Prolonged Rock Climbing Activity Induces Structural Changes in Cerebellum and Parietal Lobe

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Abstract: This article analyzes whether climbing, a motor activity featured by upward movements by using both feet and hands, generation of new strategies of motor control, maintenance of not stable equilibrium and adoption of long-lasting quadrupedal posture, is able to modify specific brain areas. MRI data of 10 world-class mountain climbers (MC) and 10 age-matched controls, with no climbing experience were acquired. Combining region-of-interest analyses and voxel-based morphometry we investigated cerebellar volumes and correlation between cerebellum and whole cerebral gray matter. In comparison to controls, world-class MC showed significantly larger vermal lobules I–V volumes, with no significant difference in other cerebellar vermal lobules or hemispheres. The cerebellar enlargement was associated with an enlargement of right medial posterior parietal area. The specific features of the motor climbing skills perfectly fit with the plastic anatomical changes we found. The enlargement of the vermal lobules I–V seems to be related to highly dexterous hand movements and to eye-hand coordination in the detection of and correction of visuomotor errors. The concomitant enlargement of the parietal area is related to parallel work in predicting sensory consequences of action to make movement corrections. Motor control and sensory-motor prediction of actions make the difference between survive or not at extreme altitude. *Hum Brain Mapp* 34:2707–2714, 2013. © 2012 Wiley Periodicals, Inc.

Key words: word-class rock climbers; cerebellum; cerebral cortex; region of interest; voxel-based morphometry

INTRODUCTION

Climbing is a complex motor activity in which the sustained vertical motion, and the peculiar role of upper

limbs, distinguishes it from other land-based movements [Quaine and Martin, 1999]. The activity is characterized by short bouts of high-intensity exercise, with short intermitted periods of rest. The upper body checks the posture, while the lower limbs are mainly involved in sustaining the body mass [Bourdin et al., 1998]. Besides the production of these voluntary motor activities, climbing requires motor learning of new motor schemes, coordination of the body parts involved in the vertical movement (synergia), and ability to carry out rapidly the voluntary movements in successive sequences (diadochokinesis) in order to keep the body in balance. For human beings, indeed, moving

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Received for publication 11 January 2012; Revised 29 February 2012; Accepted 16 March 2012

DOI: 10.1002/hbm.22095

Published online 21 April 2012 in Wiley Online Library (wileyonlinelibrary.com).

TABLE I. Demographic and anthropometric data

	Word-class MC (<i>n</i> = 10)	CG (<i>n</i> = 10)	Student's <i>T</i>	<i>P</i> value
Age (years ± SD)	38 (8)	39 (8)	$t_{(18)} = -0.21$	0.8
Gender	All men	All men		
Handedness (The Edinburgh Handedness Inventory)	All right-handed	All right-handed		
Height (cm ± SD)	176 (5)	175 (6)	$t_{(18)} = 0.47$	0.6
Weight (kg ± SD)	70.8 (6)	71.4 (6)	$t_{(18)} = -0.35$	0.7
BMI (kg/m ² ± SD)	22.6 (1)	21.4 (4)	$t_{(18)} = 0.94$	0.4

World-class MC, world-class mountain climbers; CG, control group; BMI, body mass index.

vertically requires per se a motor learning. Additionally, it has been found [Zampagni et al., 2011] that expert climbers acquire two adaptive features. More in details, they adopt and well manage a peculiar motor pattern consisting in a paradoxical “destabilization” of the center of mass (COM) oscillations in the lateral direction and surprisingly large distances of the body from the vertical structure. Moreover, during climbing in order to keep the body in balance, upward center of mass COM displacements are prevalently guaranteed by the greater vertical forces generated onto the feet’s support, whereas the forces onto the hands act much more in overhanging position [Noe, 2006; Noe and Quaine, 2006; Noe et al., 2001]. As it is known, the cerebellum is organized into functional divisions with distinct connections to the brain and spinal cord. The vestibulocerebellum controls balance and eye movements, spinocerebellum adjusts on-going movements and cerebrocerebellum coordinates the planning of movements [Glickstein et al., 2009]. Furthermore, cerebellum has been considered a region largely involved in motor learning [Manto and Jissendi, 2012]. All together, the cerebellum appears not only strongly implicated in the control of movement but simultaneously it appears to have functions that go beyond this control. Its role in motor learning is continuously required because normal motor behavior and even more motor complex learned activity which require constant adaptation as circumstances change. Thus, in this study investigating the relation between a motor complex learned activity, such as climbing, and cerebellar macrostructural changes appeared particularly appropriate.

Experimental studies suggest a causal relationship between motor skill learning, exercise and structural changes of cerebellar structures [Anderson et al., 2002; Kleim et al., 1997]. Also human studies demonstrate that learning-induced neuroplasticity is reflected at a structural level in brain areas demanded by the practiced task [Bezola et al., 2011; Draganski et al., 2004; Hanggi et al., 2010; Jancke et al., 2009].

The cerebral neuroanatomical underpinnings of motor skills have been studied in differently motor-expert individuals, ranging from highly trained professional musicians [Hutchinson et al., 2003], to experienced typists [Cannonieri et al., 2007], and basketball players [Park

et al., 2009]. These studies indicate that skill acquisition and training in various domains, such as motor or cognitive functions, evoke substantial changes in brain anatomy and the increase of cerebellar volume represents one of the main structural adaptation to long-term motor training.

The present study was aimed at exploring whether the peculiar vertical movement characterizing the rock climbing can induce cerebellar volume differences in world-class mountain climbers (MC) compared to control group (CG); and whether eventual cerebellar morphometry modifications were associated to neocortical gray matter (GM) volume in world-class MC.

For this purpose, we applied two different and well-validated structural analysis techniques: a region of interest (ROI) imaging approach, based on manual tracing of the ROIs, to investigate cerebellar volume changes; and the voxel-based morphometry (VBM), an automatic images procedure, to analyze the whole brain GM and investigate whether cerebellar volumes (ROIs) are related to neocortical GM.

MATERIAL AND METHODS

Subjects

A rare group of ten male world-class MC with previous high-level experience of climbing in the Alps, Himalayas and Andes, were included in this study (Table I).

All of them had been for at least 10 years before we collected MRI images. MRI images of nine out of 10 world-class MC have been already reported in a previous study on gray and white matter cerebral changes [Di Paola et al., 2008]. Ten healthy male subjects with similar age, anthropometric traits and with no experience in climbing, were selected as CG to cross-match comparisons (more details in [Di Paola et al., 2008]). As shown in Table I, there were no significant differences in demographic and anthropometric data between groups. Before participating in the study, all subjects (world-class MC and CG) read and signed the informed consent form. All participants provided written informed consent. Consent was obtained according to the Declaration of Helsinki, and the study was approved by the ethical committee of IRCCS Santa Lucia Foundation, Rome, Italy.

MRI Acquisition

All MRI data were acquired at IRCCS Santa Lucia Foundation, Rome, Italy, by using an MR scanner operating at 1.5T (Siemens, Magnetom Vision, Erlangen, Germany). All world-class MC were assessed 8 weeks after they returned from the expedition [mean time in weeks (SD) = 7.6 (0.7)]. The following pulse sequences, for both world-class MC and CG, were obtained in a single session: (a) axial T2-weighted fast spin-echo (SE) (TR/TE: 3800/90 ms); (b) axial fluid-attenuated inversion-recovery (FLAIR) (TR/TE: 9.000/119 ms; TI: 2.470 ms); (c) 3D T1-weighted magnetization-prepared rapid-acquisition gradient echo (MPRAGE) (TR/TE: 11.4/4.4 ms; TI: 20 ms; flip angle: 15°). For the T2-weighted and FLAIR sequences, 21 axial slices, 5-mm-thick, with an intersection gap of 1 mm, a 240 mm field of view, and a 256 × 256 matrix were acquired. For the MPRAGE sequence, 159 slices, 1 mm-thick, with sagittal orientation, a 256×256 matrix size, and a 256 mm field of view were acquired. Two experienced observers (M.D.P. and U.S.), unaware of whom the scans belonged to, independently reviewed the T2-weighted and FLAIR scans of all subjects to identify, by consensus, pathological hyperintensities.

MRI Analysis and Post-Processing

Radiofrequency bias field corrections were applied to all images, to eliminate intensity drifts due to magnetic field inhomogeneities [Sled et al., 1998]. To adjust cerebral measurements for individual and group differences in brain size, in order to reduce the interindividual variability in gross brain size, different reference measures such as forebrain volume, cranial capacity, or cross-sectional cerebral area have been used in various studies either as a ratio [Jancke et al., 1997, 1999a], or as a covariate corrected statistic [Schmitt et al., 2001a; Wang et al., 1992]. Recently, by testing different methods [Bermudez and Zatorre, 2001], it was concluded that a reliable brain volume normalisation could be obtained by registering the MRI brain volumes into the Talairach proportional stereotaxic space using the algorithm developed by Collins et al. [1994]. In this way, gross brain size differences are ruled out and the error-prone collecting of an index of brain size is circumvented. For these reasons, in this study, to adjust cerebral measurements for individual and group differences in brain size, each of the MRI brain volumes, from which the cerebellar measures were collected, have been registered into the Talairach proportional stereotaxic space using a nine-parameter registration algorithm similar to that used in the previous study [Bermudez and Zatorre, 2001]. The normalised Talairach stereotaxic space cerebellar measures were obtained by applying the appropriate dimension of scaling recovered during the Talairach stereotaxic brain volume transformation.

Cerebellar Vermis Volume

The cerebellar vermis was traced on the midsagittal slice. The midsagittal slice was identified by selecting the sagittal image showing lobular anatomy of the vermis, cerebral aque-

duct, corpus callosum, spinal cord, and fourth ventricle. The boundaries were delineated according to the previously existing protocol [Mostofsky et al., 1998; Schmitt et al., 2001b]. Briefly, after the midsagittal MRI section was selected, the cerebellar vermis was subdivided into three ROIs. The vermian ROI1 (anterior vermis) including the lobules I–V, the vermian ROI2 including the lobules VI and VII, and the vermian ROI3 (posterior vermis) including the lobules VIII–X. The cerebellar tonsils and hemispheres were excluded from the vermian ROIs (Fig. 1A). The whole protocol for segmentation of the cerebellar vermis is described elsewhere [details in Mostofsky et al., 1998; Schmitt et al., 2001b].

The significance level was adjusted for the 5 independent statistical comparisons (vermian lobules I–V; vermian lobules VI–VII, vermian lobules VIII–X, left hemisphere and right hemisphere, see paragraph below) (Bonferroni correction, $P = 0.05/5 \sim 0.01$).

Cerebellar Hemisphere Volume

To trace each cerebellar hemisphere, the hemispheric GM and white matter, the cerebellar tonsils, the vellum, and the corpus medullare were taken into account, whereas the vermis, the cerebellar peduncles, and the fourth ventricle were excluded. The protocol for segmentation of the cerebellum hemisphere is described elsewhere (details in [Park et al., 2006; Raz et al., 2001]) (Fig. 1B).

All cerebellar ROIs (vermian lobules and hemispheres) were mapped by using DISPLAY, an interactive program developed by J.D. McDonald (Montreal Neurological Institute). This program permits the labelling of voxels belonging to an anatomical region on each section of the MRI brain volume and allows for simultaneous visualization in 3D of the movement of the cursor in the sagittal, axial, and coronal planes of the MRI. Any volume can be selected by using the DISPLAY mouse-brush to color the voxels of the volume in the ROI. This coloring procedure accompanied by the 3D view of the MRI planes allows an unambiguous identification of the ROI. The ROI was identified by its landmarks and the voxels of this volume were then colored. It is important to point out that DISPLAY extracts the value of each MRI voxel intensity by positioning the cursor on it and can also color code the images according to the pixel intensity value. Accepted intrarater reliability for the volumetric measures was Cohen $\kappa > 0.80$.

The significance level was adjusted for the five independent statistical comparisons (vermian lobules I–V; vermian lobules VI–VII, vermian lobules VIII–X, left hemisphere and right hemisphere, see paragraph below) (Bonferroni correction, $P = 0.05/5 \sim 0.01$).

Correlations Between Cerebellar Measure and Whole-Brain GM Volume in World-Class MC Group

We were interested in studying whether and how differences in cerebellar morphometry (vermis and/or

Figure 1.

Cerebellar regions of interest tracing. Panel **A** shows the circumscription of the cerebellar vermis on the midsagittal brain slice ($X = 0$). The vermis is divided into three portions, the lobules I–V (in red), lobules VI–VII (in green), and lobules VIII–X (in blue).

Panel **B** shows a representative image of a 3D model of the cerebellum. In light-blue cerebellar hemispheres, in fuchsia the whole (3D) vermician lobules (although, in the present study we measured only the vermician midsagittal slice, as shown in Panel A).

hemispheres) in world-class MC group were associated to whole-brain GM volume modifications. Thus, we run a multiple regression analysis in SPM5 (Wellcome Department of Imaging Neuroscience, University College London, UK), entering in the matrix the GM maps for each world-class MC subject and the values of those cerebellar subregions resulted different in our world-class MC group when compared with CG, by the main analyses.

To obtain whole-brain GM maps, we processed and analyzed the images, by using VBM analysis [Ashburner and Friston, 2000; Good et al., 2001] in the statistical parametric mapping framework (SPM5, Wellcome Department of Imaging Neuroscience, University College London, UK). To improve image registration, images were first manually reoriented to approximate the orientation to that of the ICBM-152 default SPM5 template. Each volume was segmented into GM partitions. Then, the Diffeomorphic Anatomical Registration Through Exponential Lie Algebra (DARTEL) toolbox was applied to the GM partitions. This imaging processing allows a high-dimensional normalization, better preserving brain topology. Template creation is incorporated into the algorithm and a new template based on the entire sample is created at the end of each iteration. This technique improves the realignment of small inner structures [Yassa and Stark, 2009]. Then, we used a script, for transforming DARTEL template and images to MNI space (D. MacLaren, pers. commun.). Finally, GM partitions (modulated data) were smoothed using a Gaussian kernel of 8 mm full width at half maximum (FWHM) and entered into subsequent statistical analyses.

For each subject (world-class MC and CG) we extracted and averaged the voxels of those cerebellar regions we found different, as result of the main world-class MC vs. CG morphometric analysis. Then we run two (one for each group of subjects) correlational analyses in SPM5, entering the total GM values as covariate. Given the lack of literature data linking cerebellar and neocortical GM features in rock climbers, we performed an exploratory investigation, using an uncorrected threshold (to reduce the risk of excluding false-negatives).

Statistical Analysis

All data were normally distributed (Shapiro–Wilk’s test) and no significant difference in the distribution of variance was present among dependent variables across subjects (Levene’s Test). Data belonging to world-class MC and CG were compared by applying Student’s *t*-test for independent groups. Furthermore, cerebellar measures and whole-brain GM volumes in world-class MC group were correlated by using a multiple regression in SPM5.

RESULTS

By correlating age of subjects and cerebellar volumes (vermician lobules and hemispheres), no significant correlation was found either in world-class MC and CG subjects.

The volumes of left and right hemispheres were highly significantly correlated in both world-class MC ($r = 0.941$;

TABLE II. Cerebellar volumes

Subjects	Vermis				Hemisphere	
	Whole	Lobules I-V	Lobules VI-VII	Lobules VIII-X	Left	Right
Word-Class MC Mean ($\pm$ SD)	1.33 (0.09)	0.55 (0.04)	0.34 (0.03)	0.44 (0.05)	87.7 (6.3)	88.0 (5.2)
CG Mean ($\pm$ SD)	1.21 (0.10)	0.49 (0.03)	0.30 (0.06)	0.42 (0.06)	81.8 (12.1)	82.9 (12.5)
Student's <i>t</i> -test $t_{(18)}$	2.864; $P = 0.01$	3.632; $P = 0.002$	1.710; $P = 0.104$	0.991; $P = 0.335$	1.364; $P = 0.19$	1.212; $P = 0.241$

Volumes are reported in cm^3 . World-class MC, world-class mountain climbers; CG, control group

$P < 0.0001$) and CG ($r = 0.995$; $P < 0.0001$) groups. Conversely, total volumes of the hemispheres positively correlated with volume of vermal lobules VIII-X only in CG subjects (right hemisphere vs. lobules VIII-X, $r = 0.784$; $P = 0.007$; left hemisphere vs. lobules VIII-X, $r = 0.795$; $P = 0.006$). In fact, in world-class MC subjects such correlations were not significant (right hemisphere vs. lobules VIII-X, $r = -0.055$; $P = 0.881$; left hemisphere vs. lobules VIII-X, $r = -0.074$; $P = 0.839$).

Cerebellar Vermis Volumes

World-class MC group had a larger total vermis volume compared to CG as revealed by the Student's *t*-test ($t(18) = 2.864$; $P = 0.01$). Namely, lobules I-V contributed in determining the significant difference in the cerebellar vermis volume between groups. In fact, lobule I-V volume was greater in world-class MC subjects compared with the controls ($t(18) = 3.632$; $P = 0.002$). Nevertheless, also the other cerebellar lobules (VI-VII and VIII-X) presented larger volumes in world-class MC compared with CG, although differences did not reach the significance level (Table II and Fig. 2).

Figure 2.

Vermal lobules overlapping. The vermal midsagittal slice volume ($X = 0$) of one world-class MC subject (in green) and one CG subject (in red) are overlaid, after normalization, on the rock climber T1-weighted normalized brain. In world-class MC, the whole vermis appears bigger, but just lobules I-V are significantly larger in comparison to CG. MC, world-class mountain climber; CG, control group.

Cerebellar Hemisphere Volumes

No significant difference in the cerebellar hemispheres volumes between groups was found, as revealed by the Student's *t*-test, although once more the values of the hemisphere volumes in world-class MC were bigger compared with CG (Table II).

Correlations Between Cerebellar Measures and Whole-Brain GM Volume in World-Class MC Group

Given the main morphometric analysis showed that the principal difference between world-class MC and CG was at level of the lobules I-V, we extracted the mean value of this cerebellar area for each world-class MC and CG subject. Then, we run two separate multiple regression analyses in SPM5, by correlating lobules I-V values to the whole GM map both in world-class MC and CG groups separately (as we described previously).

Interestingly, a positive correlation between the lobules I-V and the right medial posterior parietal area (superior

Figure 3.

Correlations between vermal lobules I-V and gray matter. The significant positive correlations between the vermal midsagittal slice volume of lobules I-V and neocortical GM map volume in world-class MC group is illustrated. Results are shown at cluster level $P = 0.001$ uncorrected. SPL, superior parietal lobule; R, right.

parietal lobules, SPL) ($P = 0.001$ uncorrected) was found only in the world-class MC group (Fig. 3).

Moreover, there was no significant difference in average whole cortical brain volume between world-class MC and CG (mean $\pm$ SD, MC: $1,540 \pm 290$ ml; CG: $1,529 \pm 220$ ml, $P = 0.33$, n.s.).

DISCUSSION

In the last decades, *in vivo* macrostructural brain change associated to disease condition received a lot of interest. In some cases the brain modification has been suggested to be used as a biomarker [Dubois et al., 2007]. In pathologies, different pattern of increased/decreased brain volumes can be related to distinct diseases or phenotypes [Baldacara et al., 2011a,b; Bolduc et al., 2011; Cauda et al., 2012; Watson et al., 2012]. In healthy subjects with specific excellent learned abilities, usually increased volume in definite brain regions has been reported [Gaser and Schlaug, 2003; Hutchinson et al., 2003]. Even the lower metabolic activity described in the brain regions involved in peculiar skills seems to reflect the minor effort in executing the motor performance by the skilled group compared to control group [Koenke et al., 2004]. According to these data we expected to find an increased cerebellum volume in our world-class MC. Indeed, in agreement with previous literature [Cannonieri et al., 2007; Hutchinson et al., 2003; Park et al., 2009], the present findings demonstrate that long-term motor training occurring in adulthood is associated to cerebellar modifications not randomly distributed, but related to the specific features of the motor skills. Namely, we found a macrostructural difference in the volume of vermian lobules I–V in world-class MC long practicing vertical movements, compared to age/gender-matched controls with no experience in rock climbing.

Similar to other studies, analyzing the relations between brain structure and function [Hutchinson et al., 2003], we are unable to determine whether the structural differences we observed exist as a result of differences in function (prolonged and unusual motor experience) or whether the structural difference enabled the difference in function to arise. In other words, we are unable to determine whether a climber brain will produce an expert climber or whether an expert climber will modify his brain in a climber brain. Interestingly, animal studies demonstrate that differences in experiences and behaviors lead to structural differences of the brain in general, and of the cerebellum in particular. Animals whom environment requires to learn new motor skills, as opposed to execute mere motor activity, present an increase in size and numbers of synapses per Purkinje cell, in the cerebellar cortex [Black et al., 1990]. Furthermore, animals reared in an enriched environment allowing acquisition of complex motor behaviors, show increase in density and length of dendritic spines along the distal dendrites of Purkinje cells [Lee et al., 2007], differences in spine density and dendritic branching of striatal interneurons [Cutuli et al., 2011] and in pyramidal neocortical neurons [Gelfo et al., 2009].

The observation of structural changes related to motor skill acquisition fits particularly well with the well-known cerebellar involvement in motor learning and adaptation [Smith and Shadmehr, 2005; Criscimagna-Hemminger et al., 2010]. Furthermore, the lack of macrostructural differences in other vermian lobules, as well as in the hemispheres, in world-class MC supports the notion that the specific features of the motor skills are responsible for plastic changes in the different anatomical areas [Hutchinson et al., 2003; Park et al., 2006; Park et al., 2009]. For example, in basketball players, where the movement is mainly linked to eye-hand coordination for dribbling, visually guided saccades and bimanual coordination for “shooting” the ball through the top of a basketball hoop, Park et al. [2009] found an enlargement in different vermian lobules, specifically in lobules VI–VII.

As shown by PET studies on movement control, most cerebellar signals are attributable to sensory information processing [Jueptner and Weiller, 1998]. And indeed the cerebellum strongly utilizes kinesthetic feedback to monitor and coordinate movements, thereby acting as a sensorimotor predictor based on a combination of sensory inputs and efference copies of motor commands [Bastian, 2006; Kleber et al., 2009]. Additionally, cerebellar function is highly correlated with the timing of complex sequential movements [Braitenberg et al., 1997; Doyon et al., 1997; Mandolesi et al., 2010].

All these mentioned neuro-physiological features of cerebellum account for its involvement in rock climbing activity, which requires accurate control of vertical quadruped locomotion involving complex and unusual postural adjustments, arm-leg coordination for the diagonal gait, eye-hand coordination for reaching and grasping movements and motor learning to maintain accurate movements and balance in the presence of external or internal perturbations.

Another interesting aspect of rock climbing is the peculiar role of the upper limbs. Indeed, while at rest on a vertical wall a hanging rock climber keeps his balance due to horizontal supporting forces, when he releases one hold, the vertical and horizontal forces, no more equally distributed on the remaining holds, counteract the perturbations and balance the climber on the remaining holds. Thus, rock climbing is characterised by sustained and intermittent bouts of isometric forearm contractions, with, as consequence, an increased demand placed upon the upper body during climbing. Thus, climbers exhibit greater strength and endurance in the fingers, arms, and shoulders. Accordingly to this, world-class MC group exhibited a significant enlargement of the vermian lobules I–V, which are involved in dexterous finger and hand movements [Catalan et al., 1998; Sadato et al., 1996], especially under high demands of hand movement [Debaere et al., 2004; Jancke et al., 1999b], as well as in eye-hand coordination in the detection of and correction for visuomotor errors.

These data are also in agreement with the functional topography of the cerebellum [Manni and Petrosini, 2004;

Schmahmann, 1991, 1996, 2004; Stoodley and Schmahmann, 2010] in which cerebral cortical areas concerned with sensorimotor processing are linked with the cerebellar anterior lobe (lobules I–V). In particular, movement of the hand localizes to ipsilateral lobules V (and VIII) [Grodd et al., 2001] and leg and foot sensorimotor representations are observed in lobules II and III. Even the cerebellar motor syndrome, characterized by impairment of balance and gait ataxia, limb dysmetria, and oculomotor disorders, results when lesions involve the anterior lobe (lobules I–V) and parts of lobule VI, interrupting thus cerebellar communication with cerebral and spinal motor systems.

We have also found that in our world-class MC group the enlargement of lobules I–V was related to the enlargement of right medial posterior parietal area (superior parietal lobules, SPL). The parietal cortex receives input from the cerebellum via the thalamus [Clower et al., 2001] and sends connections in the opposite direction via the pons [Glickstein, 2000]. The right medial posterior parietal area (superior parietal lobules, SPL) is part of a circuit involved in hand orientation during reaching and grasping movements. Thus, it serves in locating objects in space and serves as a point of convergence between vision and proprioception to determine where objects are in relation to a spatial reference frame [Fattori et al., 2009; Filimon, 2010]. Since both the parietal lobe and the cerebellum play a role in sensorimotor prediction [Blakemore and Sirigu, 2003], it is likely that they work in parallel to predict the sensory consequences of movement, and to monitor and make movement corrections. Clearly, action prediction is of extreme importance during climbing and can make the difference between survive or not at extreme altitude.

ACKNOWLEDGMENTS

Special thanks go to Drs. A. Zijdenbos, J.D. Mac-Donald D.L. Collins and A.C. Evans of the Montreal Neurological Institute, McGill University, Canada, for providing us with software for image analysis.

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