Brain activation during maintenance of standing postures in humans

Yasuomi Ouchi, Hiroyuki Okada, Etsuji Yoshikawa, Shuji Nobezawa and Masami Futatsubashi

Summary
The regulatory mechanism of bipedal standing in humans remains to be elucidated. We investigated neural substrates for maintaining standing postures in humans using PET with our mobile gantry PET system. Normal volunteers were instructed to adopt several postures: supine with eyes open toward a target; standing with feet together and eyes open or eyes closed; and standing on one foot or with two feet in a tandem relationship with eyes open toward the target. Compared with the supine posture, standing with feet together activated the cerebellar anterior lobe and the right visual cortex (Brodmann area 18/19), and standing on one foot increased cerebral blood flow in the cerebellar anterior vermis and the posterior lobe lateral cortex ipsilateral to the weight-bearing side. Standing in tandem was accompanied by activation within the visual association cortex, the anterior and posterior vermis as well as within the midbrain. Standing with eyes closed activated the prefrontal cortex (Brodmann area 8/9). Our findings confirmed that the cerebellar vermis efferent system plays an important role in maintenance of standing posture and suggested that the visual association cortex may subserve regulating postural equilibrium while standing.

Keywords: postural balance; brain activation; PET; statistical parametric mapping

Abbreviations: ANCOVA = analysis of covariance; ANOVA = analysis of variance; BA = Brodmann area; rCBF = regional cerebral blood flow; SPM = statistical parametric mapping

Introduction
The mapping of human brain regions responsible for maintenance of standing posture is an unprecedented study, which may be comparable with the first report, in which the investigators used single photon emission tomography (SPECT) and described a focal increase in regional cerebral blood flow (rCBF) in the hand somatosensory area by simple finger movement (Lassen et al., 1977; Roland et al., 1980). Standing itself may be classified as simple behaviour, but maintenance of the postural balance requires rapid processing of signals from the visual, vestibular and somatosensory systems (Nashner, 1976). Alterations in these sensory functions relating to standing postures in human brain could never be studied with ordinary tomographic scanners. To date, the role of the sensory information for postural control has been investigated with a movement kinematic method by measuring body sway in conditions in which a certain sensory input was changed or limited.

It is common clinically that patients with vestibular deficits can show gait ataxia, abnormal head and body righting reactions, and difficulties in balancing on one leg and in heel-to-toe stance (Horak et al., 1988). The movement kinetic studies stressed that somatosensory as well as vestibular information was important in selection of postural movement adjustment according to the environmental context (Diener et al., 1984; Horak et al., 1990). It was also reported that vision ameliorated the fluctuation of the body position caused by standing with a narrow stance width or with eyes closed (Day et al., 1993). For elderly people, disequilibrium can be a common problem, as revealed by posturography (Fife and Baloh, 1993). Their instability can be triggered easily by malfunctioning responses to visual cues (Nashner et al., 1982), vestibular (Norre et al., 1987) and proprioceptive reflexes (Lord et al., 1991). Previous clinicopathological studies suggested that the cerebellum plays a central role in controlling postural balance (Holmes, 1922a, b) and that both the spinocerebellum and vestibulocerebellum participate in this sensory processing (Parent, 1996). Despite these lines of evidence, no conventional radiological scanners are suitable for mapping functional topography in the cerebellum involved in the postural equilibrium system for standing in humans.

Previous animal studies on cerebellar functions for body balance stressed that the cerebellar vermis located in the
with feet in a tandem position and standing with eyes closed, standing postures, such as standing on one foot, standing on substrates which are related to the process of maintaining the standing posture with the feet. However, is essentially different from the motor function (Nitschke, 1997). Moving the feet in the supine position, the supine position (Nitschke et al., 1996; Wessel and Nitschke, 1997). Moving the feet in the supine position, however, is essentially different from the motor function related to maintaining the standing posture with the feet.

The purpose of this study was to investigate neural substrates which are related to the process of maintaining standing postures, such as standing on one foot, standing with feet in a tandem position and standing with eyes closed, using PET with $^{15}$O.

**Methods**

**Subjects**

Eight healthy, right-handed (right-footed) female volunteers (31.8 ± 6.5 years, mean ± SD) participated in the present PET experiment. Before the study, the participants rehearsed the standing postures required, and the height of the scanner’s gantry was adjusted to each subject’s stature for optimal imaging. The present study was approved by the Ethics Committee of the Hamamatsu Medical Center, and written informed consent was obtained from all participants after the nature and possible risks of the experiment were explained.

**Experimental design**

The study consisted of five different tasks. The control task was to adopt the supine posture (Fig. 1A, Task A) and stare at a target (a round object) hanging 1 m ahead of the subject. Subsequently, subjects were instructed to adopt different standing postures: (i) standing with feet together and eyes open and focused on the target (Fig. 1B, Task B); (ii) standing on one foot with eyes open and focused (Fig. 1C, Task C); (iii) standing in a tandem posture with eyes open and focused (Fig. 1D, Task D); and (iv) standing with feet together and eyes closed (Fig. 1E, Task E). Since all participants were right-footed, the one-legged posture consisted of standing on the right foot (Task C), and standing in tandem consisted of having the left heel directly in front of the right toes (Task D). All tasks except for Task E required volunteers to stare at the target during PET measurement. Their ocular movements during measurements were monitored by videotaping. PET measurements in which marked ocular movement was observed in the replay checked just after the PET scan were discarded, and the same scan was repeated. As physiological parameters, blood pressure and pulse rate were measured before and after each PET scan.

Before PET measurement, a preliminary study was performed to investigate the magnitude of sway in each standing posture by measuring maximal lateral deviation of the head in the lateral direction and counting the number of sidesteps (collapse of posture) within a period of 60 s (Table 1). Each subject stood upright in a series of postures against the wall with a lattice measuring scale on it. Although the situation in the present PET study was not the same as that in this preliminary study in terms of fixation of the head, no significant differences \( P > 0.05 \), one-way ANOVA (analysis of variance) with Scheffe’s \( F \) test in the magnitude of sway were observed among standing-related tasks except for Task E. This result permitted further comparison among standing tasks in the present PET study. However, care was necessary in interpreting results from Task E-involved comparisons because head fixation might be expected to influence standing posture significantly.

**PET procedure**

We used a high-resolution PET scanner (SHR2400, Hamamatsu Photonics, Hamakita, Japan) with spatial resolution of 2.7 mm (full-width at half-maximum) transaxially and 5.5 mm axially and with 80 mm axial field of view (Yamashita et al., 1990). This PET system had a mobile gantry which enabled vertical movement (up to 165 cm from the bottom) and tilting (−20° to +90°). The restricted axial field of view obliged us to determine beforehand the scanning area required in the PET study on the mid-sagittal image obtained by MRI (see below) (Ouchi et al., 1997). By tilting the PET gantry, the axial field of view could cover the area from the middle frontal gyrus to the lower part of the cerebellum. After backprojection and filtering (Hanning filter,
cut-off frequency 0.2 cycles per pixel), image resolution was
8.0 × 8.0 × 6.5 mm full-width at half-maximum. The voxel of
each reconstructed image measured 1.45 × 1.45 × 8 mm.

The head was fixed using a specially made thermoplastic
face mask and head holder which was fitted firmly to the
urethane holder receiver attached to the internal surface of
the gantry hole of the PET scanner. After fixation of the
head in the holder, a 20 min transmission scan was obtained
in the supine position. After the first emission scan in the
supine posture with eyes open and focused on a target
hanging 1 m ahead (Task A), the head holder was removed
temporarily from the receiver and the position of the gantry
position was realigned satisfactorily to the position of the
in the holder, a 20 min transmission scan was obtained
the gantry hole of the PET scanner. After fixation of the
the axial direction using a static magnet (0.3 T MRP7000AD,
both MRI and PET measurements.

Data analysis
Statistical parametric mapping (SPM) software (SPM96;
Wellcome Department of Cognitive Neurology, London,
UK) implemented in Matlab (Mathworks Inc., Sherborn,
Mass., USA) on a HyperSPARC ss-20 workstation (Sun
Microsystems Co., Montain View, Calif., USA) was used to
realign all PET scans to the first emission scan to correct for
head movement (Friston et al., 1995a, b). After realignment,
all images were transformed into a standard stereotaxic
anatomical space (Talairach and Tournoux, 1988) and filtered
with an isotropic Gaussian kernel of 8 mm full-width at half-
maximum to increase the signal-to-noise ratio and to allow for
the gyral anatomical differences among individuals. The effect
of variance due to global cerebral blood flow was removed by
using voxel-by-voxel ANCOVA (analysis of covariance) with
the global flow normalized to 50 ml/100 g/min as a
confounding covariate. This process generated normalized
mean rCBF values on a voxel-by-voxel basis for each task.
Comparison of adjusted mean rCBF in a specific task with
the peak height: 1.7* 0.0

Standing with feet together 17.9 ± 1.8 0.0 ± 0.0
Standing on one foot 20.1 ± 2.3 0.3 ± 0.5
Standing in tandem 20.4 ± 1.9 0.1 ± 0.3
Standing with feet together (eyes closed) 21.7 ± 1.7* 0.0 ± 0.0

Values are expressed as mean ± SD. *P < 0.01 versus standing with feet together and eyes open
(one-way ANOVA).

Table 1 Postural stability in preliminary measurements (60 s duration)

<table>
<thead>
<tr>
<th>Posture</th>
<th>Maximal sway (mm)</th>
<th>No. of sidesteps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing with feet together</td>
<td>17.9 ± 1.8</td>
<td>0.0 ± 0.0</td>
</tr>
<tr>
<td>Standing on one foot</td>
<td>20.1 ± 2.3</td>
<td>0.3 ± 0.5</td>
</tr>
<tr>
<td>Standing in tandem</td>
<td>20.4 ± 1.9</td>
<td>0.1 ± 0.3</td>
</tr>
<tr>
<td>Standing with feet together (eyes closed)</td>
<td>21.7 ± 1.7*</td>
<td>0.0 ± 0.0</td>
</tr>
</tbody>
</table>

Results
Physiological changes during PET
measurements (Table 2)
There were no significant differences in systemic blood
pressure or pulse rate before and after each PET measurement
under any of the experimental conditions (P > 0.05, repeated
ANOVA). Neither significant reduction in blood pressure nor
increase in pulse rate were observed during standing.

MRI procedure
MRI was performed to determine the scanning brain area in
the axial direction using a static magnet (0.3 T MRP7000AD,
Hitachi, Japan) with the following acquisition parameters:
three-dimensional mode sampling, TR/TE (200/23), 75° flip
angle, 2 mm slice thickness with no gap and 256 × 256
matrices. The spatial relationship between the locus of the
centre of the magnetic field and that of PET images was
 calibrated in advance. This calibration permitted us to perform
PET scans parallel to an arbitrarily sectioned MRI plane and
to select the brain area concerned in an axial direction by
tilting PET detector rings (Ouchi et al., 1997). The same
thermoplastic face mask and head holder were used during both
MRI and PET measurements.
Table 2  Physiological data for each condition

<table>
<thead>
<tr>
<th>Posture</th>
<th>Systolic blood pressure</th>
<th>Pulse rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-scan</td>
<td>Post-scan</td>
</tr>
<tr>
<td>Supine</td>
<td>122.0 ± 17.7</td>
<td>124.7 ± 18.7</td>
</tr>
<tr>
<td>Standing with feet together</td>
<td>121.6 ± 17.3</td>
<td>127.9 ± 19.8</td>
</tr>
<tr>
<td>Standing on one foot</td>
<td>123.0 ± 17.7</td>
<td>129.3 ± 20.6</td>
</tr>
<tr>
<td>Standing in tandem</td>
<td>123.2 ± 17.9</td>
<td>130.9 ± 21.8</td>
</tr>
<tr>
<td>Standing with feet together (eyes closed)</td>
<td>121.3 ± 16.2</td>
<td>125.8 ± 19.1</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.

Table 3  Coordinates and Z scores for significant activation during standing postures (P < 0.05, corrected) compared with supine position

<table>
<thead>
<tr>
<th>Posture</th>
<th>Brain region</th>
<th>Coordinates</th>
<th>Z</th>
<th>%ΔCBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing with feet together</td>
<td>R lingual/inferior occipital gyri (BA 17/18)</td>
<td>26</td>
<td>-90</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>R cerebellar anterior lobe (culmen)</td>
<td>24</td>
<td>-80</td>
<td>-16</td>
</tr>
<tr>
<td></td>
<td>Cerebellar anterior vermis</td>
<td>-2</td>
<td>-72</td>
<td>-10</td>
</tr>
<tr>
<td>Standing on one (R) foot</td>
<td>R cerebellar anterior lobe (culmen)</td>
<td>20</td>
<td>-34</td>
<td>-24</td>
</tr>
<tr>
<td></td>
<td>Cerebellar anterior vermis</td>
<td>-6</td>
<td>-56</td>
<td>-20</td>
</tr>
<tr>
<td></td>
<td>R cerebellar posterior lobe (lateral cortex)</td>
<td>46</td>
<td>-42</td>
<td>-28</td>
</tr>
<tr>
<td>Standing with feet in tandem</td>
<td>R cerebellar anterior vermis</td>
<td>16</td>
<td>-80</td>
<td>-10</td>
</tr>
<tr>
<td></td>
<td>R inferior occipital gyrus (BA 18)</td>
<td>24</td>
<td>-86</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>R inferior temporal gyrus (BA 37)</td>
<td>56</td>
<td>-58</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>Cerebellar posterior vermis</td>
<td>4</td>
<td>-58</td>
<td>-40</td>
</tr>
</tbody>
</table>

BA = Brodmann area; R = right; L = left. These standing conditions required subjects to keep eyes focused on the target during PET measurements.

Brain activation during standing postures compared with the supine position (P < 0.05, corrected) (Table 3)

Nomenclature in the cerebellum (Ito, 1984) was based on the MRI atlas (Courchesne et al., 1989). Comparison of bipedal standing with the supine posture showed significant rCBF increases in the right primary and secondary visual cortex [Brodmann area (BA)17/18], the left cerebellar anterior lobe (culmen) and the anterior vermis (Fig. 2A).

Comparison of standing on one foot (right) with the supine posture showed significant activation in the right-sided cerebellar anterior lobe (culmen) and the anterior vermis, and the right posterior lobe (Fig. 2B).

Comparison with the supine posture, standing with feet together in a tandem relationship activated the cerebellar anterior and posterior vermis, and the inferior occipital (BA 18) and temporal cortex (BA 37), considered to be the visual association cortex (Fig. 2C).

Brain activation for balancing in upright postures: comparison of standing in tandem posture with standing with feet together (P < 0.05, corrected) (Table 4, Fig. 3)

Compared with the upright posture with feet together, standing with the feet in tandem activated focal regions in the medial longitudinal cerebellar zone (vermis) and the left midbrain corresponding to the red nucleus. This vermal zone included the central lobule and culmen anteriorly and the uvula and nodulus posteriorly. Activation, albeit not statistically significant (Z = 3.01), was also seen in the left thalamus.

Brain activation during standing with eyes closed, compared with standing with eyes open (P < 0.05, corrected) (Table 5, Fig. 4)

Shifting from the eyes open to eyes closed condition during bipedal standing (‘Romberg manoeuvre’) resulted in significant activation in the bilateral middle frontal gyr (BA 9 and 8).

Discussion

The present study was performed to determine the brain topography for maintenance of postural balance during standing in humans. However, there were several methodological limitations of the present study. First, fixation of the head sacrificed a free and natural standing style intrinsic to each subject and impaired the subjects’ ability to correct for imbalance during standing. It was unpredictable to what extent volunteers depended on the head fixation system during standing, but our preliminary study measuring the
Brain and standing postures

Fig. 2 Results of SPM in comparisons of several standing postures with the supine position ($P < 0.01$, corrected) with the eyes open. (A) Standing with feet together versus supine; (B) standing on one foot versus supine; (C) standing with feet in a tandem relationship versus supine. Details of coordinates and Z-values are given in Table 3.

### Table 4 Activated foci in balancing posture: standing with feet in tandem versus with feet together

<table>
<thead>
<tr>
<th>Brain region</th>
<th>Coordinates</th>
<th>Z</th>
<th>%ΔCBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>R cerebellar anterior vermis</td>
<td>8, -40, -8</td>
<td>4.28</td>
<td>3.7</td>
</tr>
<tr>
<td>L midbrain (red nucleus)</td>
<td>-6, -18, -4</td>
<td>4.04</td>
<td>3.3</td>
</tr>
<tr>
<td>L cerebellar anterior vermis</td>
<td>-16, -44, -10</td>
<td>3.94</td>
<td>3.1</td>
</tr>
<tr>
<td>Cerebellar posterior vermis</td>
<td>-4, -52, -46</td>
<td>3.91</td>
<td>2.9</td>
</tr>
</tbody>
</table>

R = right; L = left.

Sway magnitude while adopting different standing postures showed that there were no significant differences in sway level among postures with eyes open. These differences in sway magnitude indicated that different stimuli caused by altering upright posture could cause focal brain activation in the areas contributing to each postural regulation. This was supported by the PET activation study showing that different types of movement of a unilateral upper limb resulted in alterations in activated intensity and foci in the brain (Colebatch et al., 1991). Secondly, the removal of head fixation between scans could have caused positional errors which might have resulted in errors on final analyses. However, the use of the face mask and head holder which covered the volunteer’s craniofacial part throughout the PET
Fig. 3 Significant rCBF increases in a comparison of standing in tandem (Task D) with standing upright (Task B) were observed in the anterior and posterior vermis and the midbrain corresponding to the red nucleus. Weak (not significant) activation of the left thalamus was also observed. The numerals denote z-directional distance from the AC–PC (anterior–posterior commissural) line on Talairach’s standardized brain atlas. The coloured bar indicates Z-values from 0 to 5.

Table 5 Activated foci during ’Romberg test’: standing with eyes closed versus eyes open

<table>
<thead>
<tr>
<th>Brain region</th>
<th>Coordinates</th>
<th>Z</th>
<th>% ΔCBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>L middle frontal gyrus (BA 9)</td>
<td>−26 48 34</td>
<td>4.58</td>
<td>3.9</td>
</tr>
<tr>
<td>R middle frontal gyrus (BA 8)</td>
<td>30 40 42</td>
<td>3.91</td>
<td>3.0</td>
</tr>
</tbody>
</table>

BA = Brodmann area; R = right; L = left.

examination and a three-directional laser marker permitted maintenance of the initial position and allowed further analysis using SPM96. Thirdly, our scanner’s axial field of view was insufficient to cover the whole brain, and therefore we had to exclude the brain region covering the primary somatosensory foot area. An animal experiment showing that a cat lacking the cerebrum was able to walk (Miller et al., 1975) suggested that the cerebral cortex was not involved in walking control. However, there was anatomical evidence of ascending efferent fibres from cerebellar nuclei projecting to the contralateral primary motor area (Parent, 1996), along with evidence of significant activations in the foot area while walking in humans revealed by our previous SPECT study (Fukuyama et al., 1997). Thus, the primary foot somatosensory area cannot be neglected as a candidate for postural control. Fourthly, physiological conditions, especially in the brain haemodynamics, may be altered by shifting from the supine position to the standing position. However, stabilization of systemic blood pressure and pulse rate of each subject measured before and after each scan reduced this possibility. In addition, ANCOVA eliminated the confounding effect from the global cerebral blood flow change during statistical analysis in SPM96.

The present study showed that the activated brain areas during upright standing in humans were localized to specific divisions of the cerebellum (the anterior lobe and the medial longitudinal zone, i.e. vermis) and the visual cortex. Our preliminary sway measurement study showed that compared with normal bipedal standing, balancing unipedal and tandem directional upright postures scored a little worse (Table 1).
Fig. 4 Significant rCBF increases in a comparison of bipedal standing with eyes closed (Task E) versus that with eyes open (Task B) were found in the bilateral middle frontal gyri (BA 8/9).

This might indicate that the latter postures could possibly require more accurate co-ordinating responses to postural adjustment for shifting the centre of gravity (Mitchell, 1971; Richardson et al., 1996). Our results showing anterior lobe and medial cerebellum activation during standing supported the observations of previous human lesion studies which indicated that medial cerebellar lesions disturbed balance and gait, while the lateral cerebellar lesions impaired motor co-ordination in the distal extremities (Ivry et al., 1988; Diener et al., 1989). Thus, our findings confirmed that the cerebellar anterior lobe, specifically the anterior vermis, plays a central role in upright postural equilibrium during standing in humans.

Functionally, the vermal and paravermal cortical areas are specific parts of the cerebellum encompassing fastigial nuclei which are concerned primarily with mechanisms that modify extensor muscle tone for postural control (Chambers and Sprague, 1955; Ito, 1984) and interposed nuclei (emboliform and globose) for facilitation of flexor muscle tone for proper maintenance of posture via the rubrospinal tract (Courville, 1966; Flumerfelt et al., 1973). Vestibular nuclei project to the uvula, nodulus and flocculus which, in part, comprise the posterior vermis and contribute to postural equilibrium (Kotchabhakdi and Walberg, 1978; Carpenter, 1988). These findings might be supported by the present result that comparison of the bipedal posture with feet in a tandem relationship with the normal bipedal posture showed significantly activated foci rostrocaudally in the cerebellar medial longitudinal areas (Fig. 3). Activation in the anterior vermis and the midbrain corresponding to the red nucleus along with weak thalamic activation (Fig. 3) suggested that the cerebellar–rubrothalamic projection system (Appelberg, 1960; Eager, 1963; Tolbert et al., 1978) may function as a regulatory neuronal output to adjust upright balance during standing. The posterior vermal activation in the present study might reflect augmentation of vestibulo-ocular responses because the posterior vermis (nodulus and uvula) plays an important role in habituating and stabilizing the vestibulo-ocular reflex in head positioning (Waespe et al., 1985). It was reported that alterations in platform angle disturbed correct information from the vestibular system, resulting in collapse of upright posture in aged subjects (Diener et al., 1986; Norre et al., 1987). Adopting such a distorted platform in the present study would have caused explicit activation in the vestibulocerebellum.

The lack of lower brainstem (vestibular nuclei) activation in the present study might be partly due to use of the head fixation and restriction of the ocular movement by gaze fixation. The important contribution of vision to proprioception is that of sensing the movement of the head in space. In cats, the visual proprioceptive neurons responding to moving objects in a specific direction were localized in the
rostral pontine region (Baker et al., 1976). This brainstem region might also be important in humans for visual proprioceptive control because a human lesion study showed that lesions of the pontomedullary vestibular nuclei and the rostral tegmentum disturbed the pattern of co-ordinated eye–head roll motion (Brandt and Dieterich, 1987). Thus, activations in the lower brainstem would have been expected in the condition permitting a volunteer to perform self-paced postures without any head fixation.

The present study showed significant activation in the visual cortex on comparison of standing postures with the supine condition. Monitoring of ocular movement by videotape ensured that this activation in the visual cortex was not ascribed to saccadic eye movement during standing. However, this method was not sufficient to monitor minute ocular motions or changes in optic focus. Therefore, it is possible that there might be electrooculographic or retinoscopic ocular adjustment for stereopsis during standing because the stereoscopic processing requires activities of area 18 in the right hemisphere (Ptito et al., 1993; Nagahama et al., 1996). In the present study, the activated cortical areas outside the cerebellum were chiefly confined to the human V2–V3 areas (McKeefry et al., 1997). It was reported that areas V2–V3 were involved in the processing of the stereoscopic or disparity vision and orientation discrimination (Clarke and Miklossy, 1990). Interestingly, standing in tandem showed significant activation in the fusiform gyrus corresponding to V5 for motion vision (Zeki et al., 1991). These findings suggested that standing with the eyes open itself may accompany concurrent activation of the visual cortical fields which may subserve stereopsis and motion vision to maintain proper standing posture. This speculation was supported by the clinical evidence that distortion of visual input caused deterioration of postural balance during standing (Wolfson et al., 1992).

Comparison of standing with eyes closed versus eyes open showed significant activation in the bilateral middle frontal gyri (BA 8/9), a little anterior ventral to the reported frontal eye field (Paus, 1996) (Fig. 4). The frontal eye field and the supplementary eye field (medial part of the superior frontal gyrus) were shown to be activated during imagined saccade without eye movement (Bodis-Wollner et al., 1997). In addition, an imaginary mental task activated area 8 and its reciprocally connected dorsolateral prefrontal cortex (BA 9/46) (Cohen et al., 1996). These results suggested that standing with eyes closed may resemble mental imagery resulting in significant activation in the BA 8/9 in the present study. Clinically, this type of manoeuvre, i.e. shifting from eyes open to eyes closed during standing with feet together, is known as the ‘Romberg test’ and categorized as a neurological test for sensory ataxia (Haerer, 1992).

Conclusions

We identified functional brain fields associated with equilibrium of upright posture during standing in humans. Our findings confirmed the idea that the cerebellar vermis efferent system is involved in the active maintenance of body balance, and suggested that the visual association cortex contributes to its stability possibly by monitoring three-dimensional orientation in space while standing.

Acknowledgement

We thank Mr Toshihiko Kanno for his technical assistance.

References


Received June 8, 1998. Revised August 27, 1998
Second revision on September 30, 1998. Accepted October 5, 1998