily correlated with total time awake and may be enhanced when coupled with severe cognitive workload. Other known factors, which cause cognitive impairment, such as drugs, alcohol, brain trauma, and dementia may or may not be associated with a perception of fatigue, but it is still hypothesized that these factors cause a reduction in the neural network connections reducing the level of consciousness, resulting in cognitive impairment.

Dementia may in part be a more long-term, either partial or severe, permanent degradation of these neural networks necessary for consciousness and normal cognitive performance.

The *CogSpeed* test as developed is a direct test of this theory. A person's speed of information processing is a key variable in cognitive performance ability. It is thus proposed that measurement of changes in the speed of the brain's information processing ability is actually measuring changes in the brain's momentary or long-term levels of consciousness, that is, changes in the integrity of its neural network connections. EEGs and brain scans would be expected to correlate levels of neural network connectivity with changes in cognitive processing ability shown by *CogSpeed* scores.

A person's overall decrease in information processing speed that occurs with increasing perception of fatigue over time, or with drugs, alcohol, brain trauma or dementia factors, is proposed as window into reduced neural networking integrity. *CogSpeed* is attempting to objectively measure this phenomena. It is further proposed that the Bill's blocking that occurs during *CogSpeed* testing is actually an instantaneous, momentary micro-reduction and recovery in a person's level of consciousness. These blocks increase with increasing perception of cognitive but also are seen as reflecting fluctuating levels of neural network connections, resulting in slower *CogSpeed* scores.

Objective Cognitive Performance Measurement Needed in the Field
As in laboratory settings, there doesn't exist a reliable objective method to rapidly and accurately measure cognitive performance in real-world settings, which, could be argued, is a more pressing requirement. The range of behavioral settings chosen for evaluation is limited. Few practical tools are available to an investigator to evaluate a person's cognitive fitness to perform safely in hazardous situations.

The methods used are usually subjective or observational, not objective. Current studies give insight into how a group is performing in a certain situation, but a reliable method is needed to identify the cognitive capability for a given individual.

The development of a practical, objective tool like *CogSpeed*, could not only greatly advance cognitive science but also provide significant societal benefits, such as improved worker productivity and accident prevention which could potentially save lives. Extremely impaired workers could be immediately identified to their safety managers, on any work site, regardless of time. There is a host of important practical applications for this type of measurement technology. This paper describes the development of a device to address the needs of both the laboratory and the field, along with its theoretical underpinnings.

Background

For my PhD dissertation, I wanted to develop an objective device to measure US Air Force pilot fatigue that could potentially when they were flying operational missions. That device was labeled the Discrete Information Processing Test (*DIPT*). At that time, only subjective measures had been used. The existing subjective fatigue scales were time-consuming to fill out, could be easily be faked by subjects not wanting to reveal their true feelings, and were laborious to compile and analyze by hand. The computer-based task I developed was intended to capture a pilot's momentary cognitive performance decline in a single score while they were flying a long-duration missions. However, initial development started with research in an aircraft simulator.

Theoretical Assumptions

The fundamental assumption of the proposed measurement technique was that a major underlying driver of the quality of cognitive performance is a function of how fast a person can accurately process information, that is, their cognitive processing speed. For the purposes of development of this measurement device, it meant accurately processing a relatively small set of visual information and correctly responding to a complex reaction time task. The less visual information the subject had to process during the test, the less response variability would be introduced, and hence increase the accuracy of the scores. This also made the test easier to learn to a stable baseline. It was not necessary to measure the amount of visual information processed for this test to work.

The *DIPT* measured a person's on-going speed of cognitive processing, figuratively a "speedometer for the brain." But actually, it doesn't measure true brain speed, it measures the rate at which visual information can be processed and accurately responded to. The value of this approach is that measuring objective decline in this one behavior, i.e., the response to a complex reaction time test, is an analogue for expected decline in performance for other more sophisticated behaviors.

The test developed was based on the supposition that the fastest rate a person can accurately process simple visual information is a direct correlate of how well his brain is performing at that moment, i.e., the quality of their cognitive processing ability. It is further assumed that this rate is directly affected by a phenomenon known as Bill's Blocking. As a person is responding to information, when the presentation rate becomes too rapid to process, the brain will momentarily and uncontrollably stop responding, or "block." (Bills, 1931). The brain will then instantaneously recover and continue to function.

Research has shown "blocking" to be a somewhat frequent occurrence, and this test used blocking as a marker of cognitive processing ability. Blocking is expected to occur more frequently at greater cognitive levels, and at faster visual presentation rates. That phenomenon is what the computer algorithm in the test used to determine cognitive processing ability. If the subject gets more right than wrong, the computer speeds up the presentation rate. If the subject get more wrong than right, it slows down. The computer hunts for the fastest presentation rate the subject can reliably and accurately respond to, until Bill's Blocking occurs.

Blocking might occur at a slower than the maximum presentation rate that the subject might be able to correctly respond to. The computer algorithm is designed to take this anomaly into consideration. The computer automatically checks if the subject could have reliably and accurately responded to a higher presentation rate. A rapid retest is administered to determine if that faster rate is valid. Conversely, the subject may by chance respond to a rate that is above their true current cognitive processing ability. These exceptionally high responses are unrepresentative of their actual ability to perform. And they are assumed to occur very infrequently. Thus, in order to minimize measurement error, before the test result is reported, testing continues until two consecutive scores are produced within an acceptable tolerance.

When a subject was in a normal cognitive processing state, they could typically respond correctly to continual display rates of between 1000 and 1400 milliseconds per presentation. For ease of analysis, the response time is converted to a score between zero and one hundred. The entire testing operation usually took less than two minutes to arrive at a single, best estimate, of their cognitive processing score.

The maximum presentation rate at which the blocking occurs is considered the upper limit of the person's cognitive processing speed. The rate remains relatively stable until cognitive fatigue sets in. If the person's maximum response score is significantly lower than their standard baseline score, the test predicts that the individual has lowered cognitive processing ability. The ability to accurately and rapidly process information is critical to a person's ability to behave adequately in a real world situation. If accurate processing speed falls below a critical point, this would indicate their behavior is a potential danger to himself or others, especially in hazardous situations. A fundamental value of this test is to determine if and when that point has occurred.

Early Development

The Discrete Information Processing Test (*DIPT*) display and response panel was installed in a flight simulator and controlled by an external PDP 12 Computer. The test incorporated design features from the beginning with the intention that it would eventually be useful in the field, i.e., it would collect data on Air Force pilots while on flying duty during actual combat missions. The *DIPT* was the forerunner of *CogSpeed.*

Subjective fatigue data and objective flying performance scores from the instrumented simulator were also simultaneously collected under controlled experimental conditions. This provided comparison data for validating the *DIPT*. The subjects were instructed to follow precise heading, course, altitude, turn-rate, and airspeed while flying a randomized flight plan over long-duration, fatiguing 12-hour missions. The simulator instrumentation measured their deviations from the required course during the entire flight. Normal aircraft cannot be instrumented in such a way as to objectively and precisely score a pilot's flying performance in actual flight.

Half of the subjects began their flights immediately upon waking; the other half began after being awake for 12 hours. The *DIPT* was administered every hour during the flight. Statistical analysis showed the *DIPT* data was highly significantly correlated with flight duration, and also correlated with the subjective fatigue data. And importantly, the DIPT correlated significantly with the objectively measured flying performance measures which were collected continuously over many hours simulated flying. But the *DIPT* test took less than two minutes of each hour to administer.

The research was carried out at the USAF School of Aerospace Medicine at Brooks Air Force Base, Texas. The dissertation is documented in Fatigue Stressors in Simulated Long-duration Flight: Effects on Performance, Information Processing, Subjective Fatigue, and Physiological Cost (Perelli, 1980).

The *DIPT* device was built into the dashboard of the flight simulator and connected to a mainframe computer. But I saw a need for portable device that could be used in the field during actual flying operations. I subsequently wrote a description of an idea for a hand-held device incorporating the *DIPT* adaptive computer algorithm. The intent was that the device could be used during any military flying operation. It was to be connected to a modem in order to download the data back to a central command post for analysis. I received a patent for this invention, (Perelli Patent US4464121, 1984).

Development Of *CogSpeed*

The development of this hand-held device I had envisioned in my patent would not be possible until required supporting technology, namely the internet, the smart phone, and cloud based computing was sufficiently matured. The first iPhone debuted in 2007; the first iPad in 2010. But they were only marginally capable of supporting the *CogSpeed* computing requirements until a few years later. I began development of an improved version of the *DIPT* in October 2011. The working prototype, designated *CogSpeed*, was produced in 2014.

Everyone experiences a range of cognitive processing performance, from fully functioning on the one hand, to the inability to function clearly and safely on the other. With *CogSpeed*, it became apparent that in measuring cognitive processing speed, fatigue was not being measured directly, but only the effects of fatigue on the brain. In addition, I recognized that several other factors could have similar effects on reducing cognitive processing ability from a normal baseline. These additional factors included both short-term, alcohol, prescription and illegal drugs, and traumatic brain injury (TBI), and long-term, dementia or senility. Brain tumors, strokes, and aneurysms can also affect cognitive processing ability that *CogSpeed* would be sensitive to.

The objective *CogSpeed* test is thus more useful than if it only measured fatigue. It represents the decrement with a single score and can be administered as often as necessary. Immediate corrective action can be initiated. While *CogSpeed* will detect the cognitive performance decrement due to any of these factors, it cannot currently differentiate among them. It can only detect if a change, either an improvement or decline, from the subject's previous processing capability has occurred. Further analysis can be performed to help distinguish the specific cause. However, accurate knowledge of the time at which this change has occurred would be of significant value, for both laboratory and real world situations.

In this sense, *CogSpeed* is analogous to a simple fever thermometer. It is easy to operate, fits in a pocket, and is inexpensive. It works for all humans around the world, in any culture, and gives immediate, reliable results in a short period of time. At thermometer can detect fever caused by a myriad of diseases. However, a physician may be needed to determine which disease. But knowledge of the presence of a fever is extremely valuable. If the thermometer detects a high enough temperature, the person's life may be in danger and demands immediate attention. *CogSpeed* performs in a similar manner, but, does require a short learning period for the user, while a thermometer does not. However, it is easier to fake body temperature with a thermometer than to fake normal cognitive functioning with a *CogSpeed* score. And a fever thermometer isn't connected to the internet.

Incorporation of the Samn-Perelli Subjective Fatigue Scale

Subjective data is a valuable way to identify changes in human performance capability. The vast majority of fatigue studies in both the laboratory and the field have had to rely primarily on subjective data.

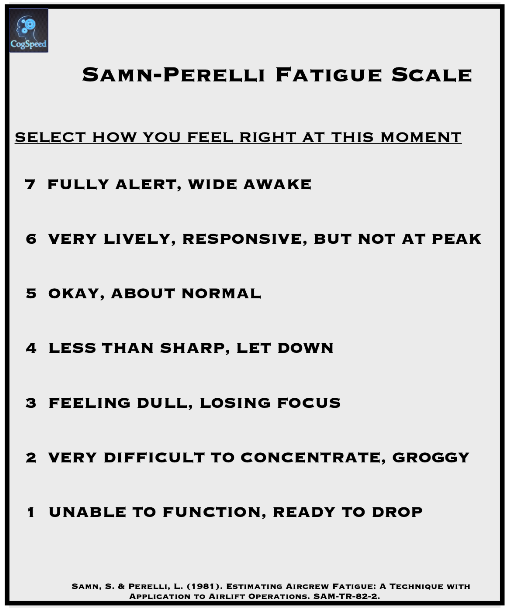
As a result of short-comings noted in the subjective fatigue scales that were currently in use when the my dissertation research was conducted, I developed a 7-point Likert scale checklist and validated it during a human factors field evaluation of the C-141 Fuel Savings Advisory System (Perelli, 1981). I then used that fatigue checklist in a computer simulation to predict air crew fatigue in simulated C-141 air crew missions (Samn and Perelli, 1982). Since then, that fatigue scale has become known as the Samn-Perelli Fatigue Scale and used by many researchers around the world since 1984.

The Samn-Perelli Fatigue Scale is recommended by the International Air Transport Association (IATA), International Civil Aviation Organization (ICAO) and the International Federation of Airline Pilots' Associations (IFALPA), highly respected aviation trade associations. Its use in airline fatigue management is described in The Fatigue Management Guide for Airline Operations, 2nd Edition, 2015. Many diverse organizations also recommend the checklist, for example, the oil and gas industry (Managing fatigue in the workplace. 2019).
The Samn-Perelli Fatigue Scale has been incorporated directly into the flight management system of a commercial Air New Zealand 777-200 aircraft for inflight recording of pilot fatigue (Powell DMC, Spencer MB, and Petrie KJ, 2011).

Subjective reports, such as the Samn-Perelli Fatigue Scale, have been shown to work well in research studies where large numbers of grouped scores are subjected to statistical analysis. This method is useful in evaluating the effects of issues such as work-rest cycles on the group's overall fatigue level and thus their cognitive performance capability. Studies have indicated that subjects reporting fatigue scores of the lowest categories on the Samn-Perelli Fatigue Scale are typically unable to function effectively.

It is expected that statistically significant reports of increased subjective fatigue will usually precede objectively-measured cognitive performance decline. That is, statistically significant reports of increased subjective fatigue can often be obtained before statistically significant measures of objective cognitive decline can be detected. In fact, it is possible to have statistically significantly reports of increased fatigue without any noticeable or measurable cognitive decline, if the measurement period ends before severe fatigue sets in.

Because of the proven value of subjective fatigue data, I have incorporated the Samn-Perelli Fatigue Scale into *CogSpeed.* Before taking the *CogSpeed* test, *t*he application records the subject's current feeling of fatigue, which is related to their of feelings of performance ability. A copy of the Samn-Perelli Fatigue Scale checklist is at Figure 1.



SAMN-PERELLI FATIGUE SCALE

SELECT HOW YOU FEEL RIGHT AT THIS MOMENT

7 FULLY ALERT, WIDE AWAKE

6 VERY LIVELY, RESPONSIVE, BUT NOT AT PEAK

5 OKAY, ABOUT NORMAL

4 LESS THAN SHARP, LET DOWN

3 FEELING DULL, LOSING FOCUS

2 VERY DIFFICULT TO CONCENTRATE, GROGGY

1 UNABLE TO FUNCTION, READY TO DROP

SAMN, S. & PERELLI, L. (1981). ESTIMATING AIRCREW FATIGUE: A TECHNIQUE WITH APPLICATION TO AIRLIFT OPERATIONS. SAM-TR-82-2.

Figure 1. The Samn-Perelli Fatigue Scale included in *CogSpeed*

The Samn-Perelli Fatigue Scale asks the subject for a single number between one and seven to rate their subjective energy level, not just specifically their feeling about fatigue. Therefore, with this one question, the Samn-Perelli Fatigue Scale allows a person to report if they feel they are declining for factors other than fatigue, such as drugs, alcohol, or brain injury.

The Samn-Perelli Fatigue Scale a gives a person the opportunity to reflect on how they actually feel to help them become more aware of their true fitness to perform. It can also help reinforce their acceptance of the *CogSpeed* Score. Honest reporting of subjective fatigue is obviously sensitive to a feeling of fatigue but even though the subject feels fatigued, their performance may not suffer. However, in other cases, such as euphoria from alcohol or drug intoxication, a person may not feel too tired, but in fact their cognitive capability is nonetheless significantly compromised. Evaluating both *CogSpeed*'s objective score and the person's subjective reporting, this situation can be better understood.

CogSpeed collects, stores, and transmits the Samn-Perelli Fatigue Scale scores electronically, researchers can use *CogSpeed* for collecting both subjective and fatigue objective data. This simplifies simultaneous collection of both the subjective and objective data, reduces recording errors, saves valuable research time in compilation, and expedites data sharing among researchers.

The advantage of the objective *CogSpeed* test is that it is designed to detect severe cognitive impairment in situations when respondents are unwilling or unable to provide accurate subjective fatigue scores, or when cognitive decline is due to factors other than fatigue, such as drugs, alcohol, aging, or brain trauma.

Just as the Samn-Perelli Fatigue Scale is recognized as a universal measurement standard for subjective fatigue, it is hoped that one day a device similar to *CogSpeed* will become the standard for objective measurement of an individual's cognitive performance decline.

Design Features of The *CogSpeed* Test

I incorporated as many human factors design principles and practical features as possible into this new device to enable effective use in the real world, not only in a laboratory setting. The *CogSpeed* test can be taken quickly, anywhere, anytime. All that is required is that the subject be able to devote a few minutes of their full attention to the task.

CogSpeed is purposely designed as a single, universal, test instrument that can detect significant cognitive decrement caused by five different factors: cognitive, alcohol, both prescription and illegal drugs, traumatic brain injury, and senility. Thus, it saves time and eliminates multiple testing devices.

A breathalyzer only measures blood alcohol content, but doesn't give any indication of the person's actual cognitive performance capability, or detect cognitive decline due to any other factors. An activity monitor gives some sleep information, but cannot predict when performance decline might occur later in the day. No other simple test exists that can determine cognitive fatigue, alcohol, drug, senility, or concussion effects on cognitive processing ability in the field and represent it with a single score.

Because it is programmed in Java Script as a web app operating over the internet, it is easily portable as it will work on any smart phone or tablet with a wi-fi or phone connection. The app could also be configured to work in a stand-alone mode, storing scores locally.

If used on a smart phone, it requires no outside power source and can be carried in a pocket. The computer program resides as "Software as a Service," and is thus extremely economical to distribute for world-wide data collection with relatively little effort. No unique or special equipment needs to be purchased. Data collection is automatic, error-free, and can be transmitted over the internet to the investigating entity.

The *CogSpeed* web app is simple and easy to use; the test is quickly and easily learned to a stable baseline after only a few practice tests. *CogSpeed* was not designed as a game. That is, once a stable baseline has been reached, the highest maximum score cannot be significantly improved upon. The score is only dependent on the subject's current state of cognitive processing ability.

The testing challenge uses only simple number and dot associations. Thus there is no special language requirement. It is culture-free and useable by anyone in any country in the world, or anywhere at sea, or in the air. Figure 2 shows the number-dot associations to be learned for the *CogSpeed* test.

Taking the actual *CogSpeed* test is quick, usually lasting under two minutes, so it won't cause a major disruption to on-going activities or significantly interfere with work schedules. However, the user must be able to safely devote their full attention while taking the test.

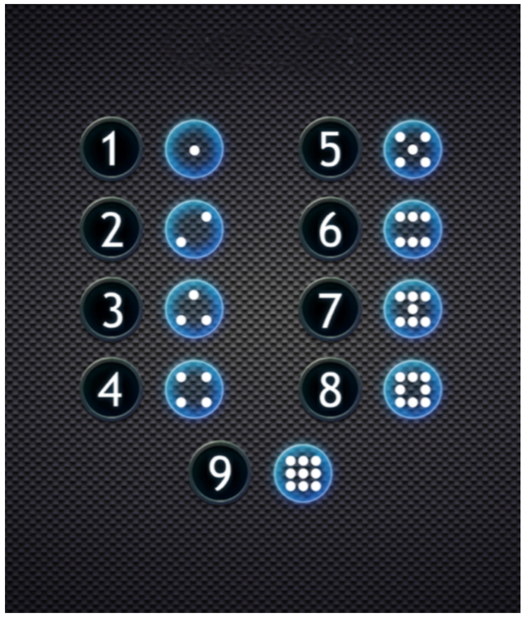


Figure 2. Number-dot associations to be learned for the *CogSpeed* Test

The *CogSpeed* test also has the following benefits and human factors features incorporated into its design:

The Display has large, easily readable text and can be used in low light conditions. Figure 3 presents a sample *CogSpeed* Test Display.

Figure 3. A sample *Cogspeed* test Display

The test doesn't use sound, thus there is no hearing requirement, and can be used in noisy environments.

The test operation is silent so as not to disturb anyone around.

The test doesn't rely on colors, thus it doesn't require color vision.

The subject can use their smart phone alarms to remind them of when to take the test.

The app allow subjects to record their estimated sleep duration and quality, and Samn-Perelli Fatigue score.

The sophisticated adaptive computer testing algorithms detect random inputs, faking, cheating, and spoofing.

There are no "false starts." *CogSpeed* can tell if you are distracted, not paying full attention, or just responding randomly. *CogSpeed* can't be fooled by guessing. The test automatically requires retesting if an anomaly is detected, and can automatically report improper testing behavior to a monitoring agency.

The entire results for each *CogSpeed* test, including user id, location, date and time of test, estimated sleep duration and quality, and Samn-Perelli Fatigue score, all response times, displays presented, and user responses (whether correct or not), test products, and final scores are recorded internally by the smart phone.

If desired, all or part of this data can be transmitted immediately to a research organization for evaluation.

The electronic data can be entered into a spread sheet or data base for statistical analysis and comparison with other measures. Scores can be tabulated and/or graphed over days, weeks, and months to analyze long-term increases and decreases in cognitive performance by time of day.

The geo-location of the device is recorded to identify the exact place where the test was taken. This feature can be of use if a hazardous condition has to be addressed. Real time cognitive performance capability for operators throughout the world could be displayed on electronic maps.

To improve accuracy and reliability, each *CogSpeed* test continues until two consecutive scores are within an acceptable tolerance before reporting the final score. The subject is unaware they are being retested.

The entire test procedure normally takes two minutes or less to arrive at the single performance score, including re-verification.

Utilizing high-speed computer operations, there is no pause between scoring, analyzing, and storing response accuracy and time, or creating randomized displays and instantaneously presenting them at appropriately modified rates.

Rates are increased or decreased depending on the subject's performance.
The computer is hunting for the fastest presentation rate the subject can reliably and accurately respond to.

Reaction time responses and display rates are measured to within one millisecond.

> Results are available to the user immediately. Scores can also be transmitted instantly to any number of third parties by e-mail.
>
> *CogSpeed* is password protected at login. All data and personal information are stored using SSL security to prevent tampering and resist legal challenges. To increase data integrity, the correct user is taking the test, the app could be modified to include facial recognition while taking the test.
>
> *CogSpeed* scores are not considered medical data, and therefore do not require HIPPA-level data protection.

In summary, *CogSpeed* has been purposely designed for ease of use by anyone in the field, under any environmental conditions. Any future attempts at developing similar measurement devices should consider these features and how to make the test faster to complete, easier to learn, and more accurate.

Open Use of *CogSpeed*

A functioning version of *CogSpeed* is available for examination on the web. Just as with the Samn-Perelli Fatigue Scale, this version of *CogSpeed* is free of charge for personal use and for any non-commercial research.

Researchers are encouraged to incorporate *CogSpeed* as an adjunct with their on-going studies to assist in demonstrating its validity and reliability, establishing testing methodologies, and producing age-related baselines. Its use in on-going research will help identify any modifications that would make it more effective.

Requests for more information, such as how to set up directed data transmission, transmit e-mail scores, create storage and retrieval procedures for scoring data, obtain passwords, or to adapt *CogSpeed* for use in a specific research study, contact Layne Perelli, PhD, owner of Gray Matter Metrics, LLC, at lperel@sbcglobal.net.

Licensing arrangements for rights to use *CogSpeed* in commercial settings can also be made through Gray Matter Metrics.

Practical and Commercial Applications of *CogSpeed*

A *CogSpeed* program to evaluate continual cognitive performance capability within a company can save money, reduce accidents, and save lives. *CogSpeed* is economical and can be used to obtain direct measurement of the cognitive fatigue levels of a company's world-wide workforce. Anyone involved in demanding, high-risk operations can be evaluated with minimal intrusion in their daily routines. Round-the-clock, ever-changing, or unusually long work schedules can be professionally evaluated for adverse impact on cognitive performance.

A company's use of *CogSpeed* can increase employee morale by demonstrating it is investing in the latest technology to protect their safety and the lives of the general public. By reducing its risk of accidents, the company may receive more favorable insurance rates. The *CogSpeed* program will improve a company's public image as an industry leader in workplace safety.

CogSpeed can be used to evaluate the effectiveness of safety programs designed to reduce operator fatigue. *CogSpeed* will create an historical data base that can be used to identify habitually low-scoring operators who need counseling. *CogSpeed* will provide a new class of actionable corporate analytics for evaluating operator reliability and improving business decisions.

CogSpeed can monitor any employees involved in stressful, critical, or tiring duties which require high levels of mental alertness. This could include assessing the mental fitness of air traffic controllers, security guards, night watchmen, power plant operators, oil field workers, the police force, firemen, emergency response teams, and many more.

There are also numerous opportunities for the general public to use *CogSpeed* to improve their personal well-being. An extensive description of these applications is at Appendix 2.

Summary

This paper attempts to point out the values that could be obtained from developing an objective measure of cognitive ability suitable for both laboratory and field use. *CogSpeed* or a similar technology could provide a significant benefit to society. *CogSpeed* has been described in detail to provide one example. It is hoped this paper has challenged behavioral and cognitive scientists and technology centers to explore the use of *CogSpeed*, or to create their own viable alternative.

Please provide comments to Layne Perelli, PhD, at lperel@sbcglobal.net .

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Appendix 1

The entire results for each *CogSpeed* test, including user id, location, date and time of test, all response times, every display presented, user responses (whether correct or not), test products, and final scores are recorded and stored internally by the testing device, ie a smart phone. If appropriate, that data can be transmitted electronically to a research organization for analysis. The test constants in the software program can be modified for research purposes to investigate scoring accuracy versus test administration time. An example of *CogSpeed* raw data output, along with the test constant settings for a particular test subject is provided below.

statusCode = 0
status = success
success = true
message = Test completed successfully
testDuration = 34874
numberOfRounds = 34
blockingRoundDuration = 1023
cognitiveProcessingIndex = 71
machinePacedBaseline = 1236.8333333333333
version = c40b147c6d3fb5ac1cead9b1c73cce73313bde70
fatigueLevel = 5
numberOfRollMeanLimitExceedences = 0
finalRatio = 1.2218963831867058
blockCount = 2
lowestBlockTime = 1013.2064389402666
highestBlockTime = 1032.6817346242356
blockRange = 19.475295683968966
finalBlockDiff = 19.475295683968966
totalMachinePacedAnswers = 23
totalMachinePacedCorrectAnswers = 13
totalMachinePacedIncorrectAnswers = 0
totalMachinePacedNoResponseAnswers = 10
quickestResponse = 967
quickestCorrectResponse = 967
slowestResponse = 1384
slowestCorrectResponse = 1384
meanMachinePacedAnswerTime = 1134.826086956522
meanCorrectMachinePacedAnswerTime = 1170.7692307692307
_date = 2024-03-19T19:08:12.580Z
_date_minute_offset = 300
_id = 4596a04e-f73a-4d1f-9efc-049a426f3fa1
geolocation = 29.381077207432597,-98.73601783703623
normalizedLocation = John D Ryan Boulevard, Blue Skies of Texas, Bexar County, Texas, 78252, United States
localDate = 3/19/2024
localTime = 2:08:12 PM

| Answer logs |
(Rm = rolling mean average)
Num	Type	Duration	Response	Status	Ratio	Rm	Query	Location	Clicked	Previous
1	0	-1	1429	correct	0	n/a	1dot	3	3	null
2	1	-1	1319	correct	0	n/a	5num	1	1	null
3	1	-1	1483	correct	0	n/a	9dot	3	3	null
4	1	-1	1148	correct	0	n/a	2dot	1	1	null
5	1	-1	1136	correct	0	n/a	8num	5	5	null
6	1	-1	1533	correct	0	n/a	7dot	6	6	null

7	1	-1	1402	correct	0	n/a	9num	1	1	null
8	2	1236.83	1217	correct	0.98	1	3num	4	4	null
9	2	1185.38	1187	no response	1	0.88	3dot	5	null	null
10	2	1185.38	1216	correct	1.03	1	2num	2	5	correct
11	2	1141.02	1117	correct	0.98	1	8num	5	5	null
12	2	1092.98	1083	correct	0.99	1	7dot	4	4	null
13	2	1048.26	1050	no response	1	0.88	4dot	3	null	null
14	2	1048.26	1117	correct	1.07	1	3dot	1	3	correct
15	2	1013.21	1014	no response	1	0.88	4num	6	null	null
16	2	1013.21	1015	no response	1	0.75	8num	5	null	null
17	3	1463.21	1872	correct	1.28	n/a	9num	1	1	null
18	3	1463.21	1100	correct	0.75	n/a	3dot	3	3	null
19	2	1463.21	1200	correct	0.82	1	2dot	5	5	null
20	2	1378.36	1218	correct	0.88	1	5num	4	4	null
21	2	1307.19	967	correct	0.74	1	9num	1	1	null
22	2	1220.88	1221	no response	1	0.88	9dot	6	null	null
23	2	1220.88	1233	correct	1.01	1	4dot	5	6	correct
24	2	1173.26	1175	no response	1	0.88	9dot	6	null	null
25	2	1173.26	1384	correct	1.18	1	5num	4	6	correct
26	2	1147.4	1051	correct	0.92	1	9num	6	6	null
27	2	1091.87	1094	no response	1	0.88	8dot	2	null	null
28	2	1091.87	1183	correct	1.08	1	2dot	5	2	correct
29	2	1057.3	1059	no response	1	0.88	5dot	6	null	null
30	2	1057.3	1234	correct	1.17	1	9dot	2	6	correct
31	2	1032.68	1033	no response	1	0.88	1num	5	null	null
32	2	1032.68	1033	no response	1	0.75	7num	1	null	null
33	5	1482.68	1884	correct	1.27	n/a	3dot	3	3	null
34	5	1482.68	1250	correct	0.84	n/a	3num	6	6	null

Appendix 2
Examples of Potential Commercial Applications and Practical Uses by the General Public for *CogSpeed*

Transportation Industries

CogSpeed could be used to determine when any workers in the transportation industry become too tired to continue working and constitute a danger to themself or others. Programs could be established for the trucking industry, airlines, railroads, maritime shipping and cruise lines, and bus and metro public transportation organizations. It would identify operators unfit for duty because of drug or alcohol abuse and those having consistently high levels of cognitive fatigue. Chronically fatigued operators could be identified as candidates for sleep hygiene counseling. *CogSpeed* may also be able to help companies identify operators prone to sleep apnea.

Companies can also conduct safety research to determine the patterns of onset of fatigue to identify particular routes that cause excessively high levels of fatigue and should be changed, and to evaluate the effectiveness of their programs to reduce driver fatigue. Data mining could extract a wealth of information built up from thousands of *CogSpeed* tests from all over the country, at all times of day and night.

A large corporation's safety headquarters could economically monitor and manage their workers' cognitive fitness levels throughout the world from a single location. Identifying specific individuals at risk in real time and taking immediate corrective action would protect both human and material resources.

Knowing a *CogSpeed* test is coming provides a strong incentive for the truck driver to show up for work well-rested. Operators would benefit because their health would be improved by getting better sleep before work, and they would be involved in fewer accidents. *CogSpeed* also could provide a reliable way for truck drivers to monitor their fatigue levels on their own. Family members would be reassured knowing that they are working in safer conditions.

CogSpeed could be installed in truck stops and travel centers to help all drivers understand what their fatigue levels are and when they should take a break.

CogSpeed can be used to determine if pilots and cabin attendants are able to perform their jobs safely and if they become a danger to themselves and others, to determine which crew members are most susceptible to cognitive fatigue, to determine which routes are the most physically demanding and tiring, and to maintain historical records of crew members' overall fatigue levels. *CogSpeed* provides a reliable way for pilots and flight attendants to monitor their fatigue levels on their own and provides strong incentive for them to show up for duty well-rested. *CogSpeed* can be used to identify chronically fatigued crew members so management can provide counseling.

In the maritime industry, *CogSpeed* can be used to determine the overall fitness of an entire ship's crew, determining if the seamen on a ship is able to perform watch duty safely or if they are becoming a danger to themselves and others. A *CogSpeed* program could maintain complete records of each ship's crew fatigue levels, from port to port, throughout the year. The company could clearly see which particular ships have more serious problems with crew fatigue, and reward officers who are able to maintain low levels of overall crew fatigue.

The corporate image of companies using a state-of-the-art *CogSpeed* monitoring program would benefit by demonstrating to the public that they take safety seriously and are trying to reduce accidents.

Organizations, travel agencies, schools, and church groups who hire private coaches, vans and charter buses may want an indicator to show if their drivers are fit to drive. By requiring drivers to take the *CogSpeed* test at various intervals throughout the trip, these groups would have peace of mind knowing that their drivers are well-rested and drug and alcohol free.

The Insurance Industry

A company using *CogSpeed* is demonstrating positive steps to reduce accidents and save lives, saving money for both the company and their insurer. Companies, especially those transporting hazardous cargo, can work with their insurers to get reduced rates for monitoring drivers' fitness in real time. The rate reduction could pay for the *CogSpeed* program.

In addition, insurance companies can use the real-time data collected by *CogSpeed* in their risk assessment models. They could adjust rates by having a better understanding the risks involved.

A Security Tool for Cognitive Risk Assessment

Currently, access to secure areas is limited to identity verification. But what if the person signing out a commercial vehicle or operating a critical computer system is extremely fatigued, or using drugs or alcohol? They may pass ID screening, but may be extremely fatigued. Modern security procedures need to assess cognitive "fitness for duty" along with identity verification. A successful *CogSpeed* test can provide the assurance at the point of entry and throughout a duty cycle at any time .

A wide range of high-value assets go unprotected from the threat of human error. There are countless examples of operators who should receive cognitive evaluation prior to receiving access authorization, such as truck drivers, mariners, pilots, engineers, nuclear control personnel, construction workers, power plant employees, refinery/oil field workers, security guards, medical staff, computer operators, emergency responders, and military troops, to name a few.

What if after access is granted, the person becomes too fatigued or takes a drug and is unable to function safely during their shift? Cognitive risk assessment needs to be done as often as necessary, at the job site, on the vehicle, anywhere. And then, management must be rapidly notified to take appropriate corrective action.

Sports Applications

After determining the sensitivity of *CogSpeed* to brain trauma and concussion effects, *CogSpeed* could be used in any sports venue to instantly assess the severity of blows to the head. The testing can be done at any time, especially during practice sessions when trainers and medical personnel may not be in attendance.

NOTE: *CogSpeed* is NOT a diagnostic test to make "return to play" decisions, but it does capture important information that can help speed the decision to obtain medical treatment. A "normal" *CogSpeed* score would not necessarily mean head injury did not occur. But a very low score would indicate the player should be prevented from returning to play and given immediate medical attention. The benefit of an objective assessment is that it can prompt coaches to take quick action and test results make them aware of the importance of taking potential brain trauma seriously.

In a typical assessment routine, players would provide a baseline score at the beginning of the activity, and be tested again whenever a severe blow to the head was suspected. In addition, because *CogSpeed* can be so easily and quickly administered, all players can be routinely retested at the end of the activity to help insure that no head injury went undetected.

Medical Support

It is important to understand that *CogSpeed* is NOT a medical device and does not produce medical data or diagnoses. However, the type of information concerning cognitive decrement it does provide can be useful to medical personnel.

As a neuropsychological test, *CogSpeed* can be used in a clinical context to quickly help evaluate the extent of cognitive performance decrement due to brain trauma. It could be used to assess impairment after an injury or illness known to affect neuro-cognitive functioning such as stroke, concussion, or senility. For patients with brain injury, *CogSpeed* can assist in tracking progress during rehabilitation.

Taking the *CogSpeed* test frequently also may provide therapeutic, measured cognitive stimulation to keep the brain active immediately after trauma.

CogSpeed can determine the baseline of a patient's pre-operation cognitive functioning to compare to post-operation functioning. It could also be used to track recovery from anesthesia.

CogSpeed can track the extent of the temporary detrimental cognitive effects of chemotherapy and assist in monitoring the patient's recovery from those effects, suggesting when a patient would be able to drive.

For in-home care or skilled nursing or assisted living facilities, *CogSpeed* can monitor the state and progress of senility, determine the extent of cognitive impairment caused by medication, and evaluate the overall energy level of residents.

CogSpeed can be used to obtain direct measurement of the cognitive fatigue levels of an entire hospital staff with minimal intrusiveness. The data can be collected with little interference to their daily routines. Cognitive processing abilities of doctors, interns, and nurses can be easily analyzed to determine when their workload or schedules are creating excessive cognitive fatigue levels which may impact the quality of care they provide.

This powerful information can lead to more effective management of the hospital's workforce and improve patient care by reducing treatment errors. The hospital administration's attention to the problems caused by cognitive fatigue levels will contribute to improving the staff's overall feelings of well-being and general health.

Government Applications

Here are just a few of the examples of potential uses.The military could use *CogSpeed* to evaluate a soldier, sailor, or airman's cognitive fitness for duty on long-duration missions and monitor their ability to perform combat duties effectively.

CogSpeed is an economical screening measure to detect decline in cognitive performance with age. As a screening test for fitness to drive, it could be used by each state's transportation department to determine if an applicant needs a thorough neurological examination before receiving a license.

The Federal Aviation Administration could monitor air traffic controllers for their cognitive alertness when they come on duty and throughout their shift.

Education

School administrators, counselors, and educators can determine their student body's overall "readiness to learn" on a daily basis. With an established baseline, they can identify students who are chronically fatigued, not getting enough sleep, or have other cognitive performance problems. Counselors can then interview them to find out the root cause of their problem and provide assistance.

As an added benefit, *CogSpeed* provides students an inexpensive, but sophisticated research tool for Science Fair experiments concerning cognitive functioning. Use in Science Fair projects could speed up formation of a baseline for the general population if tied to a unified database. *CogSpeed* could also be used for classroom demonstrations and student research projects.

Improving Personal Well-being

Because *CogSpeed* measures the effect of many different stressors on one's energy level and cognitive performance, it can be used for a wide variety of investigations by the general public. Here are some questions individuals could explore with *CogSpeed*:

Am I (or my children) getting enough sleep?
Are my children alert enough to perform well in school?
Am I too tired to continue driving on a long trip?
Have I recovered from time zone changes?
How does my energy level and cognitive processing speed fluctuate during the day and night, over a long period of time?
Should I consider a different work-rest schedule?
Is my shift work making me too tired to drive home?
Do my prescription drugs make me too drowsy to drive?
How seriously are medications or alcohol affecting my energy level or ability to concentrate?
At what time of the day am I most mentally alert? Am I a "morning" or "night" person?
Are my sleeping pills really effective in reducing my daily fatigue levels?
If I use marijuana, will it affect my cognitive performance, and possibly my driving?
How does my energy level and cognitive processing speed compare to others?
Do life style changes in diet or exercise improve my energy level or cognitive processing?
Do those energy drinks or vitamin supplements really improve my mental performance?
Do "brain training" exercises improve my mental ability?
Are these "mental exercise" tests really improving my cognitive performance? If so, how long does the effect last?
Am I, or someone I know, becoming unable to continue to drive safely?
How much has my cognitive fitness changed over time?

If someone is getting enough sleep, not using alcohol to excess, and not on medications known to cause drowsiness, yet are still tired all the time and produce poor *CogSpeed* scores, they may suffer from Chronic Fatigue Syndrome. In addition, persistent exhaustion can be a symptom of many underlying medical conditions. If chronic fatigue persists, accompanied by low *CogSpeed* scores, that should be an indication to seek the advice of a physician.

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