Breathing Carbon Dioxide (4% for 1-Hour) Slows Response Selection, Not Stimulus Encoding

Max Vercruyssen

Hawaii Academy, Longitudinal Research and Statistical Modeling
University of Hawaii, Educational Psychology

This experiment sought to determine whether breathing carbon dioxide (CO_2), a toxic environmental stressor known to impair reaction time, slows human information processing in the stimulus encoding or response selection stage, or both, and whether this effect is influenced by time-on-task and exposure duration. In a 2 X 2 X 2 X 4 (Gas X Degradation X Compatibility X Time-on-Task) within-participants design, six highly practiced (more than 10,000 trials) healthy young male participants performed a serial choice reaction time (SCRT) task while breathing either 4% CO_2 (with 50% O_2) or room air (0.03% CO_2 and 21% O_2) for 60 minutes. Task variables manipulated were stimulus degradation (intact vs. degraded) and stimulus-response compatibility (high vs. low). Data from each 20-min SCRT test were subdivided into 5-min and 2-min intervals to determine the effects of time-on-task (and exposure duration). There were significant increases in SCRT from breathing carbon dioxide ($p = .004$), degrading the stimulus ($p < .001$), lowering compatibility ($p = .004$), and increasing time-on-task ($p = .020$). Lowering compatibility served to exaggerate the impairment produced by carbon dioxide inhalation ($p = .038$). Time-on-task (and exposure duration), however, did not interact with gas, degradation, or compatibility. Thus, SCRT, analyzed according to the Additive Factors Method (Sternberg, 1969, 1998), (1) was sensitive to the degrading effects of breathing CO_2 at an undetectable concentration that did not produce clinical symptoms, (2) determined the locus of this effect was associated with the response selection stage of processing, (3) demonstrated that the progressive deterioration in performance due to increases in time-on-task (and exposure duration) affects both the stimulus encoding and response selection stages in a similar manner, and (4) ruled out alternative explanations by showing the results did not vary with distribution analyses, data trimming, error analyses, and analyses for tradeoffs of speed-accuracy, SCRT-DT, and other performance operating characteristics.

INTRODUCTION

The effects of stressors on one's ability to respond both physically and mentally to events in the environment are of interest to many, especially those who must perform their assigned tasks in extreme or hazardous conditions where less than optimal reactions jeopardize personal health and safety. It is of theoretical interest to determine the stage(s) of information processing disrupted by environmental stressors.

Previous research (e.g., Vercruyssen, 1984a; Vercruyssen & Kamon, 1984; Vercruyssen, Kamon, & Hancock, 2007) has shown that (1) breathing 4% CO_2 for 60 minutes is above the maximum allowable concentration for most closed circuit self-contained breathing systems (CC-SCBAs) but it does not produce clinical symptoms and is undetectable; (2) reactive processes are susceptible to performance degradation from breathing CO_2; (3) stimulus encoding and/or response selection are processing stages suspected to be affected by and sensitive to the inhalation of this toxic gas; (4) the serial choice reaction time (SCRT) task is known to be highly sensitive to the effects of environmental stressors on performance; and (5) the Additive Factors Method (AFM; see Sternberg, 1969, 1984, 1998, 2001, 2011, 2013) has demonstrated the ability to identify the stage(s) of processing (e.g., stimulus encoding versus response selection) affected by the stressor (e.g., Sanders, 1980, 1983, 1990, 1998). Therefore, this experiment was undertaken to ascertain whether breathing an elevated but subclinical and undetectable concentration of carbon dioxide (4% CO_2 with 50% O_2) slows information processing (as measured by serial choice reaction time) by impairing either stimulus encoding or response selection, or both. Of secondary interest was determining if the stressor effects vary with time-on-task (and duration of exposure). Also of interest were stressor effects on clinical symptoms and whether results for all dependent measures varied when using the statistical procedures of data trimming, distribution analyses, and performance operating characteristics. Figure 1 illustrates the stressor and task variables as they might affect stages of information processing.

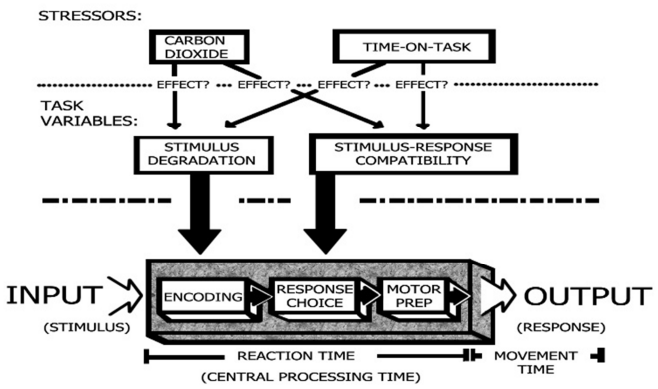

Figure 1. Effects of stressors on stages of processing. Information flow diagram of the Additive Factors Model showing structural processing stages and corresponding variables in the reactive process. The purpose of this experiment was to determine which stage(s) were affected by the stressors.

METHOD

Participants

Six nonsmoking healthy males between 21 and 29 years of age, with aerobic capacities of 50 to 56 $ml*kg^{-1}*min^{-1}$, were selected from recruited volunteers to serve as paid volunteers. Five of them were graduate students and one was an undergraduate. All participants appeared to be highly motivated to perform at their best levels during each session; and following extensive practice, all were skilled at performing the experimental task.

Apparatus and Task

SCRT Apparatus. The SCRT apparatus was housed in a cabinet (33 X 44 X 10 cm) which contained the electronic components and was mounted on a typewriter stand. On top of the cabinet was a wooden baseboard (61 X 76 X 1.5 cm). The imperative stimulus, one of four digits (i.e., "1", "2", "3", "4"), appeared as a red light emitting diode (LED) in a simple rectangular numeric display (2.0 X

2.5 cm) filling a 0.7 X 1.2 cm pattern (stroke width was 0.1 cm). All stimuli were randomly presented with the restriction that no digit succeeded itself more than twice. The signal display was centered directly before the participant at a distance of 65 ± 10 cm (*SD*), 30 cm below eye level and 15 cm above the baseboard near the rear of the apparatus. The response keys were micro switches mounted in adjustable wooden hand rests (18 X 20 X 2 cm) in a "V" pattern similar to that of slightly separated index and middle fingers. The 2.1-cm micro switch depression arms protruded 0.6 cm from the surface and required only a slight deflection (0.2 cm) to activate. The participant rested his index and middle fingers of each hand on personally adjusted microswitches. A correct response was the depression and immediate release of the appropriate microswitch, i.e., the switch corresponding to the prescribed S-R mapping for that particular condition. Release of the switch activated the presentation of the next stimulus and this sequence continued for 20 minutes.

The SCRT apparatus was connected to a Digital Equipment Corporation (DEC) PDP11-23 mini-computer with a real-time clock (resolution of ±1 msec) to permit on-line data collection. The computer randomly presented the stimuli and recorded the response latencies (reaction, dwell, and response times) and elapsed time, as well as measures of rate (total number of trials performed) and accuracy (stimulus LED presented, response key struck, and the error status) for each response. A circuit diagram and description of the hardware and software for the SCRT apparatus is detailed in Vercruyssen (1984b). Each 20-min session was preceded by a 5-sec count-down series of auditory signals (continuous, approximately 70 dBA, 1000 Hz, of varied durations) and ended by a single 500-msec auditory signal (also continuous, 70 dBA, 1000 Hz). On the average, 1000-1600 responses were recorded per 20-min session.

Stimulus Degradation. The task variables manipulated were stimulus degradation (intact vs. degraded) and S-R compatibility (high vs. low). In the intact stimulus condition, clear, unobscured digits (signals) were presented. In the degraded stimulus condition, a translucent photonegative film with a visual noise pattern (random opaque spots) was superimposed on the LED display. This film caused the digits to be partially obscured, i.e., degraded, in an unpredictable fashion (see Figure 2). The film's position over the LED was changed with each 20-min session. The degree of stimulus degradation (as measured by the increase in average SCRT in the degraded condition compared to the average SCRT in the intact condition) was manipulated in pilot studies using multiple films to produce the same loading on SCRT (i.e., SCRT S Degraded – SCRT S Intact) as was produced by S-R compatibility (i.e., SCRT S-R low – SCRT S-R high). Thus, the amount of visual noise was based on an attempt to match the task variable challenges.

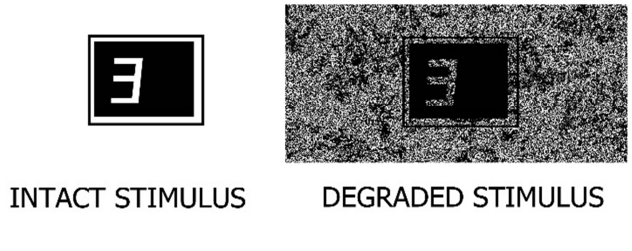

Figure 2. Stimulus degradation conditions. Illustration of the intact and degraded stimulus conditions. The imperative stimulus (digits 1-4) were presented in a red LED display.

S-R Compatibility. In the high S-R compatibility conditions the responses were organized in a coherent pattern of 1-4 from left to right, corresponding directly to the digit display of 1-4. The left portion of Figure 3 shows the position of the arms. A correct response to a "1" signal was depressing the key under the left middle finger. If a "2" signal appeared the left index finger was to be used. A "3" required use of the right index finger and a "4" the right middle finger.

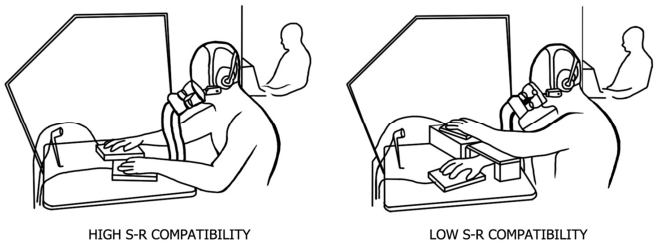

Figure 3. Stimulus-response compatibility conditions. In the high S-R compatibility condition (left), in the response to each imperative stimulus the subjects pressed microswitches in a natural mapping of 1-4, from left to right with the arms parallel. The low S-R compatibility (right), in contrast, used an unnatural S-R mapping with the arms crossed and a mixed order of the response keys (2, 3, 1, 4).

In contrast, the low compatibility conditions assured an unnatural S-R mapping by demanding awkward positions for the limbs and a complicated stimulus-response pattern. Each participant was positioned with his right forearm resting on the baseboard surface and his left arm comfortably resting on a padded, elevated 10-cm bridge structure that crossed over his right arm (see right portion of Figure 3). In this position, the participant responded to the stimulus digits according to the following complicated pattern: "1" prompted the right index finger, "2" the left middle finger, "3" the left index finger, and "4" the right middle finger.

Gas Inhalation System. Two gas mixtures were employed in an open-circuit system (see Figure 4): (1) room air as a control condition, consisting of approximately 0.03% CO_2 and 21% O_2 and (2) CO_2 as an experimental condition, consisting of 4% CO_2 with 50% O_2. The gas inhalation system was designed to deliver a constant mixture of inspired air to the participant. A 150-liter Douglas bag served as a mixing reservoir into which room air, CO_2 and O_2 were mixed. En route to the participant, the mixture was heated and humidified by passage through warm water in a large beaker to insure participants were not able to detect the colder air of bottled gases compared to warm room air.

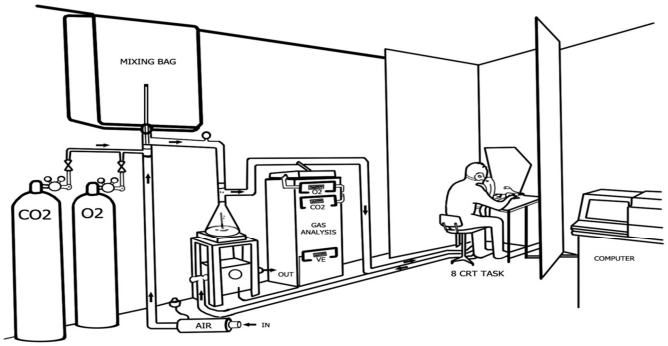

Figure 4. CO_2 inhalation system and laboratory layout. Carbon dioxide and oxygen were combined with room air in a large mixing bag before heating and humidification en route to the participant. Expired ventilation was sampled by a dry gas flow meter at the end of the open circuit system.

The inspired gas mixture was controlled by continuous sampling and monitoring on an Applied Electrochemistry S-3A Oxygen Analyzer and an LB-2 Beckman Medical Gas CO_2 Analyzer. Expired ventilation (V_E) was determined by routing expired gases through a dry gas flow meter for 2-min samples during steady state periods. Pressure release and minimal resistance valves were used to improve the accuracy of the V_E recordings by minimizing leakage through the face mask and Kogel unidirectional valves. Expired air

was released into the well-ventilated testing room. The prescribed gas mixture, accurate to ±0.1% (*SD*) was inhaled for a period of 63 ± 0.2 min (*SD*) on each experimental test day.

Laboratory Environment (see Figure 4). The experiment was conducted in an air-conditioned laboratory. To reduce the possibility of visual distractions, black curtains surrounded the performance testing area and all visible surfaces (except the stimulus display) were painted flat black. The ambient light was controlled by masking all window light with black polyethylene opaque film and using normal florescent ceiling tubes as the only light source. To reduce auditory distractions, a quiet condition was maintained for the entire wing of the building, sound insulating head gear (with extra sound-attenuating foam liners) was worn by the participants, and a low level of continuous white noise was produced by the normal sounds of the instruments in the room (computer drives, electric fans, gas analyzers, etc.).

Gas Concentration and Exposure Duration. A previous CO_2 experiment by Vercruyssen (1984a; Vercruyssen, Kamon, & Hancock, 2007) found that breathing 4% CO_2 (with 50% O_2) for 60 minutes, while running on a treadmill for two 15-min work bouts at 70% of each participant's aerobic capacity, was a reasonable concentration for performing non-invasive studies without the confounding of participant distractions from clinical symptoms. A pilot study (Vercruyssen, 1984a) found that breathing 5% CO_2 (with 50% O2) for one hour, including two 15-min work bouts at 80% VO_2max, to be too severe for the purposes of this experiment.

Treatment of the Data

The following dependent measures were collected: (1) total number of trials performed on each 20-min session (speed measure), (2) percentage of errors (accuracy measure), (3) response time, (4) SCRT, (5) dwell time, (6) heart rate, (7) ventilation, and (8) clinical symptoms. Also collected were the total number of correct trials per 20-min session, total number of errors per 20-min session, LED signals displayed, microswitches depressed, elapsed time, and subjective estimates of performance quality. In cases where previous testing insured a reliable decrement in performance from breathing CO_2, data were analyzed using one-tailed hypotheses (Vercruyssen & Hendrick, 2012).

RESULTS AND DISCUSSION

Reaction Time

The most important results were associated with the significant main and interaction effects on serial choice reaction time (SCRT). Breathing CO_2 produced significant SCRT distribution shifts to the right (longer time) and there was an interaction of gas by S-R compatibility such that the increase in the SCRT means due to breathing CO_2 was exaggerated by the effects of reducing S-R compatibility. The latter findings suggest that CO_2 impairs the response selection stage of processing. Degrading the imperative stimulus also significantly slowed SCRT but there was no interaction of gas and degradation. This additive effect indicates that CO_2 does not affect the stimulus encoding stage of processing. There was a significant increase in SCRT with time-on-task but this effect was constant across conditions.

SCRT Distribution Histogram. Frequency histograms of SCRT latencies were generated for both the room air control and hypercapnia conditions for each participant across all combinations of compatibility and degradation. Forty-eight such plots resulted, all showing somewhat positively skewed distributions. Inhalation of CO_2 caused a shift of the entire distribution to the right, without affecting its shape (e.g., skewness or kurtosis). Figure 5 shows frequency distributions for a representative participant on separate air and CO_2 20-min sessions (each involving degraded stimuli and low S-R compatibility).

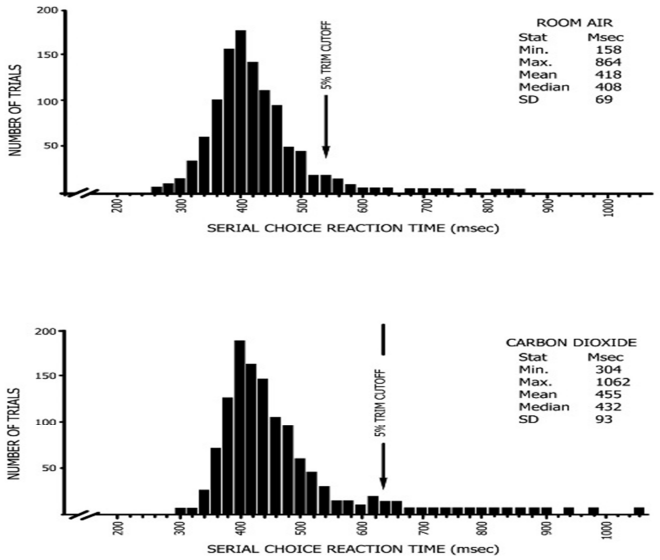

Figure 5. Sample frequency distributions of serial choice reaction time for one subject during 20-minute sessions, in which the stimulus was degraded and the S-R compatibility was low, while breathing air (upper) and CO_2 (lower).

SCRT Means

The SCRT data were analyzed in two forms -- untrimmed and trimmed. The data that underwent a procedure to remove the slowest 5% of the trials on the SCRT frequency distribution are called trimmed data. The intact data are described as untrimmed data.

The one-tailed *t*-ratios obtained from an ANOVA of the untrimmed means showed significant detrimental main effects for gas [$t(5) = 4.22$, $p = .004$], stimulus degradation [$t(5) = 16.05$, $p < .001$], and S-R compatibility [$t(5) = 4.46$, $p = .004$]. The interaction of gas and compatibility was also significant [$t(5) = 2.23$, $p = .038$, see Figure 6] with low compatibility acting to exaggerate the effects of CO_2. No other interactions were significant. The main effects together accounted for 38.4% of the total variance of the dependent measures, whereas the double and triple interactions combined accounted for less than 0.44% of the total variance.

The additivity shown in the task factors supports the presence of at least two functionally independent stages. This is a crucial requirement because the AFM is unworkable if in the control condition (air) the task factors are additive but then become interactive in the stressor conditions (CO_2). The interaction of the stressor with S-R compatibility suggests that carbon dioxide impairs the hypothesized response selection stage of information processing.

Trimming the data caused a slight lowering of the means for each condition, but did not change the SCRT findings. The one-tailed *t*-ratios obtained from an ANOVA of the trimmed data also showed significant impairments in performance due to the stressor and task variables. The effects of gas [$t(5) = 3.90$, $p = .006$], degradation [$t(5) = 17.37$, $p < .001$], and compatibility [$t(5) = 4.39$, $p = .004$] were all significant despite the removal of the longer than usual latencies on the far right tail of the SCRT distributions. Furthermore, this trimming procedure did not remove the gas by compatibility interaction. The main effects together accounted for 38.6% of the total variance of the dependent measures, whereas the double and triple interactions combined accounted for less than 0.3% of the total variance.

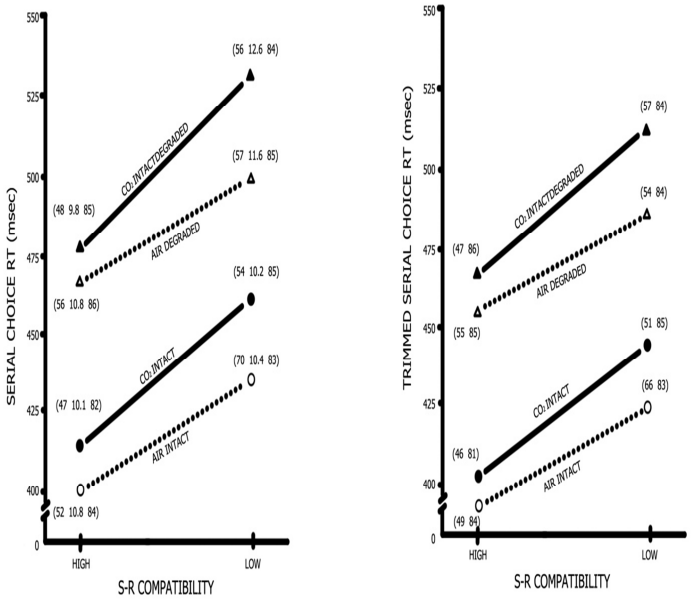

Figure 6. Mean serial choice reaction time as a function of gas, stimulus degradation, and stimulus compatibility for untrimmed (left) and 5% trimmed (right) data.
Note: Within the parentheses near each point are shown the mean within-subject standard deviation, mean percentage errors, and mean dwell time for the untrimmed group data and these values except the errors for the trimmed group data. (Each untrimmed data point represents the mean of approximately 7200 trials.)

Intra-Participant Performance Variability. Within-participant SCRT standard deviation (SD) values, averaged over trials per condition, were used to quantify performance variability. The mean within-participant standard deviations of the untrimmed and trimmed data for each combination of gas, stimulus degradation, and S-R compatibility are illustrated in Figure 7.

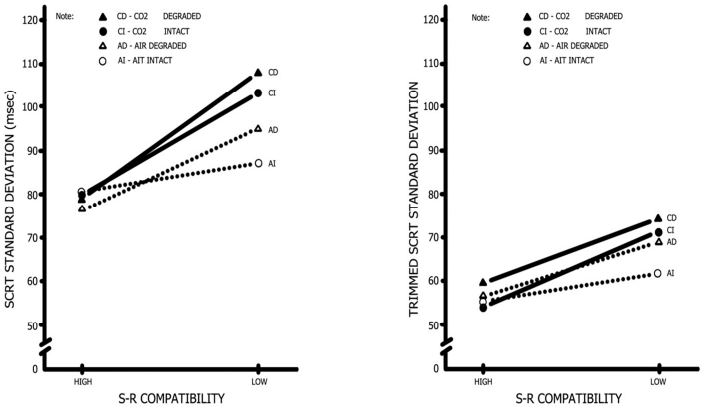

Figure 7. Mean serial choice reaction time within-participant standard deviations as a function of gas, stimulus degradation, and stimulus-response compatibility for untrimmed (left) and 5% trimmed (right) data.
Note: Each untrimmed data point represents the mean of approximately 7200 trials.

Time-On-Task (Exposure Duration) Effects

The effects of time-on-task on untrimmed and trimmed SCRT are shown in Figure 8 in 5-min time intervals.

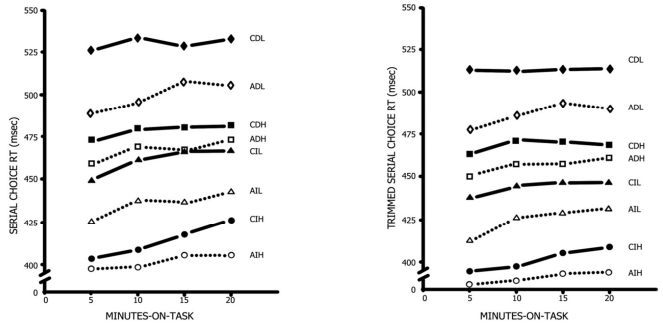

Figure 8. Mean serial choice reaction time as a function of gas, stimulus degradation, stimulus-response compatibility and time-on-task (5-minute intervals) for untrimmed (left) and 5% trimmed (right) data.
Note: A = air; C = CO_2; I = intact stimulus; D = degraded stimulus; H = high S-R compatibility; L = low S-R compatibility. Each untrimmed data point represents the mean of approximately 1800 trials.

The ANOVA of the untrimmed data showed a significant main effect of time-on-task [$F(3,15) = 11.37$, $p = .020$] in which overall mean SCRT increased progressively with time from 453 to 466 msec. Adding time as a fourth variable did not help in accounting for variance in the dependent measures. Combining three main effects variances accounted for 38.42% of the total variance, but adding the time-on-task variance accounted for only 38.07% of the total variance because the total variance also increased.

The most important finding with regard to the effects of time-on-task is that all differences in conditions due to time-on-task were additive. In other words, there were no interactions of time-on-task with gas or task variables. This suggests that although information processing is progressively impaired with time-on-task, the effect does not influence the processing of information in the stimulus encoding or response selection stages.

Rate of Responding

Total Number of Trials. The total number of trials performed in 20 minutes was also used as a speed metric for this experiment. Stronger main effects were seen by the one-tailed *t*-ratios obtained from an ANOVA on these data than from the *t*-ratios obtained from the number of correct responses data. However, the interaction of gas and compatibility failed to be significant ($p = .082$). Again, as shown in Figure 9, CO_2 slowed responding [$t(5) = 3.63$, $p = .008$] as did stimulus degradation [$t(5) = 16.99$, $p < .001$], and S-R compatibility [$t(1,5) = 4.24$, $p = .004$]. Furthermore, there was a progressive slowing of responding with time-on-task [$F(3,15) = 88.40$, $p < .001$] and this effect was constant across conditions (interaction ps > .05).

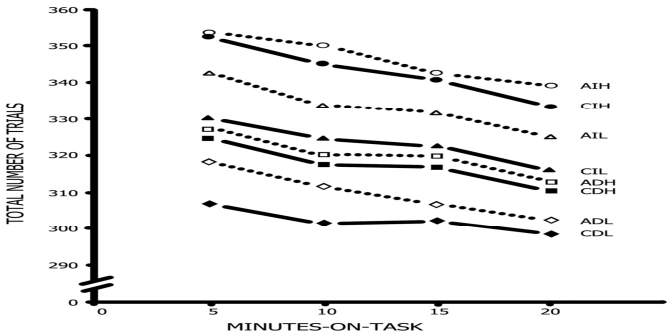

Figure 9. Mean rate of responding (i.e., total number of trials performed per 5-minute interval) as a function of gas, stimulus degradation, stimulus-response compatibility, and time-on-task.
Note: A = room air; C = CO_2; I = intact stimulus; D = degraded stimulus; H = high S-R compatibility; and L = low S-R compatibility.

Accuracy of Responding

No differential effects were noted in the absolute or relative number of errors committed. This is an important finding because it suggests the participants maintained the same speed-accuracy instructional set during practice and across all treatment conditions. The only significant contrasts relative to accuracy were those associated with extended performing. With time-on-task there was a progressive decrease in the absolute number of errors, $F(3,15) = 11.88$, $p = .018$, and the percentage of errors, $F(3,15) = 10.73$, $p = .022$. Because there were no interactions with conditions, these findings suggest that there were no changes in speed-accuracy operating characteristics between conditions. Within each condition, however, with time-on-task the participants gradually became slower and slightly more accurate in their responding.

Limitation and Salient Feature of This Research

CO_2 retention (hypercapnia) was not measured so a dose-response in relation to individual CO_2 buffering ability (e.g., Selkirk, Shykoff, & Briggs, 2010) cannot be discussed. Internal buffering of CO_2 has explained many null and equivocal results across many psychomotor tests. However, this research shows the sensitivity and robustness of SCRT and AFM for CO_2 research and for identifying what components of the human information processing system are affected by stressors.

Summary of Findings

This experiment determined that:

- Breathing 4% CO_2 caused significant increases in mean SCRT in all conditions.
- Breathing 4% CO_2 caused a shift to the right of the entire SCRT frequency distribution without changing the higher moments (i.e., skewness and kurtosis).
- Degrading stimulus quality and reducing S-R compatibility each produced significant increases in SCRT, but these factors did not interact.
- The effects of CO_2 and S-R compatibility interacted in such a way that the deleterious effects of breathing CO_2 were further exaggerated when combined with those of reducing S-R compatibility. CO_2 inhalation and stimulus degradation were additive.
- Breathing 4% CO_2 and performing under low S-R compatibility caused an increase in SCRT variability (as measured by both within-participant standard deviations and variances). These two factors interacted such that the effect of breathing CO_2 exaggerated the increased variability caused by decreasing S-R compatibility.
- With time-on-task, SCRT progressively increased in a similar manner across all conditions (no interactions or specific effects).
- Dwell time was constant across all levels of all factors (overall M = 84 msec, SD = 1 msec).
- The absolute and relative number of errors committed were constant across conditions (overall mean = 10.8%, SD = 0.9%).
- The rate of responding, as measured by the total number of correct trials per session and the total number of trials, was reduced by breathing 4% CO_2, degrading the stimulus, and decreasing S-R compatibility. Furthermore, in the case of the number of correct trials, the effects of breathing CO_2 were exacerbated by reducing S-R compatibility.
- Across conditions, with increasing time-on-task the response rate consistently decreased and the accuracy of responding consistently increased.
- Expired ventilation was significantly increased by breathing 4% CO2 (the range of this increase was 25.1 - 139.3%). Resting heart rate was unaffected by this stressor or the task variables.
- The inspired CO_2 concentration was highly correlated with the expired ventilatory volumes.
- Reported clinical symptoms, such as dry throat, dyspnea, and hyperventilation, occurred while breathing CO_2, but the participants were unable to identify correctly the gases they were breathing.

CONCLUSIONS

Within the limitations of this experiment, (1) breathing 4% CO_2 for one hour slows information processing by impairing the response selection stage of processing and not the stimulus encoding stage and (2) with increasing time-on-task information processing is increasingly impaired and the magnitude of this effect is similar for each processing stage. These findings help define a useful model of human information processing and identify the locus of CO_2 impairment.

REFERENCES

Sanders, A. F. (1980). Stage analysis of reaction processes. In: G. Stelmach & J. Requin (Eds.), *Tutorials on motor behavior* (pp. 331-354). Amsterdam: North Holland.

Sanders, A. F. (1983). Toward a model of stress and human performance. *Acta Psychologica, 53*, 61-97.

Sanders, A. F. (1990). Issues and trends in the debate on discrete vs. continuous processing of information. *Acta Psychologica, 74*, 123-167.

Sanders, A. F. (1998). *Elements of human performance: Reaction processes and attention in human skill*. London: Erlbaum.

Selkirk, L. T. A., Shykoff, B., & Briggs, J. (2010). Cognitive effects of hypercapnia on immersed working divers. *Navy Experimental Diving Unit Report* (NEDU TR 10-15; TA 09-01). NAVSEA, 321 Bullfinch Road, Panama City, FL 32407-7015.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (Ed.), Attention and performance II, *Acta Psychologica*, 30, 276-315. Doi: 10.1016/0001-6918(69) 90055-9

Sternberg, S. (1984). Stage models of mental processing and the additive-factors method. *Behavior and Brain Sciences*, *7*, 82-84. Doi: 10.1017/S0140525X00 026285

Sternberg, S. (1998). Discovering mental processing stages: The method of additive factors. In D. Scarborough & S. Sternberg (Eds.), *An invitation to cognitive science, Volume 4: Methods, models, and conceptual issues*, (pp. 702-863). Cambridge, MA: MIT Press.

Sternberg, S. (2001). Separate modifiability, mental modules, and the use of pure and composite measures to reveal them. *Acta Psychologica*, *106*, 147-246. Doi: 10.1016/S0001-6918(00)00045-7

Sternberg, S. (2011). Modular processes in mind and brain. *Cognitive Neuropsychology, 28*, 156-208. Doi: 10.1080/02643294.2011.557231

Sternberg, S. (2013). The meaning of additive reaction-time effects: Some misconceptions. *Frontiers in Psychology, 4*(744), 1-3. Doi: 10.3389/fpsyg.2013.00744

Vercruyssen, M. (1984a). Breathing 3-4% CO2: Behavioral effects. In: E. Kamon, N. S. Deno, & C. F. Ryan, *Physiological responses of miners to emergency* (*Volume 2*, 56-74). Contract report to the Bureau of Mines (Contract No. 5O-100092). Washington, DC: U.S. Department of the Interior.

Vercruyssen, M. (1984b). *Carbon dioxide inhalation and information processing: Effects of an environmental stressor on cognition*. Doctoral dissertation. State College, PA: The Pennsylvania State University.

Vercruyssen, M., & Hendrick, H. W. (2012). *Behavioral research and analysis: An introduction to statistics within the context of experimental design, 4th ed*. New York: CRC Press (Taylor & Francis Group).

Vercruyssen, M., & Kamon, E. (1984). Behavioral effects of one-hour breathing of high concentrations of CO2 and O2 while doing physical work. *Journal of the International Society for Respiratory Protection*, *2*, 63-89.

Vercruyssen, M., Kamon, E., & Hancock, P. A. (2007). Effects of carbon dioxide inhalation on psychomotor and mental performance during exercise and recovery. *International Journal of Occupational Safety and Ergonomics*, *13*, 15-27.