EMULATING A CARBON DIOXIDE TRIGGER FOR THE FEAR RESPONSE

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INTRODUCTION

Breathing excess carbon dioxide can provoke the mammalian fear response, in particular the dread of smothering. This effect is mediated by pH changes which carbonic acid produces on brain *acid sensing ion channels* (ASIC). In this paper, the author extends his computerized human nervous system function emulation (HNSFE) technology to exhibit the effects of inhaled carbon dioxide on imitation ASIC receptors, thereby triggering hyperventilation, adrenalin release, simulated fear memories and avoidant behavior.

Chemistry

Carbon dioxide (CO_2) is a byproduct of animal and plant respiration, organic decay, forest fires, volcanoes and human activity. The average CO_2 concentration in air is 387 parts per million (ppm); it is 1.5 times denser than air. CO_2 dissolved in water forms carbonic acid (H_2CO_3), shifting to an acidic pH. Some carbonic acid in the body is converted to bicarbonate (HCO_3^-) by removal of hydrogen ions (H^+); H^+ is eliminated by the kidneys. Bicarbonate helps buffer the pH of the blood and tissues to 7.4. CO_2 is expelled by the lungs. High CO_2 in breathed air, or with pulmonary and/or renal disorders, can be toxic [1]. The partial pressure of CO_2 in arterial blood ($PaCO_2$) is about 40 mmHg; severe hypercapnia (high $PaCO_2$) begins around 75 mmHg.

Brain Anatomy and Physiology

The amygdala are almond-shaped paired organs located in the medial aspect of the temporal lobes of the brain, close to each hippocampus. The amygdala, part of the limbic system, store and recall emotionally-charged memories. Impulses from the amygdala travel through the hypothalamus to reach the sympathetic nervous system and to other areas of the brainstem. Some effects of activation of the limbic system include triggering of fear memories, epinephrine release from the adrenal glands, and fight-or-flight behavior [2].

Neurons in the amygdala are rich in ASIC type 1a receptors, making them effective low-pH hydrogen ion sensors [3-4]. Acidosis upsets membrane calcium ion activity, inhibits the sodium-potassium pump, and makes zinc ions much more toxic to neurons [5].

MATERIALS AND METHODS

Human Nervous System Function Emulator

At the 2009 CMBES the author described in great detail his HNSFE, which imitates the biochemical-neural-cognitive operations of the human brain [6]. The HNSFE is the artificial intelligence portion of the Robot Control System (RCS) the author created to operate his meter-tall *ANNIE* robot ("Android with Neural Network, Intellect and Emotions"). Briefly, the RCS is based on a multitasking Forth language program derived from IEEE 1275-1994, a plug-and-play system originally used for IBM, Sun and Apple workstations and personal computers. The author calls the original RCS "*ANDROID.FORTH*" or *AF* [7]. AF runs on an Intel x86-based PC/104 bus multiprocessor network enhanced with 8-core 32-bit CPUs, analog circuits to support an artificial neural network visual subsystem and synthetic emotions, and cellular membrane substrate-receptor binding activity simulations.

AF contains a dictionary-like English-language knowledge base file of everything *ANNIE* knows (up to 32,000 items); a personality description file; a long-term memory file; a schema system for artificial intelligence, containing sensory recognition cues and activity scripts for behavioral responses [8]; and a meta-file to accommodate the object clusters found in situational fear learning. Short-term memory is located in RAM on the CPU board. The author calls this much-extended version of AF "*BRAIN.FORTH*" or *BF* [9].

The knowledge file contains basic emotion cues for each item known, as signed 8-bit numbers with positive and negative values, such as *regard* (Figure 1, left). The meta-file clusters can modify these item values to produce new behavioral responses such as *evasion* (Figure 1, right) [10].

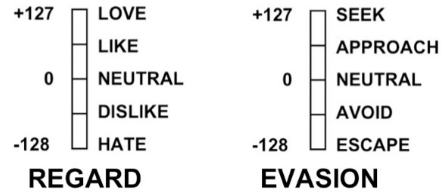

Figure 1: HNSFE item emotional / behavioral scales.

ASIC Emulation

The ASIC function is represented by a commercial CO_2 sensor (Figure 2) which responds to varying concentrations of carbon dioxide gas in air [11]. These sensors are available from several vendors [12]. The sensor used by the author employs a solid state electrolyte which is warmed by an integral heater. A lithium (Li^+) electrolyte absorbs CO_2 from the gaseous sample, forming lithium carbonate (Li_2CO_3), and producing a weak current (Figure 3). The Li_2CO_3 is recycled by sodium ions (Na^+) in the electrolyte, releasing trapped CO_2 gas and regenerating Li^+ ions.

Figure 2: Commercial CO_2 Sensor

The sensor is buffered by an operational amplifier (op-amp) per the manufacturer's data sheet and read by an 8-bit analog-to-digital converter (A/D). The sensor's response is semi-logarithmic between 400 to 10,000 ppm of CO_2 in test gas samples (Figure 3).

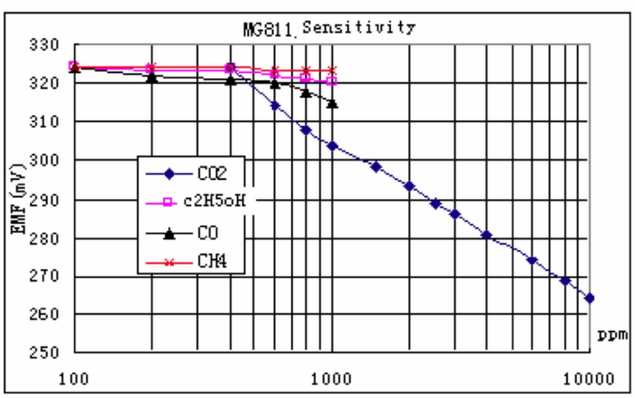

Figure 3: Sensor Response Curve (Manufacturer Data).

This sensor's minimum reading is 400 ppm CO_2, which is about 3.4% above the level in ambient air under standard conditions. This gas concentration produces a $PaCO_2$ in test animals of 40 mmHg.

Test Apparatus

The test apparatus consisted of a screw-top bottle with two gas ports, gas sensor electronics and a small electric fan in the cap (Figure 4). Precise amounts of pure CO2 gas was injected into the bottle via medical syringes. The inlet gas port tube was sealed by the CO_2 syringe; the outlet gas port had a water seal. The bottle was previously purged with nitrogen (N_2). The interior volume of the apparatus was set to 333 ml by adding an inert material (sand), making tests in ppm-CO_2 easy to achieve. For example, injecting 1 ml of CO_2 gas into the bottle yielded a final concentration of 0.3% or 3000 ppm. CO_2 and N_2 are readily available.

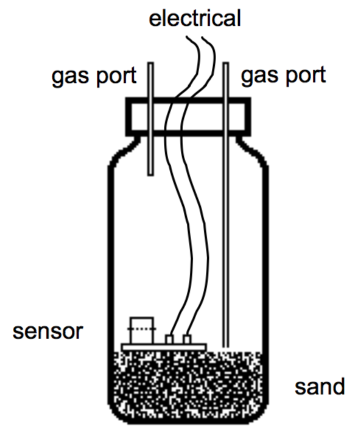

Figure 4: CO_2 Test Apparatus

RESULTS

Major effects of acute hypercapnia (blood gas CO_2 level above 45 mmHg, CO_2 concentration in air > 450 ppm) are listed below in Table 1 [13-14].

Table 1: Symptoms of High CO_2 Concentration in Air

CO_2 concentration	**Clinical symptoms**
1% = 10,000 ppm	drowsiness
2% = 20,000 ppm	awareness of dyspnea
3% = 30,000 ppm	breathing rate doubles pulse and BP increase narcosis begins hearing impaired
5% = 50,000 ppm	dizziness, headache breathing rate quadruples confusion, fear response adrenal epinephrine release attempt to escape
8% = 80,000 ppm	sweating, muscle tremor vision impaired unconsciousness, convulsions death

To reach the "fatal" 80,000 ppm level of CO_2 in the test apparatus, 26.7 ml of gas needed to be injected.

Note that this level exceeds the manufacturer's sensor response curve, which stops at 10,000. Nevertheless, this sensor can be used to 80,000 ppm CO_2 but with decreased output linearity / accuracy. At 80,000 ppm the sensor EMF output is about 225 mV. An alternative is to use Figaro's CDM4160-H00 pre-calibrated sensor module, whose accuracy is guaranteed to 45,000 ppm and which can be moderately over-driven to 80,000.

The buffered CO_2 sensor output is gain-amplified, inverted and offset so the 8-bit A/D converter reads from 0-200 full scale, where the number 1 represents 400 ppm (0.04%), 25 is 10,000 ppm (1%) and 200 represents 80,000 ppm (8%), referring to Table 1.

The A/D output was connected to the appropriate simulation units within the HNSFE, including those for: pulse rate, respiration, blood pressure, perspiration, dyspnea, muscle tremor / convulsions, auditory and visual acuity, consciousness, and overall life process. For example, when the A/D number matched 25 the consciousness simulation began to be progressively degraded; 75 was threshold for increased BP / pulse / respiration rates; 125 or higher triggered the simulated epinephrine release, fear responses and attempted escape scripts; and 200 lead to loss of consciousness, tonic-clonic seizures and cessation of life functions. All of these gas-toxic side effects can be monitored from the HNSFE control console as they occur. The exact A/D threshold variables and response scripts can also be modified from the console while the emulator runs.

DISCUSSION

As mentioned above, the HNSFE is the artificial intelligence portion of a full robot control system. If the above CO_2 sensor / trigger mechanism in the HNSFE were then attached to the *ANNIE* robot, one could see these responses exhibited just as they would in a live human subject under the same conditions.

In a robotic application, the CO_2 sensor would be appropriately located within the simulated respiratory system (nasal or pharyngeal cavity or thorax). In this position, the sensor would be able to rapidly respond to changes in gas levels as the robot "breathed".

Note that commercial sensors are also available for the following important gases: carbon monoxide (CO), methane (CH_4), liquid petroleum gas, ammonia (NH_3), hydrogen (H), hydrogen sulfide (H_2S), oxygen (O_2), water vapor, alcohols, halogenated refrigerants, gasoline and diesel fuel. Humans can sense many of these chemicals directly (for example, the odors of NH_3, H_2S, alcohols and fuels), or respond to their presence in other ways (i.e.: smothering or poisoning).

Combining this technology with other kinds of sensors, such as: infrared light / thermal, ultraviolet light (UVL), magnetic, pressure, nuclear radiation, and so on [15] in an anthropoid human or simian robot [16], would produce a most helpful companion in human-inhabited surface, maritime, aerospace and military environments, where safety issues are common, and where the mobile humanoid robot form factor would facilitate improved hazard analysis and remediation.

CONCLUSION

This HNSFE with its elementary CO_2 gas sensor produced realistic emulated hypercapnia reactions which ranged from increased ASIC neural membrane activity through fearful emotional responses and finally to complex avoidant behavior. This technology is of interest not only as a scientific exercise, but also from the vantage point of numerous practical applications.

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