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Our goal is a speech monitoring system that will automatically and unobtrusively monitor the effects of stress and neurological impairment on astronauts' ability to perform in extended deep-space missions. The project establishes a synergy between a space-analog study of climbers ascending Mount Everest, who experience stress and neural dysfunction similar to that from exposure to cosmic rays, and laboratory studies of task-induced stress. Our proposed system will detect changes before performance is severely impaired, giving crews time to invoke countermeasures. Because the system's acoustic measures are largely outside of conscious control, crewmembers will not be able to improve with practice or "fool" the system. It will protect privacy and mission security because it does not depend on the content of speech, only its acoustics.
Task induced stress and cognitive overload. In the past year, working with David Dinges's NSBRI-funded group at the University of Pennsylvania, we validated robust acoustic measures that track task-induced stress. We measured the

duration of the utterances and pauses of the spoken responses made by Dinges's subjects while performing mental arithmetic exercises that varied in difficulty. These acoustic parameters reflect the rate at which the subjects performed the task. We also measured the fundamental frequency of phonation (F0), which reflects the pitch of the subjects' voices. Utterance and pause durations discriminated the high and low-stress conditions for the 24 subjects measured with total certainty. Mean and maximum F0 and F0 range were significantly greater in the high-stress condition for 23 of the 24 subjects. The subjects all performed the tests on two different days. The acoustic parameters identified subjects who appear to have been sleep deprived when they performed the arithmetic tests the second time.

Task Description:

Exposure to cosmic rays. We also advanced research on speech and cognition in climbers on Everest. Deep-space missions will expose crews to cosmic rays, which may damage the brain, especially the basal ganglia and hippocampus. These subcortical brain structures are also vulnerable to hypoxia (oxygen deprivation) at the extreme altitudes on Everest. Thus we use climbers on Everest as models for crews in space. Everest also resembles long-term spaceflight in that a small group in close contact must make critical decisions in life-threatening situations. The research is ethical because subjects willfully expose themselves to the dangers of climbing Everest. The basal ganglia are linked with cortical regions in circuits regulating motor control, cognition and personality. A major function of the basal ganglia is regulating sequences of motor acts and cognitive operations; previous studies show impairment of motor control as well as cognitive abilities that require processing sequences, such as sentence comprehension and set-shifting.

Basal ganglia dysfunction slows speech down and impairs sequential speech motor acts such as the production of voice-onset time (VOT). VOT is the time for word-initial stop consonants, between the noise "burst" when an oral tract closure (e.g., the lips for [b] or [p]) is opened and the onset of the vowel. VOTs for voiced stops like [b] are usually shorter than 20 msec, much less than those for voiceless stops like [p]. These acoustic speech parameters in our Everest study correlate with cognitive set shifting deficits that translate into an inability to change plans when circumstances dictate, as well as slowing down the ability to comprehend the meaning of sentences. VOT ranges converge and speech slows down. We obtain speech measurements by using radios and PDAs recording climbers reading words at different altitudes. We give the Wisconsin Card Sorting Task, which requires subjects to sort stimuli using different criteria and to shift criteria. We administer sentence-picture matching tests of language comprehension. Climbers also use the PDAs to take tests of verbal and special working memory and choice reaction time on the system, developed by Stephen Kosslyn's NSBRI research group at Harvard. We added an implicit memory test reflecting hippocampal function to the PDA test battery. Our recent Everest results show that we can track impairment on sentence comprehension and set-shifting using acoustic measures of speech rate similar to that used for task-induced stress, achieving a "hit " rate of 81% by noting instances of slow speech. VOT convergence adds to the certainty of the speech monitoring technique for some subjects.

These findings set the stage for an operational system. Normative data for individual astronauts can be obtained before flight, permitting adjustment to individual speaking rates and VOTs. Our techniques have already been used to evaluate new treatments for Parkinson's disease and have potential for detecting early Alzheimer's disease. Similar techniques could be used in general aviation, where hypoxia has led to disasters. We are applying the techniques to assess verbal apraxia, a disorder affecting language and cognition in children, with the aim of isolating genetic anomalies underlying this condition. Moreover, our techniques have more general applications in detecting sleep-deprivation, monitoring stress in occupations like air traffic control, pacing computer-implemented instruction to meet individual cognitive capabilities. There also are possible forensic applications in assessing the truthfulness of statements since dissimulation generally requires greater mental effort with concomitant slower speech.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

The techniques we are developing for unobtrusively monitoring cognitive status and stress via automated measurement of speech parameters have applications in general aviation. Systems based on these techniques could be used to monitor air crews for gradual effects of partial or slow failure of aircraft pressurization systems. The hypoxia resulting from such depressurization – which degrades cognitive function so that crew members not only are unable to perform their tasks but fail to notice their own impairment – has led to flight disasters in the past. Speech-based systems could monitor both motor and cognitive dysfunction resulting from stress and sleep deprivation in occupations ranging from air traffic controllers to truck drivers.
Our project's techniques have already been used to assess the efficacy of new surgical procedures for the treatment of Parkinson's disease. They may also provide instruments that can detect memory loss in the early stages of Alzheimer's disease. Such early detection would permit clinicians to take maximal advantage of therapies that can delay or even arrest further decline. Our techniques may have application to the diagnosis, assessment, and treatment of other human pathologies stemming from impaired basal ganglia function in neural circuits regulating speech production, cognition and personality. These include not only neurodegenerative diseases but also the results of acute insult. For example, hypoxia during birth can lead to verbal apraxia in children – a syndrome where speech motor and orofacial motor control is degraded and which can result in cognitive and linguistic deficits. In a pilot study we have already applied our techniques to the diagnosis of verbal apraxia; we aim to use results of this research in isolating potential genetic anomalies underlying the condition.

Another area is stress analysis and the assessing the truthfulness of verbal statements. Dissimulation generally involves greater cognitive effort, activating more brain structures that would be the case for truthful statements. This yields slower speech which we can readily detect. Similar measures of utterance duration and pauses can be used to pace computer-aided instruction, adjusting the presentation of information to an individual's cognitive ability.

We have directed our attention towards a space-capable system monitoring both cognitive deficits deriving from cosmic-ray induced brain dysfunction and cognitive load. Acoustic measures of slow speech can be used to monitor cognitive impairment induced by hypoxic and cosmic-ray induced insult to the brain, as well as degraded cognitive performance resulting from task-induced stress. These finding facilitate system development since acoustic measures quantifying slow speech can be more readily automatized than other parameters.
Hypoxic cognitive dysfunction

As in previous years, as our climber-subjects ascended Mount Everest cognitive performance was impaired to varying degrees in different individuals. Set shifting error rates on the Wisconsin Card Sorting Test (WCST) tended to increase. WCST performance translates to the ability to adjust to change plans as circumstances change. It generally took longer to

Task Progress:	comprehend the meanings of sentences. The rate at which the subjects talked slowed down, quantified by longer vowel durations. Slowdowns in sentence comprehension or degraded WCST performance co-occurred with increases in vowel duration 91% of the time. A system that used increased vowel duration to monitor these cognitive deficits would have had a 91% “hit” rate and a 3% miss rate. Increased vowel duration would have yielded a 6%"false alarm” rate (increases in vowel duration that were not concomitant with cognitive impairment). Other acoustic parameters, such as voice-onset-time, the fundamental frequency of phonation (F0), and rapid F0 fluctuations, “jitter,” increase the accuracy of voice monitoring of cognitive impairment. Task-induced stress In a laboratory experiment in which subjects had to perform both an easy and a difficult mental arithmetic task, the duration of their spoken responses and pause durations tracked cognitive difficulties 100 % of the time. All 24 subjects spoke more slowly when they had to perform the more difficult task. Slower speech also appears to be a means of identifying those subjects who were sleep deprived. Algorithms for a space-capable system We are developing algorithms to automatically derive acoustic measures of slow speech. Our goal is a speech monitoring system suitable for space-flight that will provide astronauts and ground-control with timely warnings of brain dysfunction before profound disability occurs and that will assess the crews’ ability to perform. Earthbound application A pilot study of nine children having verbal apraxia (speech motor sequencing difficulties) shows an additional earthbound application. Our findings show that they have cognitive deficits similar in nature to hypoxic Everest climbers that appear to derive from damage to neural circuits involving basal ganglia. Clinical studies show damage to the basal ganglia in many of these children owing to difficult births in which oxygen flow was interrupted.
Bibliography Type:	Description: (Last Updated: 02/27/2014)
Articles in Peer-reviewed Journals	Hochstadt J, Nakano H, Lieberman P, Friedman J. "The Roles of Sequencing and Verbal Working Memory in Sentence Comprehension Deficits in Parkinson's Disease." Brain and Language, in press, June 2006. , Jun-2006
Articles in Peer-reviewed Journals	Lieberman P. "On the evolution of human speech: Its anatomical and neural bases." Current Anthropology. In Press, June 2006. , Jun-2006
Awards	Lieberman P. "Invited speaker at the International Morris Symposium on the Evolution of Language held at the State University of New York at Stony Brook, October 2005." Oct-2005
Books/Book Chapters	Lieberman P. "Toward an evolutionary biology of language." Cambridge, Mass. : Harvard University Press, 2006., Jun-2006
Books/Book Chapters	Lieberman P. "The FOXP2 gene, human cognition and language." in "Integrative approaches to human health and evolution : proceedings of the International Symposium: Integrative Approaches to Human and Evolution held in Madrid, Spain, between 18 and 20, April 2005." Ed. T. C. Brommage, E. Aguirre and A. Perez-Ochoa. Amsterdam ; San Diego, Calif. : Elsevier, 2006. (International Congress Series, vol. 1296). http://dx.doi.org/10.1016/j.ics.2006.03.039 , Jun-2006