ACTA NEUROBIOL. EXP. 1979, 39; 335-343

REGIONAL CEREBRAL BLOOD FLOW AND VISUAL ATTENTION IN THE AWAKE ISOLATED CEREBRUM OF THE PRETRIGEMINAL CAT

Krystyna SKOLASIŃSKA, Leszek KRÓLICKI and Bogusław ŻERNICKI

Isotope Laboratory, Institute of Physiology, School of Medicine, and Department of Neurophysiology, Nencki Institute of Experimental Biology, Warsaw, Poland

Abstract. The effect of visual stimulation on cerebral blood flow (CBF) was studied in five cats with brainstem transection at the pretrigeminal level. The CBF was measured in the occipital and frontal cortex by external monitoring of the clearance of ^{133}Xe. As a visual stimulus, a feather duster moving for 2 min in front of the cat's eyes was used. This stimulus evoked an increase of CBF. In the occipital cortex the CBF increase was greater and comparable to that evoked by elevation of the arterial pCO_2. Both in the occipital and frontal cortex the CBF response was positively correlated with the intensity of the ocular-following reflex and the cortical EEG arousal. It is concluded that the CBF increase was correlated with the degree of attention paid by the cat to the visual stimulus.

INTRODUCTION

It has been recently firmly established that visual stimulus evokes an increases of cerebral blood flow (CBF) (1, 5, 6, 10, 11, 17) and glucose consumption (16, 19) in the visual cortex. The effect of visual stimulation on the CBF in the visual cortex was also investigated in our previous study (18), in which we utilized cats with brainstem transected at the pretrigeminal level. In contrast to the cerveau isolé cat, the isolated cerebrum of the pretrigeminal cat is awake as shown by EEG patterns, the presence of ocular orienting reflexes to visual stimuli, and the possibility of elaboration of conditioned ocular reflexes (4, 20).

Because the pretrigeminal cat does not feel pain (20), it can be easily restrained in the stereotaxic apparatus and both CBF and ocular responses can be easily observed. In this preparation a strong visual stimulus (movements of a feather duster) evoked an increase of CBF in the occipital lobe (18). The CBF increase was associated with a desynchronization of cortical EEG activity and with attention of the animal as manifested by the ocular-following reflex.

In the present paper the CBF responses to a visual stimulus were further investigated in the pretrigeminal cat. In particular, the relation between the CBF response and the level of the cat's attention paid to the visual stimulus was analyzed.

METHODS

Five cats were used. Initial surgery was done under ether anesthesia. A tracheotomy was performed, a polyethylene catheter was inserted into the left lingual artery, and the brainstem was transected at the pretrigeminal level (20). Just after the transection the anesthesia was discontinued. In all cases spontaneous breathing was preserved. The scalp and temporal muscles were removed and for EEG recording two pairs of silver electrodes were placed through small holes in the bone onto the dura mater over the left occipital and frontal cortex. Two gamma-scintillator detectors were positioned over the frontal and occipital cortex (Fig. 1). For recording the electrooculogram (EOG), silver wire electrodes were placed subcutaneously above and below

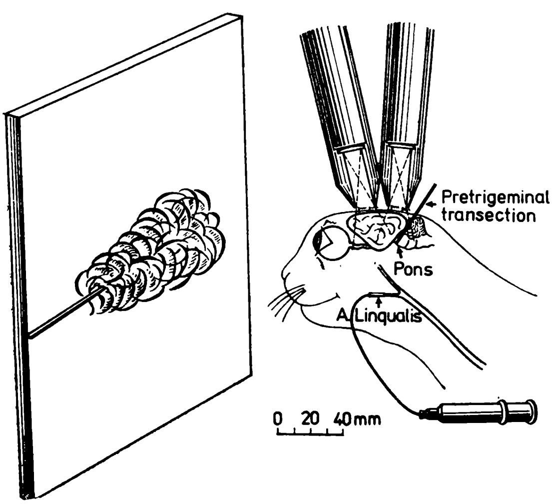

Fig. 1. A semi-schematic representation of the experimental setup. The geometry of CBF counting areas, the position of electrodes of EEG and EOG recordings, and the level of brainstem transection are indicated. The distance between the cat and the screen and the size of the feather duster are not in the scale.

the left eyeball, and then the eyes were covered with occluders fixed to the stereotaxic apparatus.

The experiment was started after the cat had recovered from anesthesia and surgery, as shown by the appearance of the ocular-following movements in response to waving a hand in front of cat's eyes; i.e. usually about 2 h after the brainstem transection. The experiment consisted of six successive 15 min measurements of the CBF (trials) in the following sequence: two control trials, three "visual" trials, and one control trial. In the visual trials about 15 s after the beginning of clearance curve slope, the eye occluders were removed and a visual stimulus was presented during 2 min, and then the eyes were occluded again. The visual stimulus was a feather duster (20 × 35°) moved by hand up and down with a speed of about 10°/s against a white screen located 40 cm from the cat's eyes. Among many visual stimuli used in the experiments in pretrigeminal cats, this evoked the strongest ocular and EEG responses (15).

In the second part of the experiment, in three cats the effect of increased arterial pCO_2 was investigated. For that purpose the cats were paralysed with Tricuran and artificially ventilated with a gas mixture containing an elevated amount of CO_2. When the EEG activity became completely desynchronized, measurement of CBF started.

Regional cerebral blood flow was measured by the intracarotid ^{133}Xe injection technique. The radioactivity was followed by two gamma-scintillator detectors (NaJ) appropriately shielded by the arrow-angle collimators. The distance from the tip of the collimator to the crystal was 35 mm and the collimator was fixed 0.5 mm from the surface of the cranium. The inside diameter of the collimator was 0.8 mm and its shield has a form of a coin with increasing thickness of the wall from 5 to 10 mm. Therefore its visual field was a circle with 10 mm in diameter. ^{133}Xe in saline solution was injected as a single bolus (0.1–0.2 ml) through the lingual artery into the left external carotid artery each 15 min, and the washout curve was recorded. After 10 min the radioactivity declined by about 90% and after 15 min was about 1 to 3% of the initial value. The CBF was calculated from the logarithmically displayed clearance curve for 2 min as

$$CBF_{initial} = 1.70 \times D_{initial} \text{ ml/min/100 g},$$

where 1.7 is the conversion factor from base 10 to natural logarithm multiplied by the tissue-to-blood partition coefficient of grey matter (0.73), and $D_{initial}$ is the slope of the initial part of the curve in percent of a decade per minute. The initial slope of the washout curve was estimated after rejecting the first 15 s (ref. 14).

The pCO_2 in the arterial blood varied from 35 to 39 torr and arterial pH from 7.34 to 7.40. The hematocrit varied from 0.40 to 0.45. The mean arterial blood pressure, measured from the femoral artery by the Statham transducer, ranged from 100 to 140 mm Hg. The body temperature was maintained at 38°C.

Statistical significance of the results was assessed by analysis of variance and the Duncan test, and by Spearman correlation test.

RESULTS

In control trials the CBF did not change markedly. The movements of the feather duster produced a clear-cut increase of the CBF in the occipital area in the first and second trials (Figs. 2 and 3). In the third visual trial the response weakened. In the frontal area the CBF increase was weaker.

The CBF increase was positively correlated with the intensity of the ocular-following reflex (Fig. 4). In the cases where the background EEG activity was synchronized, the CBF increase was usually associated with EEG arousal. In the occipital cortex the EEG arousal was usually more distinct than in the frontal cortex (Fig. 2).

Elevation of arterial pCO_2 to 63–65 torr increased the CBF both in the occipital and frontal cortex. The mean increase was 60% in the occipital cortex and 77% in the frontal cortex. The differences were significant with regard to the preceding ($P < 0.05$) and the following ($P < 0.01$) control trials. The arterial pH changed from 7.34–7.40 to 7.18–7.21 and the mean arterial blood pressure increased by about 10 mm Hg.

DISCUSSION

When a novel visual stimulus is presented to the cat, it usually evokes a clear ocular-orienting reflex (9). In other words, the animal pays attention to the visual stimulus. The powerful stimuli in this respect are moving objects. A main component of the orienting reflex to visual stimuli is an ocular-following reflex which enables the animal to see the moving object sharply. The vertical component of this reflex is basically intact in the pretrigeminal cat (13, 21).

The main result of this study was that the intensity of the CBF was positively correlated with the intensity of the vertical ocular-

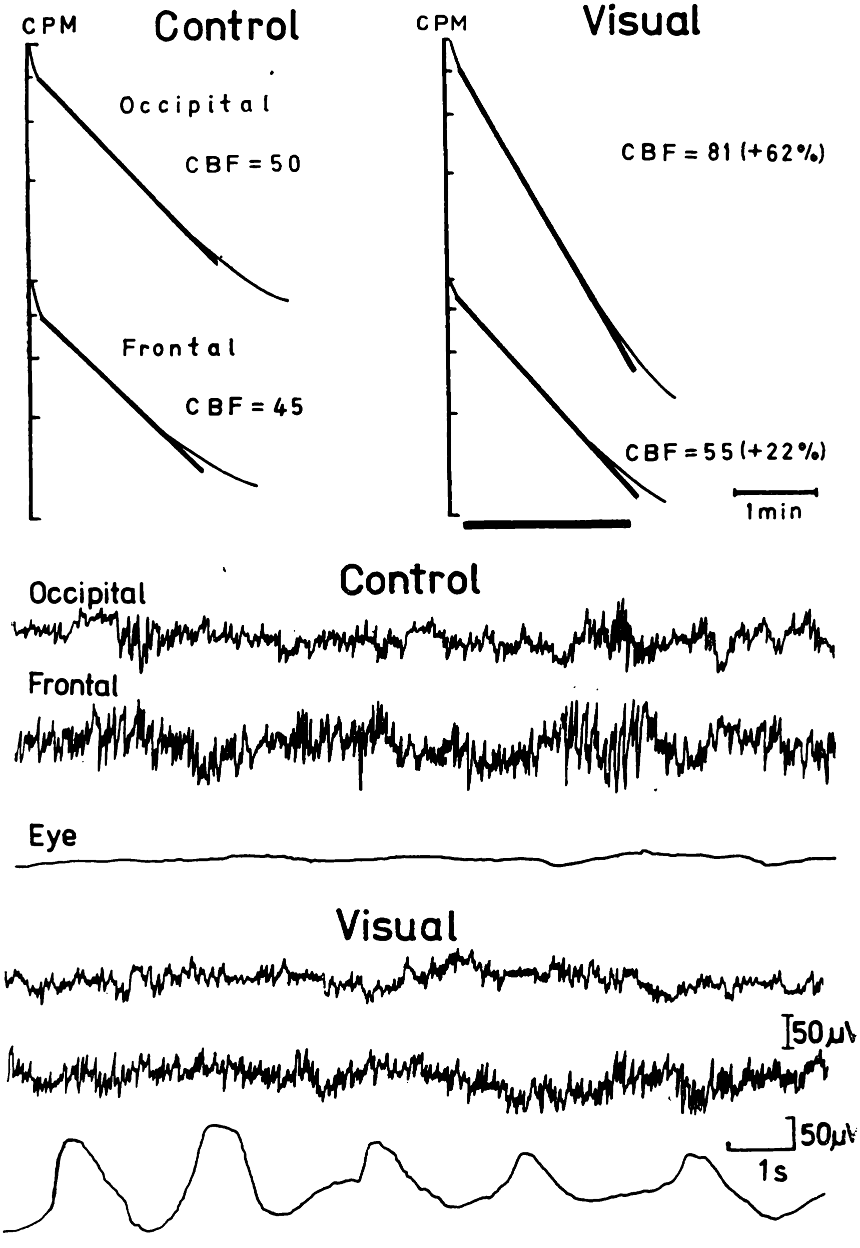

Fig. 2. An original record showing an increase of the CBF in the first visual trial. The records from two successive trials (control and visual) are presented. The cat's eyes were occluded, except for the period of the feather duster stimulation (heavy horizontal line). The CBF increase was greater in the occipital area than in the frontal one. The visual stimulus evoked also EEG desynchronization in both the occipital and frontal cortex, and the ocular-following movements. The following reflex was originally strong but weakened rapidly. The samples of the EEG and EOG records for the visual trial correspond to the first 20 s of visual stimulation. The $CBF_{initial}$ is expressed in ml/min/100 g. Cat 20, 2 h after the brainstem transection.

following reflex. In the occipital cortex the correlation did not reach the level of significance. However, we analysed statistically the previous results (18) in this respect and we found that such a correlation was significant at the level $P < 0.01$ (Spearman correlation test). Some data of other authors also suggest that the CBF increase is associated with

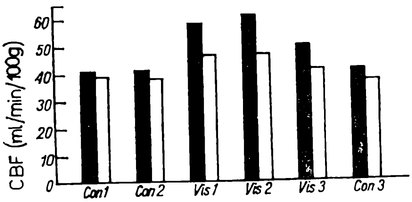

Fig. 3. An increase of the CBF in visual trials. Mean values for all cats are presented. Con, control trial; Vis, visual trial; black columns, visual cortex; white columns, frontal cortex. Ordinate, $CBF_{initial}$ expressed in ml/min/100 g. In the visual cortex the differences between visual trials 1 and 2 and control trials were significant at the level $P < 0.01$, and the difference between visual trial 2 and visual trials 3 was significant at the level $P < 0.05$. In the frontal cortex the differences were insignificant except between visual trials 1 and 2 and control trial 3 ($P < 0.05$).

the animals' attention. Bondy et al. (5) reported the increase of the CBF in the chicken's optic lobe when the animal directed its eye to the presented grain. In humans, Ingvar (10) observed increase of CBF in the occipital cortex during a test involving abstract thinking, memorizing, and problem solving, and Cooper et al. (6) during reading.

That result might be expected. The ocular-following reflex can be considered as one of the indicators of the engagement of the visual

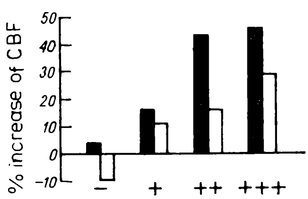

Fig. 4. A correlation between the increase of the CBF and the intensity of the ocular-following reflex. Visual trials were divided in four groups according to the intensity of the following reflex: —, lack of reflex (1 trial); +, abortive reflex (3 trials); ++, originally strong but rapidly weakening reflex (5 trials), +++, strong reflex during the whole stimulation period (6 trials). Black columns, visual cortex; white columns, frontal cortex. Ordinate, % increase of the CBF over controls. In the frontal cortex correlation was significant at the level $P < 0.05$. In the occipital cortex correlation was close to the level of significance.

cortex in the analysis of the visual stimulus. It maintains the visual stimulus in the region of sharp vision and thus the visual cortex is continuously informed about discrete features of the pattern stimulus. As shown in earlier studies (12, 22), under such experimental conditions almost all units in the visual cortex react vigorously to a moving visual pattern. Moreover, the visual cortex itself is engaged in the mediation of the ocular-following reflex. After visual decortication the ocular-following reflex is seriously impaired (7). The ocular-following reflex is also controlled by the oculo-motor center located in the frontal cortex. After ablation of this center the ocular-following reflex is increased and is much more resistant to habituation (8).

A strong CBF increase to visual stimulation was usually associated with a strong EEG arousal (in some trials the effect could not be visible since the background EEG activity was already desynchronized). A high correlation between the regional CBF and the EEG mean frequency was reported by Baldy-Moulinier and Ingvar (2). We also know (21) that in the pretrigeminal cat the intensity of the following reflex is positively correlated with the cortical EEG arousal.

The visual stimulus produced obviously a stronger increase of the CBF in the occipital cortex than in the frontal cortex. Regional differences in the CBF increase (6, 11, 17) or in glucose consumption (16, 19) in the cortex during a photic stimulus have also been observed by other authors. The usually weaker CBF increase in the frontal lobe was usually associated with a somewhat weaker EEG arousal. The fact that in the pretrigeminal cat a visual stimulus produces a weaker and shorter-lasting EEG arousal in the frontal cortex than in the occipital cortex has been clearly shown previously (21).

The absolute flow values obtained in control trials were somewhat lower than those reported by Bates et al. (3). This difference was caused to different lambda values used for CBF calculation. It is also difficult to compare the values of CBF responses to the visual stimulus obtained under our experimental condition with those of other authors. Interestingly, Baldy-Moulinier (1) using local ^{133}Xe injection technique observed an increase in local CBF of the same order in the suprasylvian gyrus in anesthetized cats. In our study the CBF response in the occipital cortex to visual stimulation was comparable to the CBF responses in the occipital and frontal cortex evoked by the increase of arterial pCO_2.

We know that in the isolated cerebrum of the pretrigeminal cat adequate ocular orienting reflexes are present and ocular conditioned reflexes can be elaborated as easily as in the intact animal (20). It is probable that the presence of good CBF regulation in the isolated cerebrum is an important factor in the preservation of its functional ability.

We thank Professor D. Ingvar for critical reading of the manuscript and Professor K. Zieliński and Dr. P. Jastreboff for help in the statistical analysis of data. We also thank Mrs. Janina Rokicka, Mrs. Jagoda Michalska and Mr. J. Folga for technical assistance. This work was supported by Project 10.4.1.01 of the Polish Academy of Sciences.

REFERENCES

1. BALDY-MOULINIER, M. 1975. Cerebral electrical activity and cerebral blood flow during brain-activation. *In* D. H. Ingvar and N. A. Lassen (ed.), Brain work. Munksgaard, Copenhagen, p. 353–360.
2. BALDY-MOULINIER, M. and INGVAR, D. H. 1969. EEG frequency content related to regional blood flow of cerebral cortex in cat. Exp. Brain Res. 5: 55–60.
3. BATES, D., CHIO, B. and SUNDT, T. M. 1976. The relevance of peripheral baroreceptors and chemoreceptors to regulation of cerebral blood flow in the cat. Circ. Res. 6: 488–493.
4. BATINI, C., MORUZZI, G., PALESTINI, M., ROSSI, G. F. and ZANCHETTI, A. 1959. Effects of complete pontine transections on the sleep-wakefulness rhythm: the midpontine pretrigeminal preparation. Arch. Ital. Biol. 97: 1–12.
5. BONDY, S. C., LEHMAN, R. A. W. and PURDY, J. L. 1974. Visual attention affects brain blood flow. Nature 248: 440–441.
6. COOPER, R. and CROW, H. J. 1975. Changes of cerebral oxygenation during motor and mental tasks. *In* D. H. Ingvar and N. A. Lassen (ed.), Brain work. Munksgaard, Copenhagen, p. 389–392.
7. DREHER, B., MARCHIAFAVA, P. L. and ŻERNICKI, B. 1965. Studies on the visual fixation reflex. II. The neural mechanism of the fixation reflex in normal and pretrigeminal cats. Acta Biol. Exp. 25: 207–217.
8. DREHER, B. and ŻERNICKI, B. 1969. Studies on the visual fixation reflex. III. The effects of frontal lesions in the cat. Acta Biol. Exp. 29: 153–173.
9. DREHER, B. and ŻERNICKI, B. 1969. Visual fixation reflex: behavioral properties and neural mechanism. Acta Biol. Exp. 29: 359–383.
10. INGVAR, D. H. 1975. Patterns of brain activity revealed by measurements of regional cerebral blood flow. *In* D. H. Ingvar and N. A. Lassen (ed.), Brain work. Munksgaard, Copenhagen, p. 397–413.
11. KATO, M., UENO, H. and BLACK, P. 1974. Regional cerebral blood flow of the main visual pathways during photic stimulation of the retina in intact and split-brain monkeys. Exp. Neurol. 42: 65–77.
12. MICHALSKI, A., KOSSUT, M. and ŻERNICKI, B. 1975. Single-unit responses to natural objects in area 19 of cats with different early visual experiences. Acta Neurobiol. Exp. 35: 77–83.
13. MICHALSKI, A., KOSSUT, M. and ŻERNICKI, B. 1977. The ocular following

reflex elicited from the retinal periphery in the cat. Vision Res. 17: 731–736.
14. PAULSON, O. B., CRONQVIST, S., RISBERG, J. and JEPPESEN, P. 1969. Regional cerebral blood flow: A comparison of 8-detector and 16-detector instrumentation. J. Nucl. Med. 10: 164–173.
15. RADIL-WEISS, T., ŻERNICKI, B. and MICHALSKI, A. 1976. Hippocampal theta activity in the acute pretrigeminal cat. Acta Neurobiol. Exp. 36: 517–534.
16. REIVICH, M., SOKOLOFF, L., KENNEDY, C. and DES ROSIERS, M. 1975. An autoradiographic method for the measurement of local glucose metabolism in the brain. *In* D. H. Ingvar and N. A. Lassen (ed.), Brain work. Munksgaard, Copenhagen, p. 377–384.
17. SCHMIDT, C. F. and HENDRIX, J. P. 1937. The action of chemical substances on cerebral blood vessels. Research Publ. A. Nerv. Ment. Dis. 18: 229–276.
18. SKOLASIŃSKA, K., KRÓLICKI, L. and ŻERNICKI, B. 1977. A cerebral blood flow increase to a visual stimulus in the occipital lobe of the cat with brainstem transection at the pretrigeminal level. Acta Neurobiol. Exp. 37: 5–14.
19. SOKOLOFF, L. 1961. Local cerebral circulation at rest and during altered cerebral activity induced by anesthesia or visual stimulation. *In* S. S. Kety and J. Elkes (ed.), Regional Neurochemistry. Pergamon Press, Oxford, p. 107–117.
20. ŻERNICKI, B. 1974. Isolated cerebrum of the pretrigeminal cat. Arch. Ital. Biol. 112: 350–371.
21. ŻERNICKI, B. and DREHER, B. 1965. Studies on the visual fixation reflex: I. General properties of the orientation fixation in pretrigeminal and intact cats. Acta Biol. Exp. 25: 187–205.
22. ŻERNICKI, B. and MICHALSKI, A. 1974. Single-unit responses to natural objects in visual areas 17 and 18 of cats reared under different visual experiences. Acta Neurobiol. Exp. 34: 697–712.

Accepted 10 April 1979

Krystyna SKOLASIŃSKA and Leszek KRÓLICKI, Institute of Physiology, School of Medicine, Krakowskie Przedmieście 26/28, 00-927 Warsaw, Poland.
Bogusław ŻERNICKI, Nencki Institute of Experimental Biology, Pasteura 3, 02-093 Warsaw, Poland.