Electroencephalography and Clinical Neurophysiology
Elsevier Publishing Company, Amsterdam – Printed in The Netherlands

EFFECTS OF CARBON DIOXIDE ON THE ALPHA FREQUENCY AND REACTION TIME IN HUMANS[1]

M. RUSSELL HARTER, PH.D.

University of Arizona and U. S. Navy Electronics Laboratory, San Diego, Calif. (U.S.A.)

(Accepted for publication: May 15, 1967)

Carbon dioxide (CO_2) has been shown to have both excitatory and inhibitory effects on various measures of sensory and cortical activity in humans. Sensory function is generally impaired when subjects breathe high concentrations of CO_2 for short periods of time (0–10 min) (Gellhorn and Spiesman 1935a, b; Stokes *et al.* 1948; Schaefer and Carey 1954; Wyke 1963, p. 58). Studies which have investigated the effect of CO_2 on cortical activity in humans show conflicting results (see Discussion). These may be attributed to the different measures, CO_2 concentrations, and inhalation periods employed.

The present study sought to investigate the effects of various CO_2 concentrations on alpha frequency and reaction time in humans. The upper limit of 7.9% CO_2 was selected since it nears the maximum concentration permissible (approximately 10%) without loss of consciousness in man. The effects were also evaluated in terms of the length of CO_2 inhalation.

METHOD AND MATERIAL

Experimental design

Five male graduate students, experienced in the reaction time (RT) task, participated in two 50-min experimental sessions. An experimental session consisted of having each subject inhale five levels of CO_2 (0, 1.5, 3.5, 5.5 and 7.9%) mixed with air for a 5-min trial. To obtain control data, air was administered for the first 30 sec of each trial. A replicated 5 × 5 balanced Latin Square was used to determine the trial on which the various CO_2 conditions were presented to each subject for the two sessions. Six within-trial changes were obtained by sampling the data for the first two 30-sec intervals and then on alternate 30-sec intervals for the remaining part of the trial. Therefore, the five subjects, five CO_2 concentrations, two sessions, and six 30-sec within-trial samples resulted in a total N of 300.

Apparatus and data recording procedure

The various CO_2 concentrations were administered by having the subjects breathe through a rubber mouthpiece, attached to a Hans Rudolph valve, from a 60 l Douglas Bag. RT was measured to the nearest millisecond by a Hewlett Packard Model 522B electronic counter and Model 560A digital recorder. A Grass photostimulator Model PS2, set at intensity "16", was used to present visual stimuli of 10 μsec duration. A hood, attached to the flash tube, fixed the subject's eyes (which were closed) 6″ from the stimulus. Stimuli were presented at intervals varying from 3 to 7 sec. A model 220 California Technical Industries 6-channel tape reader triggered the photostimulator, counter, and polygraph RT monitor. Subjects reacted by pushing a micro-switch key with their right index finger which, in turn, sent a terminating pulse to the counter and polygraph monitor. A 180 g force was required to move the key the 7 mm excursion necessary to close the switch.

Alpha frequency was measured from EEGs recorded between the midline occipital-parietal (O_z–P_z) electrodes and from C_z referred to A_1 according to the International Standard 10–20 System. The procedure and apparatus used to record EEGs has been described elsewhere (Harter *et al.* 1964). The average alpha frequency for each subject and CO_2 concentration was determined by averaging twelve alpha frequency measures obtained from the twelve 30-sec samples of the EEG record (six within-trial samples for two sessions). Alpha frequency was measured from each 30-sec sample by selecting at least 3 sec of the largest amplitude alpha waves (any rhythmic activity between 9 and 13 c/sec) in the sample, counting the number of alpha waves selected, and dividing by their accumulated duration in seconds. Therefore, the average alpha frequency for each subject and CO_2 concentration was based on at least 36 sec of alpha activity.

RESULTS AND DISCUSSION

Analyses of variance were performed on the grouped data to determine the effects of time (within-trial effects) and CO_2 concentration inhaled on RT and alpha frequency.

Changes across time

Significant within-trial changes were evident in RT and alpha frequency recorded from O_z–P_z ($P < 0.05$). Alpha

[1] Adapted from a doctoral dissertation submitted to the University of Arizona, Tucson, Ariz., and supported by funds received from the U.S. Navy Electronics Laboratory under a National Academy of Sciences–National Research Council post-doctoral fellowship, National Aeronautics and Space Administration under a pre-doctoral fellowship, and National Science Foundation under Grant GB-1384.

frequency increased and RT decreased within the first 2 min of inhalation; throughout the remainder of the trial alpha frequency progressively decreased and RT progressively increased. A similar trend was evident in the alpha frequency from the C_z electrode although it did not approach statistical significance.

Effects of CO_2

Alpha frequency (O_z–P_z and C_z–A_1) and RT were significantly affected by CO_2 concentration administered ($P < 0.01$ and $P < 0.05$, respectively). Orthogonal comparisons indicated that RT was shorter and alpha frequency was higher during the 0–5.5% CO_2 conditions than during the 7.9% CO_2 conditions ($P < 0.01$). The differential effects of 0–5.5% CO_2 on RT and alpha frequency did not approach statistical significance.

The effects of CO_2 on the alpha frequency and RT of each subject are illustrated in Fig. 1. Consistent with past findings (Schaefer 1958), the subjects differed considerably in terms of their sensitivity to CO_2. The within-subject changes in RT and alpha frequency were negatively correlated across the CO_2 conditions investigated (rank-order correlations of −0.50, −0.60, −0.90, −0.90 and −0.00, respectively, for subjects EB, GH, HM, BF and GS). A relationship between alpha frequency and RT has been noted elsewhere (Lansing 1957; Callaway 1962; Surwillo 1963).

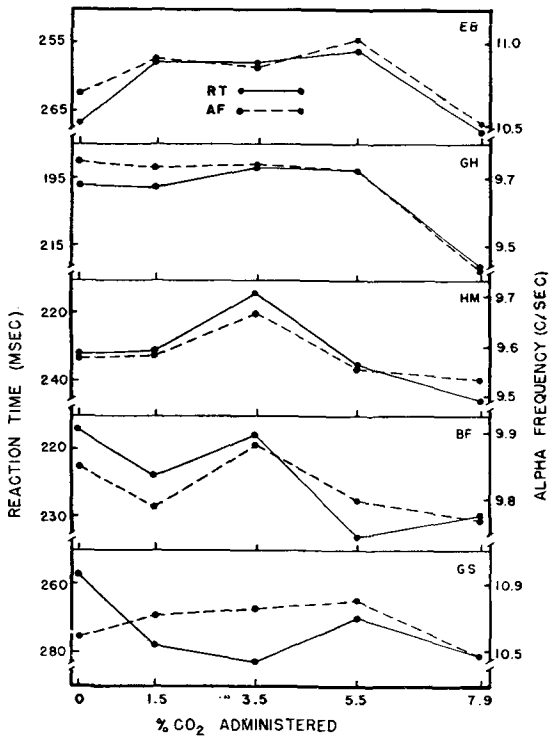

Fig. 1

Effects of CO_2 concentration administered on the reaction time (RT) and occipital-parietal alpha frequency (AF) of each subject (EB, GH, HM, BF, GS). Each plotted point is an average based on an N of 12.

In general, the threshold CO_2 concentration for "depressive" effects on both RT and alpha frequency appeared to fall between 3.5 and 7.9%. The threshold average value of approximately 5.5% CO_2 is comparable to those values found previously in sensory threshold studies (Gellhorn and Spiesman 1935a, b; Stokes *et al.* 1948). It is somewhat higher than the 3.3% CO_2 value for decreased critical flicker fusion and alpha blocking time found by Schaefer and Carey (1954). The latter discrepancy may be attributed to different inhalation periods (*i.e.*, 15 min in the latter and 5 min in the present study).

There was a suggestion that RT was shorter and alpha frequency was higher under the 3.5–5.5% CO_2 conditions as compared to the 0–1.5% CO_2 conditions. This effect, which did not approach statistical significance, has been noted previously (Gibbs *et al.* 1940; Schaefer 1949).

It has been proposed that the effects of CO_2 on the central nervous system depend on the concentration of CO_2 administered: 3–7% CO_2 causing direct depression of cortical neural activity only; 5–20% CO_2 causing generalized reticulo-cortical activation which overcomes the initial direct cortical depression; and 20% CO_2 and above causing narcosis or anesthesia and depression of reticulo-cortical activity (Wyke 1963). The results of the present study fail to support this hypothesis since (a) the changes in RT and alpha frequency suggesting an excitatory effect did not approach statistical significance; (b) there were considerable individual differences in reaction to CO_2 and (c) the CO_2 concentrations at which the second and third phases were evident in the present study were considerably lower than those proposed by Wyke (1963).

SUMMARY

The effects of acute exposure (5 min) to carbon dioxide (0–7.9%) on the EEGs and reaction times of five humans were investigated. Alpha frequency and alpha amplitude were recorded from the central and from the occipital-parietal areas of the scalp while subjects reacted with their right index finger to flashes of light. Variance analyses indicated that the percentage CO_2 inhaled significantly affected alpha frequency and reaction time. Alpha frequency and reaction time were significantly faster under the 0–5.5% CO_2 conditions than under the 7.9% CO_2 condition. A slight increase in alpha frequency and decrease in reaction time were evident under the 3.5 and 5.5% CO_2 conditions as compared to the 0 and 1.5% CO_2 conditions.

RÉSUMÉ

EFFETS DU CO_2 SUR LA FRÉQUENCE DE L'ALPHA ET LE TEMPS DE RÉACTION CHEZ L'HOMME

Les effets à une exposition aiguë (5 min) au CO_2 (0 à 7,9%) sur l'EEG et les temps de réaction de cinq hommes sont étudiés. La fréquence et l'amplitude de l'alpha dérivé des aires centrales et pariéto-occipitales du scalpe sont enregistrées, tandis que ces sujets réagissent avec leur index droit à des éclairs lumineux. Des analyses

de variance indiquent que le pourcentage de CO_2 inhalé affecte de façon significative la fréquence de l'alpha et le temps de réaction. La fréquence de l'alpha et le temps de réaction sont significativement plus rapide sous des concentrations de 0,5 à 5 % de CO_2 que sous des concentrations de 7,9 %. Une légère augmentation de la fréquence alpha et une diminution du temps de réaction apparaissent évidentes pour des concentrations de 3,5 % de CO_2 si on les compare à des concentrations de 0 et des 1,5 %.

The author wishes to express appreciation to Dr. R. W. Lansing for suggesting and supervising this project, and to Drs. N. R. Bartlett and R. H. Pool for their constructive suggestions in the preparation of the manuscript. Acknowledgment is also made to Dr. T. P. K. Lim for his medical supervision, and to other personnel of the Tucson Medical Center, Cardiopulmonary Laboratory, Tucson, Ariz., without whose support this project could not have been undertaken.

REFERENCES

CALLAWAY III, E. Factors influencing the relationship between alpha activity and visual reaction time. *Electroenceph. clin. Neurophysiol.*, **1962**, *14*: 674–682.

GELLHORN, E. and SPIESMAN, I. G. Influence of hyperpnea and of variations of O_2- and CO_2-tension in the inspired air upon hearing. *Amer. J. Physiol.*, **1935**a, *112*: 519–528.

GELLHORN, E. and SPIESMAN, I. G. Influence of hyperpnea and of variations of O_2- and CO_2-tension in the inspired air upon afterimages. *Amer. J. Physiol.*, **1935**b, *112*: 620–625.

GIBBS, F. A., WILLIAMS, D. and GIBBS, E. L. Modification of the cortical frequency spectrum by changes in CO_2, blood sugar and O_2. *J. Neurophysiol.*, **1940**, *3*: 49–58.

HARTER, M. R., EASON, R. G. and WHITE, C. T. Effects of intermittent visual input disruption, flicker-rate, and work time on tracking performance and activation level. *Percept. mot. Skills*, **1964**, *19*: 831–848.

LANSING, R. W. Relation of brain and tremor rhythms to visual reaction time. *Electroenceph. clin. Neurophysiol.*, **1957**, *9*: 497–504.

SCHAEFER, K. E. Der Einfluss eines langdauernden Aufenthaltes in 3 % CO_2 auf die Hirnaktiönsstrome. *Pflügers Arch. ges. Physiol.*, **1949**, *251*: 726–740.

SCHAEFER, K. E. Respiratory patterns and respiratory response to CO_2. *J. appl. Physiol.*, **1958**, *13*: 1–14.

SCHAEFER, K. E. and CAREY, C. R. Influence of exposure to various CO_2 concentrations on flicker fusion frequency and alpha blocking. *Med. Res. Lab. Rep. (New London)*, No. 251, Aug. **1954**.

STOKES, J., CHAPMAN, W. P. and SMITH, L. H. Effects of hypoxia and hypercapnia on perception of thermal cutaneous pain. *J. clin. Invest.*, **1948**, *27*: 299–304.

SURWILLO, W. W. The relation of simple response time to brain-wave frequency and the effects of age. *Electroenceph. clin. Neurophysiol.*, **1963**, *15*: 105–114.

WYKE, B. *Brain function and metabolic disorders.* Butterworths, London, **1963**: 161–163.

Reference: HARTER, M. R. Effects of carbon dioxide on the alpha frequency and reaction time in humans. *Electroenceph. clin. Neurophysiol.*, **1967**, *23*: 561–563.