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論文内容の要旨

The cortical organization in primary somatosensory cortex (SI), so called homunculus, and secondary somatosensory cortex (SII) in humans were drawn by Penfield and his colleagues during neurosurgical operation. Since then many studies using various methods have confirmed homunculus in both SI and SII, but detailed distribution of face area in SI and SII have not been clarified. Unit recording studies in monkeys showed different receptive fields in SI from homunculus, that is, receptive fields following stimulation of chin and nose are located more laterally than that following lip stimulation. Therefore, the objective of this study was to investigate the somatotopic organization of the facial skin area in the SI and SII in humans using magnetoencephalography (MEG), which is non-invasive method with high temporal and spatial resolution. To avoid stimulus artifacts caused by electrical stimulation applied to face, being very close to MEG recording system, we used specially made device, which induced pressure sensation induced by inflated plastic membrane by air pressure.

In the first experiment we recorded somatosensory evoked magnetic fields (SEFs), obtained by averaging MEG responses, generated in SI. We stimulated six points on the face (two points in each part of forehead, cheek and chin); lower lip and thumb. Interstimulus interval was 0.5s and approximately 200 responses were averaged. Using single equivalent current dipole (ECD) analysis, we estimated a dipole at the peak latency of a constant component around 40-50 ms following the stimulation. There were no significant differences in latency of the main component among 7 points of face stimulation. The amplitude (ECD strength) showed a significant difference (ANOVA) and the amplitude following thumb and lip stimulation are significantly larger than that following stimulation of other 6 facial skin points. The dipole

locations for SI activities were compared among eight stimulation points. The thumb area in SI was located more superior and medial to the lip area, which was consistent with Penfield's homunculus. The face area is located between the thumb and the lip. There were no significant differences of ECD location among three parts of the face as forehead, cheek and chin (represent for three branches of the trigeminal nerve). However, ECDs following stimulation of the medial part of the face was located in more lateral region significantly than those following stimulation of the lateral part of the face.

The lips occupy a large area of the face representation in SI, whereas only a small area located between the thumb and lip areas is devoted to skin covered surfaces. The lip has very sensitive particularity, a great mechanoreceptor density (Stohr and Petruch, 1979), roles in speaking and eating, and important part in tactile sensation. In contrast, the tactile function of the face is more modest. Therefore it was reasonable to conclude that the remaining facial area devoted to facial skin was small.

In the second experiment we recorded SEFs generated in SII following stimulation of five body sites: the foot, lip and three facial skin points (forehead, cheek and mandibular angle point). The interstimulus interval was longer than that used in Experiment 1, random from 2 to 4 s, since clear SII response was recorded with a long interstimulus interval. Approximately 70 - 100 responses were recorded. The consistent components with the peak latency around 100-150 ms following stimulation were analyzed. There were no significant differences in latency and amplitude of the main component. It seems strange that ECD strength following lip stimulation showed no significant difference from that following foot or facial skin areas, since lips should be more important part than the others and that in SI was significantly larger than the other facial areas. Probably SII plays more higher and complicated roles than SI and is equally sensitive for any parts of the body. With regard to the ECD location in SII,

the lip is in the most lateral area, the foot in the most medial area and the face in the intermediate area between the lip and the foot, but more closed to the lip area. However, there was no significant difference of dipole localization in SII among the three areas of the facial skin.

This is the first MEG study investigating activities in SI and SII following stimulation of various parts of the face, and the obtained results showed unique and novel findings, which are different from classic homunculus and reports using monkeys. A few recent studies using functional magnetic resonance imaging (fMRI) were also consistent with ours, that is, activities following lip and forehead stimulation are mostly overlapped. Of course, we notice what area of face is stimulated even when we close our eyes. Therefore, neurons which receive inputs from each face area should be different, but receptive fields following facial skin areas should be very closed each other, and the distance between them should be smaller than the spatial resolution of MEG. Therefore, by more studies using higher quality non-invasive methods in the future, face area in homunculus in humans will be probably changed.

論文の審査結果の要旨

触・圧覚の情報は 皮膚受容器から大脳皮質体性感覚野に至り、情報処理されている。体性感覚野には末梢との間に対応関係一体部位局在があり、古くはペンフィールドらが述べているように大脳皮質にヒトの絵(ホモンクルス)を描くことができる。このような体部位局在はヒト、サルなどで繰り返し調べられて来たが、近年になってヒトの脳活動を非侵襲的に計測可能になり、より詳細に検討されるようになった。しかし顔面領域がどのように体性感覚野に再現されているかについては十分、明らかではなかった。本論文においては、第一次体性感覚野(SI)および第二次体性感覚野(SII)において、顔面領域の再現について脳磁場計測によって詳細に調べた。

刺激は、チューブを使って顔面に圧搾空気を吹き付けることによって行い、記録は全頭型の脳磁計を用いた。実験1では、前頭部、鼻部、頬部、オトガイ部などの顔面と、対照として下唇、母指を刺激し、SI を中心にマッピングを行った。刺激後、40−50ms にピークを持つ反応が対側の SI 領域に得られた。それぞれ電流双極子を推定することにより体部位再現を検討すると、SI の中で母指は内側に下唇は外側に、顔面はその両者の間にマッピングされた。また、顔面の各領域は互いに重なって再現されていた。

実験2では、前頭部、頬部、下顎角の顔面と、対照として口唇、下肢を刺激し、SII に焦点をあてマッピングを行った。ピーク潜時が100ms 近くの反応を記録した。これは電流双極子の向きが SI 由来のものと異なることなどにより、明瞭に区別することが出来る。体部位再現を検討すると、SII の中で口唇は外側に、下肢は内側に、顔面はその両者の間にマッピングされた。一方、顔面の各領域は互いに重なって再現されていた。

このように SI, SII 両領域において、顔面は独立した領域を占めるが、顔面の中での体部位局在は互いに重なって再現されていた。このことは、従来のホモンクルスとは違う構成を示唆するのかもしれない。

このように本論文は、顔面領域の大脳皮質体性感覚野における体部位局在について詳細に検討したものである。実験方法も適切に考えられており、導かれている結論も妥当なものであり、それらは明快かつ平易な英語で記載されている。さらにこれらの結果は、すでに欧文誌に発表されており国際的にも十分な評価を受けている。これらのことから本論文は学位論文として十分にふさわしい内容であるものと結論された。