fMRI BOLD SIGNAL CHANGES AS A POWER FUNCTION OF LUMINANCE: AN INTERNAL PSYCHOPHYSICS APPROACH

Naoyuki Osaka, Hiroyuki Tsubomi, Takashi Ikeda and Mariko Osaka
Department of Psychology, Kyoto University, Kyoto 606, Japan and Department of Psychology, Osaka University, Osaka 562, Japan
<nosaka@bun.kyoto-u.ac.jp>

Abstract

An event-related functional MRI, using the blood oxygen level-dependent (BOLD) method, has become the preferred procedure for imaging the course of oxygeneration and by inference brain's neuronal activity accompanying subjective sensory experience. We measured how the BOLD imaging signal changes when perceived brightness changes as a power function of luminance. We found the BOLD signal tended to change as a power function of luminance intensity. We thus propose a new neuronal model of the internal psychophysics based on BOLD imaging signal (A BOLD psychophysics).

In 1860, Gustav Theodor Fechner published "Elements of Psychophysics (Fechner, 1860)" to establish a precise relationship between the physical and mental existence. In the last 35 years of his life his work focused on the idea that mind and matter are equal and are merely two alternative ways of regarding the universe (Tagesansicht und Nachtansicht). Through measurement and quantification he sought to prove his idea about the equivalence of mind and matter by finding a mathematical equation to describe the relationship between physical events and conscious experience (Gescheider, 1976). Fechner derived a general formula from Weber's law by integration over a series of physical intensity, and it was now known as Fechner's law. He called his ways of measurement "outer psychophusics" making bridge laws between mind and matter ignoring mediating physiology. He anticipated a later "inner psychophysics" to develop bridge laws between matter and physiology (how our brain processing the physical energy), and further bridge laws between physiology and mind (subjective experience) (how physiological energy produce our subjective experience).

Although, modern psychophysiology/physiological-psychology accumulated much knowledge on these issues, however, an essential issue on "inner psychophysics" has been neglected and remained unsolved until today.

Recent ways of measurement in neuroscience specifically "brain imaging" using functional magnetic resonance imaging (fMRI) technique represent a sophisticated development to understand "inner psychophysics".

Method

Nine graduate students participated in both brightness estimation and the fMRI experiment. Stimulus was a white circular target varying its luminance from 0.1 to 100 cd/m2 (5 steps) and subtended 1°×1° against a black background. The target was presented on a PC screen viewed at a distance of 57 cm. We used an event-related fMRI procedure in 3 blocks and the participants were asked to rate the target brightness by direct magnitude scaling using numbers (Stevens, 1971; Osaka, 1977, 1983). In the fMRI experiment, participants lay supine

in the fMRI scanner and viewed stimuli through the mirror attached to the head coil. The experiment was the same as the preliminary behavioral experiment. Prior to the experiment, auditory instruction like ”assign numbers in proportion to the observed target brightness based on modulus target” was given to the participant. The target was presented 2 s, and fMRI measure was started 6 s after target presentation which allowed separation of the BOLD signals between events. fMRI experiments were conducted in a 3-T MRI scanner with a head-volume coil (Trio, Siemens, Erlangen, Germany). A forehead strap and foam pads served for head fixation. Functional images were acquired using a T2*-weighted, gradient-echo, echoplanar imaging sequence with a prospective motion correction capability. The image acquisition parameters were as follows: repetition time (TR) = 3000 ms, echo time (TE) = 30 ms, flip angle (FA) = 90^0, field of view (FOV) = 192×192 mm, voxel size = 3.0×3.0×4.0 mm, slice number = 40 axial slices. Before the experimental session, high-resolution anatomical images were collected using a T1-weighted, magnetization-prepared, rapid-gradient echo sequence (TR = 2000 ms, TE = 4.38 ms, FA = 8^0, FOV = 195×240 mm, voxel size = 0.94×0.94×1, slice number = 208 axial slices).

Image processing and analysis were performed with SPM2 (Wellcome Department of Cognitive Neurology, London, UK) implemented in Matlab (MathWorks Inc., Shervorn, MA). The functional images were corrected for differences in slice acquisition timing, realigned to the first image for motion correction, smoothed with an isotropic Gaussian kernel of 6-mm full width-half maximum, and anatomically normalized to the MNI template (Montreal Neurological Institute, Quebec, Canada; Evans et al., 1993). Individual analysis was performed with a fixed effect model, while group analysis was performed with a random effect model. Using a general linear model, statistical parametric maps of *t*-statistics were calculated to identify voxels with event-related signal changes. Each event was convolved with a canonical hemodynamic response function. Low-frequency noise was removed using a high-pass filter with cut offs ranged 209-295s. The resulting *t*-statistics were transformed to *Z*-score maps of unit normal distribution.

Results and Discussion

We found activation in bilateral calcarine sulcus in the primary visual cortex as Fig.1 shows.

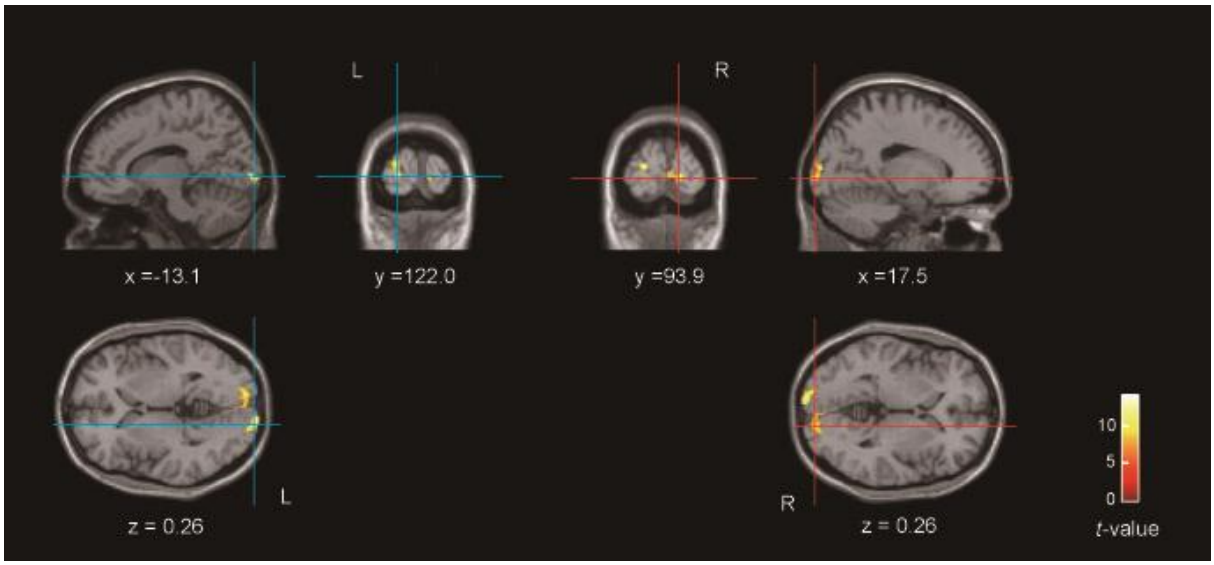

Fig. 1 Brain activation map under brightness magnitude estimation experiment

Sagittal and axial brains are shown in upper and lower panels, respectively. Activated areas in the right and left brain are indicated by bright spots in the right and left panel, respectively.

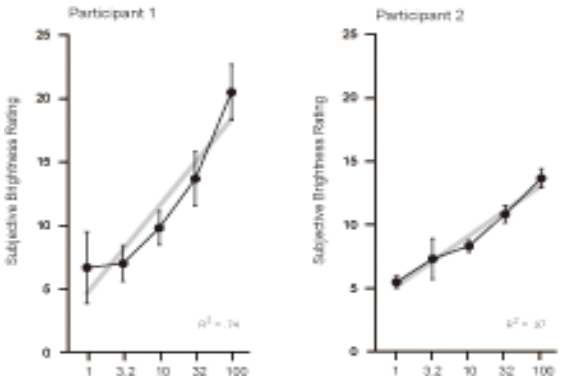

Fig.2 Subjective brightness as a function of luminance from two participants.

As Fig.2 indicates, behavioral data for brightness estimation increased as luminance increased. We then calculated fMRI's BOLD (blood oxygen level dependent) signal change (%) as a function of time. As Fig.3 shows, the BOLD signal change start to increased after 6 s after target presentation, reached maximum between 8 to 10 s, then start to decrease.

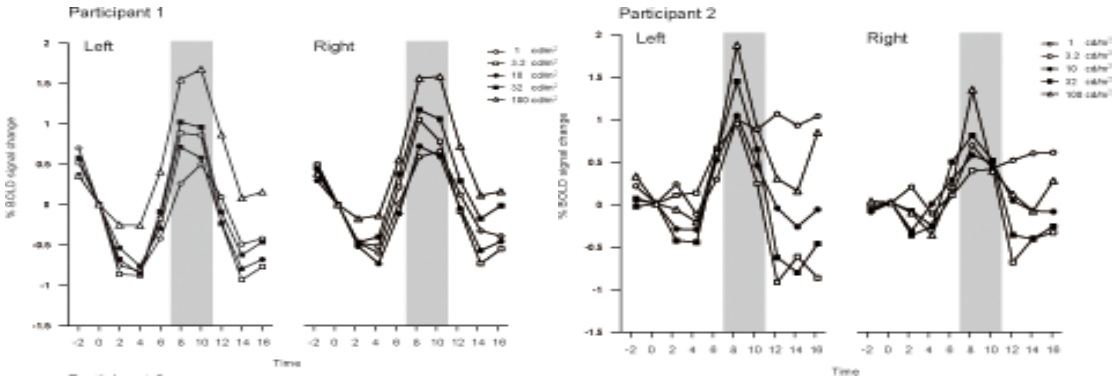

Fig.3 fMRI's BOLD signal change (%) as a function of time (s) from two participants. Parameter is luminance.

Parameter is five levels of luminance (0.1, 3.2, 10, 32, 100 cd/m2) and BOLD signal change was measured from the right and the left brain (shown in the right and the left panel, respectively). A total of 15 measures are collocted for each luminance level and participant.

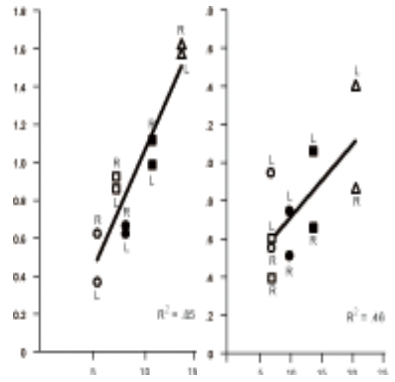

Fig.4 BOLD signal vs brightness (from two participants).

Interestingly, the BOLD signal increased as luminance level increased after 8 to 10 s target presentation. Fig.4 clearly indicates the BOLD signal increased as brightness increased.
We found in our previous study done 32 years ago, where there was no fMRI, indicated that both the latency of P1 component of visual evoked potential (event-related brain potential recorded from EEG electrode from the human scalp not the brain) and visual reaction time change as power function of luminance (Osaka and Yamamoto, 1978). This finding suggested that ”outer psychophysics” bridging physiology and behavioral response (reaction time) can also be described by power law. Today, we tried to fit power law to luminance vs BOLD signal and found tendency that BOLD signal increased as a function of luminance. Our current data are preliminary in nature and need more data and precise analysis to confirm the power law ”BOLD psychophysics” in the future.

Acknowledgements

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