Comparison of Somatosensory Evoked Potentials and Cerebral Blood Oxygenation Changes in the Sensorimotor Cortex During Activation in the Rat

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Abstract The relationship between changes in cerebral blood oxygenation and neuronal activity remains to be fully established. We compared somatosensory evoked potentials (SEP) and evoked cerebral blood oxygenation (CBO) changes in the sensorimotor cortex of the rat. In rats anesthetized with urethane and alpha-chloralose, we measured SEP and CBO using visible light spectroscopy (VLS) during neuronal activity. Increase of stimulus frequency caused a decrease of SEP amplitude, but an increase in concentration changes of deoxy-Hb and oxygen satu-ration. The difference in frequency responses between SEP and CBO might be caused by activation of inhibitory neurons, which could suppress excitatory neu-rons at high stimulus frequencies; activation of inhibitory neurons could reduce SEP amplitude, and increase oxygen saturation due to an increase of evoked cere-bral blood flow.

1 Introduction

Increases in neuronal activity in the adult normal brain are accompanied by increases in regional cerebral blood flow (rCBF) that exceeds the changes in oxygen consumption, leading to a decrease in concentration of deoxyhemoglobin (deoxy-Hb) in the veins [1]. NIRS studies have revealed that neuronal activation generally causes a decrease of deoxy-Hb with increases of oxy-Hb and total-Hb in the activation cortical area of normal adults [2, 3]. However, the relationship between changes in cerebral blood oxygenation (CBO) and neuronal activity remains to be fully established. In the present study, we compared somatosensory evoked potentials (SEP) and evoked CBO changes in the sensorimotor cortex of the rat under various stimulus conditions.

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2 Method

Male Fischer 344 rats ($n = 7$) weighing between 240 and 270 g were anesthetized with urethane (0.7 g/kg) and alpha-chloralose (0.06 g/kg). The right femoral artery was exposed and cannulated for the recording of arterial blood pressure and for sampling of blood gases. The right femoral vein was cannulated for drug administration. The rats were tracheotomized, paralyzed with pancuronium chloride (2 mg/kg/h), and mechanically ventilated with a mixture of air and oxygen to achieve physiological arterial blood levels of pH (7.33–7.50), PaO_2 (150–210 mmHg), and $PaCO_2$ (24–40 mmHg); arterial blood pressure had a range of 90–150 mmHg, and body temperature had a range of 36.2 to 36.88C. The animals were secured in a stereotaxic frame.

The right parietal bone was thinned over the sensorimotor cortex. Bipolar needle electrodes were inserted beneath the skin in the contralateral forepaw, and the median nerve was stimulated for 10 s with pulses of 8.0 mA intensity and 100 ms duration, at frequencies between 1 and 50 Hz. We recorded SEP and VLS positioned on the forepaw projection area of the somatosensory cortex. We measured SEP amplitude (P1 + N1 amplitude), and calculated SSEP amplitude (= SEP amplitude $\times$ stimulus frequency) [4].

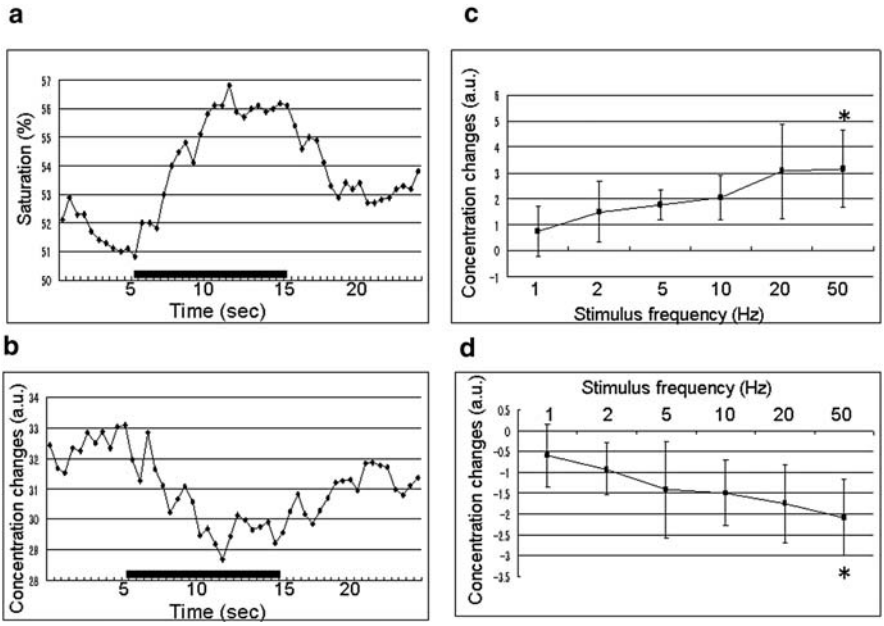

Fig. 1 (a, b) Examples of changes in oxygen saturation (a) and deoxy-Hb (b) caused by rat forepaw stimuli using VLS. The *horizontal thick bars* indicate stimulus periods. (c, d) Effect of stimulus frequency on oxygen saturation (c) and deoxy-Hb (d). Data expressed as means ± SD. There were significant differences in oxygen saturation and deoxy-Hb between 1 and 50 Hz ($P<0.05$)

did not change with increase of the stimulus frequency. The CBO change reached maximum at 50 Hz. There were significant differences in oxygen saturation and deoxy-Hb between 1 and 50 Hz ($p < 0.05$) (Fig. 1c,d).

The SEP amplitude declined with increase of the stimulus frequency (Fig. 2a). In contrast to evoked CBO changes, the maximum SSEP amplitude was observed at 2 Hz (Fig. 2b).

4 Discussion

We observed that an increase of stimulus frequency caused increases of oxy-Hb and oxygen saturation with a concomitant decrease of deoxy-Hb. This CBO change is consistent with the evoked CBO change observed during a focal increase of neuronal activity [2, 3]. Positron emission tomography demonstrated that increases of neuronal activity are accompanied by increases of rCBF that exceed the changes in oxygen consumption, leading to a decrease of deoxy-Hb in the veins [1].

Increase of stimulus frequency caused an increase of oxygen saturation with a decrease of deoxy-Hb, which reached the maximum levels at 50 Hz. In

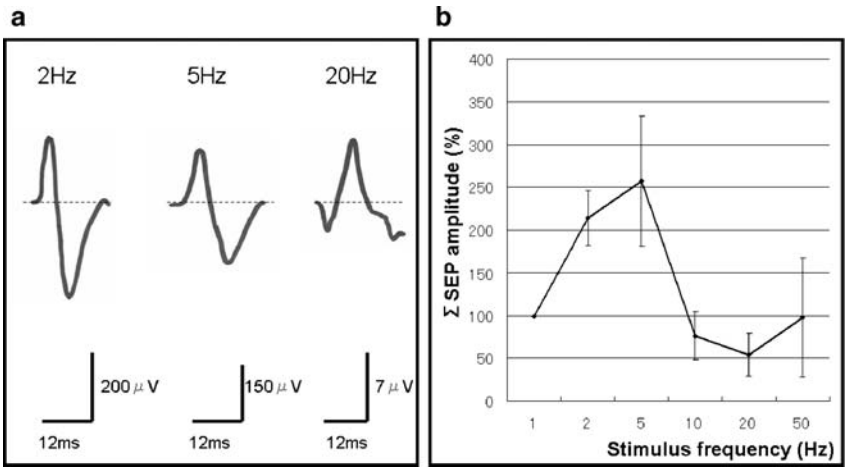

Fig. 2 (a) Stimultaneous recordings of somatosensory evoked potentials from one experiment. (b) Effect of stimulus frequency on the SSEP during rat forepaw stimuli. The maximum SSEP amplitude was observed at 5 Hz

contrast, the maximum SSEP amplitude was observed at 5 Hz. Ngai et al., employing the same equation for SSEP amplitude, evaluated the frequency response of SSEP amplitude (1∼20 Hz), and observed the maximum SSEP amplitude at 5 Hz [4]. While it is possible that the reductions of SEP are due to either inhibitory mechanisms, habituation of the peripheral nerve, or limitations of transmission of the sensory input, several studies have suggested that inhibitory mechanisms play the most important role in the reduction of SEP at high stimulus frequency [6, 7]. This might explain the physiological mechanism of the difference in frequency responses between SEP and evoked CBO responses. That is, activation of inhibitory neurons at high stimulus frequencies causes an increase of neuronal oxidative metabolism, resulting in an increase of CBO response at high stimulus frequencies. Indeed, Igarashi et al. evaluated the frequency response of the evoked changes in autofluorescence of flavoproteins, which reflect neuronal oxidative metabolism, and observed that the fluorescence attained maximal intensity at 50 Hz [8].

5 Conclusion

We compared SEP and evoked CBO changes in the sensorimotor cortex of the rat. Increases of stimulus frequency caused a decrease of SEP amplitude, but an increase of oxygen saturation with a decrease of deoxy-Hb; however, changes of stimulus frequency did not affect total-Hb concentration. Activation of inhibitory neurons at high stimulus frequencies could decrease the SEP amplitude, but in-crease evoked CBO changes.

References

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