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Using Time Perception to Measure Fitness for Duty

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Assessing fitness for duty (FFD) typically requires expensive equipment and large time windows. Here we capitalize on basic principles of human time perception to build a portable software package that can quickly and efficiently test for excessive fatigue or traumatic brain injury. Time perception involves a collaboration of many brain areas, and we hypothesize that generalized damage to the brain can be rapidly assessed by subtle disorders in simple timing tasks. We aim to produce an inexpensive, portable device for rapid detection of fatigue or brain injury both in the clinic and on the field.

Medical residents, pilots, soldiers, truck drivers, and others frequently work long shifts, which leads to sleep deprivation. Excessive sleep deprivation leads to poor decision-making, which in turn may result in avoidable accidents (Rigaud & Flynn, 1995). Currently, the main method for assessing fitness for duty (FFD) is to measure brain activity using electroencephalography (Caldwell, Prazinko, & Caldwell, 2003). Unfortunately, these EEG methods have limited usefulness because they require expensive equipment and large time windows and are generally not well received by subjects.

As a new method to rapidly measure FFD, we are leveraging basic principles of the human visual system (Eagleman, 2001) to build a light, portable apparatus that can be used to quickly and efficiently test fatigue. The recorded data are immediately available so that those unfit for duty may be temporarily relieved.

Timing is necessary for behaviors as diverse as walking, driving, speaking, and
Q1 interpreting the barrage of input at sensory receptors (Eagleman, in press; Eagleman et al., 2005). The surprise about time perception is its unexpected plasticity.

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We and others have shown that durations can be distorted during rapid eye movements (Eagleman, 2005; Morrone, Ross, & Burr, 2005), after watching a flickering light (Kanai, Paffen, Hogendoorn, & Verstraten, 2006), or simply when an "oddball" is seen in a stream of repeated images (Tse, Intriligator, Rivest, & Cavanagh, 2004; Ulrich, Nitschke, & Rammsayer, 2006; Pariyadath & Eagleman, 2007). If we inject a slight delay between a subject's motor acts and sensory feedback, we can subsequently make the temporal order of their actions and sensations appear to reverse (Stetson, Cui, Montague, & Eagleman, 2006). Simultaneity judgments can be shifted by repeated exposure to nonsimultaneous stimuli (Fujisaki, Shimojo, Kashino, & Nishida, 2004).

In the laboratory of the natural world, distortions in timing are induced by narcotics such as cocaine and marijuana (Meck, 1996) or by disorders such as Parkinson's disease (Artieda, Pastor, Lacruz, & Obeso, 1992; Riesen & Schnider, 2001), Alzheimer's disease (Curran, Wilson, Musa, & Wattis, 2004), and schizophrenia (Black, Franklin, de Silva, & Wijewickrama, 1975; Elvevag et al., 2003; Gandhi, Pariyadath, Wassef, & Eagleman, 2007). Generally speaking, time perception always worsens with damage to the brain; it never improves. This is perhaps not surprising, given that time perception is not localized to a particular spot in the brain (the way, for example, color vision or the perception of a particular pitch is) but is instead distributed in a more global fashion. This distribution of function is not surprising, given that time perception is "metasensory," meaning that one can estimate 2 seconds using a tone, a light, a touch, and so on—in other words, time is a perception that transcends the details of the other senses.

These considerations have led us toward exploring how several aspects of time perception change when the brain sustains traumatic damage. To this end, my laboratory has developed a software suite (the Texas Temporal Battery) that rapidly measures several aspects of time perception in humans. Our program consists of three tests invented in our laboratory. The tests collectively quantify seven different measures of the brain's functioning in the time domain. The battery is designed to measure not only fitness for duty but also to catch signs of early traumatic brain injury (TBI). Below we briefly outline the three tasks and their purposes.

SPEED OF DISTINGUISHING ALTERNATING IMAGES

When two stimuli are delivered within tens of milliseconds, they will perceptually overlap as though they were presented simultaneously. For instance, if we rapidly alternate an image and its negative, they will fuse such that the image is impossible to perceive. However, if the two stimuli are flashed more slowly, they are easily readable. The duration below which two separate events will be interpreted as simultaneous is known as the *window of simultaneity*. Under conditions of fatigue or injury, the window of simultaneity may lengthen. This hypothesis is based on such lengthening generally seen under conditions of reduced arousal or integrity of the central nervous system, measured using the technique of flicker fusion (Curran & Wattis, 2000). Flicker fusion is a simple technique but requires special equipment and expertise to administer. Our software (Figure 1) tests the window of simultaneity rapidly, with no expertise required. With the software, we can measure whether one's fusion threshold is significantly different from normal (Stetson, Fiesta, & Eagleman, 2007), indicating abnormal brain function.

REACTION TIME, VETO TIME, CAUSALITY SENSITIVITY, AND TEMPORAL RECALIBRATION

The second test in the battery is a simple video game (Figure 2a) that allows us to measure (a) reaction time, (b) "veto time," (c) temporal sensitivity to causality, and (d) the amount and speed of temporal recalibration when a delay is injected into actions and sensory feedback (see Stetson et al., 2006, for more on the topic of temporal recalibration). When subjects click on the green square, it "jumps" to a new location. On sporadic, interleaved trials, the green square jumps at a random time just before the click; if the subject believes that the green square jumped before he clicked on it, he indicates this by pressing the space bar. This allows us to measure not only reaction time on regular trials but also "veto time"—how much time it takes for a subject to *not* click on a square if it has just jumped away on its own (for most subjects this is ~250 ms). Additionally, we can measure temporal sensitivity to causality: how long before your click did the green square need to jump for you to report that you were not responsible? Finally, in an "injected delay" condition, the green square jumps 200 ms after the subject's click. This allows us to measure the recalibration of causality judgments (most subjects recalibrate within about 10 trials, Figures 2b, 2c).

THE BRAIN'S TEMPORAL RESPONSE TO NOVELTY AND FAMILIARITY

To measure the brain's response to repetition, we have developed a novel modification to the traditional flicker fusion frequency paradigm. In flicker fusion experiments, a light is rapidly turned on and off: at a low frequency, flicker is perceived, whereas at a high frequency, the light appears to be steady. The frequency at which perception switches from flicker to a steady light is called the *critical flicker fusion threshold* (CFFT). We noted that CFFT experiments always consist of a single stimulus (the light) presented repeatedly. Because there are subjective duration differences when viewing familiar versus novel stimuli, we hypothesized that the

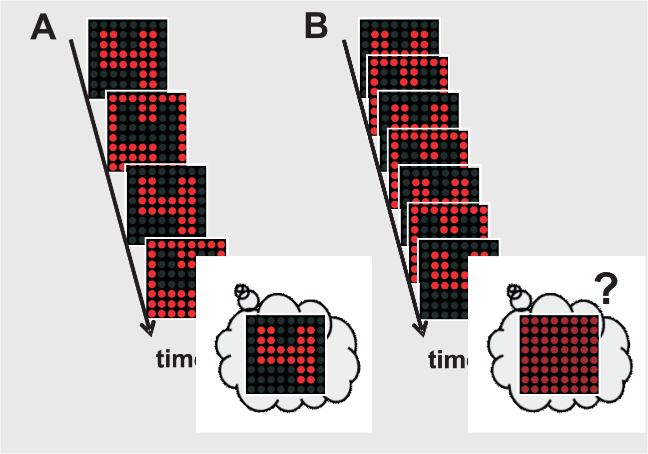

FIGURE 1 Using alternating images to measure the speed of alternation at which observers can report numbers. (a) When a digit is alternated slowly with its negative image, it is easy to identify. (b) As the rate of alternation increases, the patterns fuse into a uniform field, indistinguishable from any other digit and its negative (see Stetson et al., 2007).

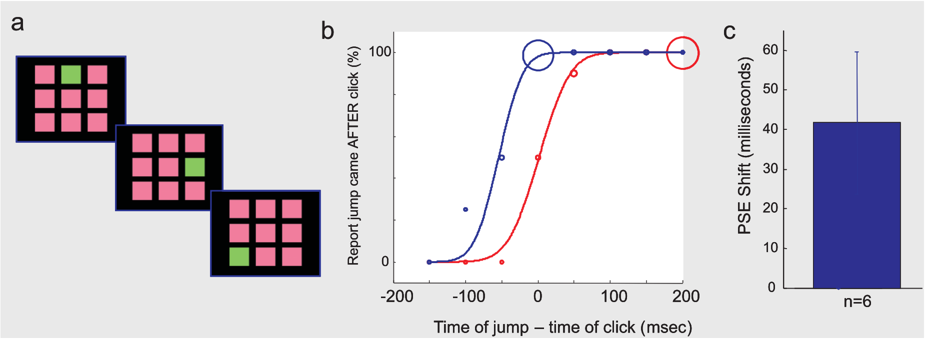

FIGURE 2 Measuring four aspects of timing and time perception using a simple video game. (a) The green square "jumps" to a new location each time it is clicked. On some trials it jumps just before being clicked, and subjects report when this occurred. (b) Representative data. The blue curve represents 0-ms delay block; the red curve represents 200-ms "injected delay" block. The shift in the point of subjective equivalence (PSE) was 56 ms. (c) Average recalibration (difference between red and blue curves) shift for 6 subjects.

CFFT will change if the rapid stimulus could be made novel each time it appeared. To this end, we developed a variation of the flicker fusion paradigm to study the differences in duration judgments for novel and familiar stimuli (Pariyadath & Q2 Eagleman, in press).

In this task, subjects fixate on a cross at the center of the screen. On each trial, stimuli are flashed one at a time in a randomized location. Perceptually, the rapidly presented stimulus does not map onto the physical reality because of visual persistence, the phenomenon that a briefly presented stimulus appears to last longer than the time it was physically presented: in general, stimuli < 100 ms in physical duration seem to last for ~100 ms (Di Lollo, 1977; Efron, 1970). Because of visual persistence, each stimulus in the presentation seems to last longer than presented and therefore the physically present stimulus is accompanied by the "ghosts" of stimuli that were presented recently. Thus, more than one character appears to temporally overlap on screen. We term the resulting multiplicity of stimuli as the *proliferation effect*.

We employed two conditions: in the first, the same stimulus was presented; in the second, different stimuli were presented (Figure 3a). Participants report the number of stimuli subjectively present on screen at any one moment of time; that is, how many characters appeared to share screen time. We have found that numerosity differs significantly between the repeated and random conditions (Figure 3b). The difference between the two conditions holds across different stimuli, including faces, objects, words, and pseudowords. These results are explained by a contraction in the visual persistence of repeated stimuli, leading to less temporal overlap and a reduced number of stimuli perceived to be simultaneously present. We have recently been testing the proliferation effect on patients with schizophrenia and have found that they show a very different signature, with no difference between repeated and random stimuli (Gandhi et al., 2007). We expect that damage to inhibitory networks in the brain—caused reversibly by excessive fatigue or permanently by TBI—will yield a similar diagnostic signature.

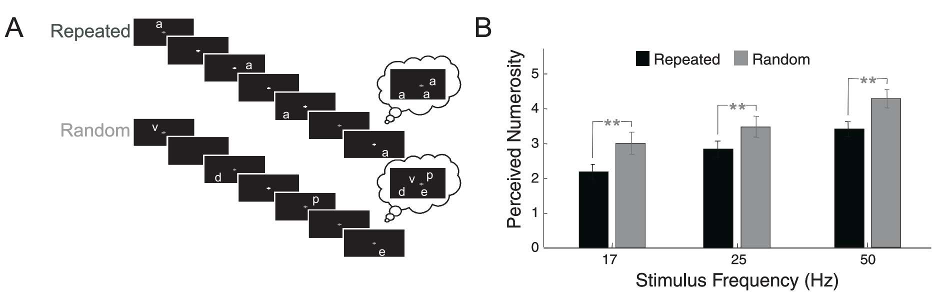

FIGURE 3 Measuring the brain's temporal responses: repeated stimuli subjectively proliferate less than random stimuli. (a) Example sequences of stimulus presentation and perceived numerosity for repeated and random stimuli. (b) Number of characters perceived to be present for repeated and random stimuli. Participants report more characters present on screen when the stimuli are different than when they are repeated ($n = 31$; error bars indicate *SEM*).

SUMMARY AND FUTURE DIRECTIONS

We have validated the above set of three tests using dozens of healthy controls and are now preparing to examine timing disorders that may accompany fatigue and TBI. For measures of fatigue, we have begun collecting preliminary data with West Point cadets and post-call medical residents in the Texas Medical Center in Houston. For measures of TBI, we are about to launch a large-scale study with hundreds of veterans returning from Iraq. Diagnostic sensitivity and accuracy of our tests will be determined by cross-correlating with several other tests from our colleagues as well as physician diagnoses in the case of TBI.

Looking toward the future of this research, we hope to reduce the computer software to a handheld device about the size of a cell phone. This would allow for easy use of this fitness for duty measure in field settings.

To our knowledge, there are no similarly rapid and portable FFD devices in use. Instead, to measure FFD, several companies have pursued EEG measurements. For example, Advanced Brain Monitoring Inc. and Alertness Monitoring Inc. (both of Carlsbad, California), have been developing drowsiness monitoring device prototypes for several years. ABM's drowsiness monitoring device is housed in a baseball cap and includes two electrodes that pick up EEG signals from the appropriate place on the scalp. EEG data are transmitted by radio frequency signals to a processor/analyzer located within 20 feet of the user. But the electrodes require a small amount of conductive gel, which makes the headgear even less appealing to potential users. Both companies have targeted the transportation industry as potential markets for their head-mounted sensors because of the risk of
Q3 traffic accidents caused by drowsy drivers. However, as reported on neurotechreports.com, "Both firms received a frosty reception from truck drivers and their unions who are not too eager to wear headgear, especially the type that makes management privy to their mental state." We hope that our portable, easy-to-use battery might overcome some of these social and technical limitations.

In summary, temporal measures are currently missing entirely from the clinical landscape, but we have good reason to believe they may provide a rapid, accurate, and inexpensive way to screen and identify excessive fatigue and/or traumatic brain injury. The temporal principles elucidated in our laboratory over the past year are being leveraged to build a novel, visual, noninvasive software test, opening the door for the first time to rapid screening both in the clinic and on the field. If our expectations are met, the Texas Temporal Battery will serve as an inexpensive and highly useful diagnostic tool.

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