The role of motion analysis & motor control

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The functional definition of the central nervous system organization of movement in terms of correlations between the activation of certain "neural networks" and the execution of motor actions involves the description of the skeletal-system movement in terms of specific sets of axes or frames that are either global or local.

Upper limbs and motor control

Many neurophysiological studies of motor cortical areas have been devoted to the analysis of the relationships between neural activity and movement variables. The movements tested were, in most instances, motions of a single joint.

Multijoint movements require the synergistic action of several muscles.

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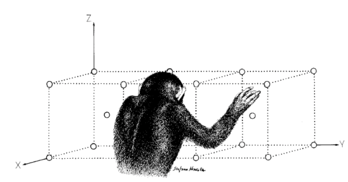
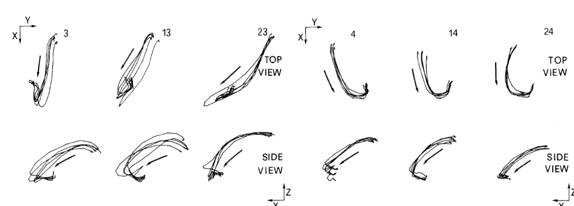
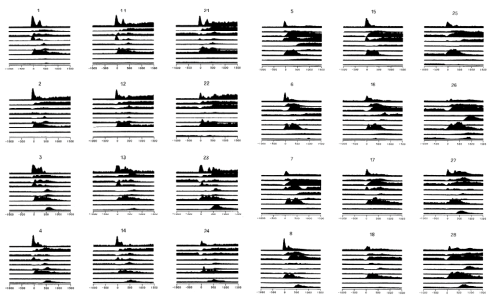


An example: within any one cube, the animals make arm movements in 8 different directions, all starting from a common central position. Because of the side-by-side arrangement of the cubes, the 8 different directions in any 1 cube were parallel to the 8 different movement directions in both of the other cubes but occurred within different regions of extrapersonal space.

An optoelectronic device helped the scientists to detect the trajectories of the right upper arm in each direction of the space.

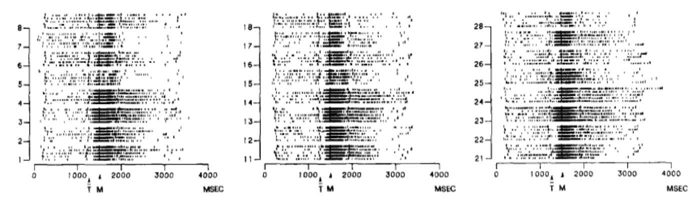


Two-dimensional plots of top and side views of hand trajectories for movements in directions 3-13-23 and 4-14-24.

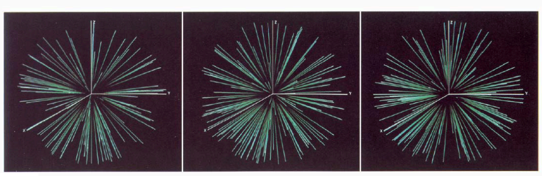


EMG activity of 9 proximal muscles recorded during the task. Activity is shown for triplets (5-15-25, 6-16-26, 7-17-27, 8-18-28) of movements having similar directions but performed within different parts of space. In each panel, from top to bottom, data refer to the activity of caudal trapezius, cranial trapezius, spinal deltoid, clavicular deltoid, long head of triceps, lateral head of triceps, biceps longus, teres major, and pectoralis. Conventions and symbols as in Figure 5.

. • Preferred Directions of Motor Cortical Neurons



Impulse activity of a motor cortical cell (area 4) recorded during the task. Rasters of 5 replications for every movement direction within the 3 different parts of the work space were aligned to the movement onset (*M*). Target onset is indicated by *T*. Longer vertical bars indicate, from left to right, beginning of the trial, target presentation, movement onset, beginning, and end of target holding time. *Numbers* on the vertical axes indicate directions of movement as labeled in Figure 1. This cell was directional within the entire work space.

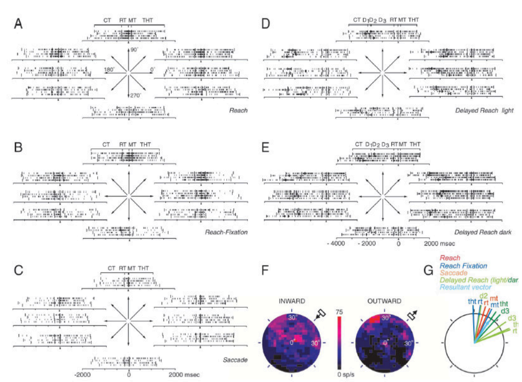


Three-dimensional plots of the distributions of the spatial orientations of cells' preferred directions obtained as the animals performed in the left, center, and right parts of the work space.

Movement population vectors were computed from cell activity recorded in the left, center, and right parts of the work space. In all instances, they provided a very good description of the direction of movement regardless of where in space movement occurred. Population codes based on the same model have been used to describe direction of reaching also in cortical area 5 (Kalaska et al., 1983) and the cerebellum.

Most neurophysiological studies of reaching have been devoted to the analysis of motor and premotor cortical mechanisms, regarded as a late stage in the information processing flow leading from vision to movement (Georgopoulos 1996; Wise et al. 1997); some have been devoted to the operations of parietal cortex, considered as an intermediate node responsible for holistic representations of movement (for reviews see Mountcastle 1995; Wise et al. 1997).

Psychophysical studies (e.g., McIntyre et al. 1997, 1998) indicate that coding of reaching could be achieved through the combination of different information (target location, gaze direction, arm position, and movement direction). Knowledge of signal processing at the early nodes of the parietofrontal network could be of critical importance, because it could reveal "motor" influences on the composition of motor commands and, at the same time, could shed some light on the nature of the visual-to-motor transformation underlying reaching.



Impulse activity of a neuron studied during the Reach (*A*), Reach-Fixation (*B*), Saccade (*C*), Delayed Reach, under light (*D*) and dark (*E*) conditions, and in the Visual Fixation (*F*) task. Rasters of 4 replications for every movement direction (arrows) were aligned to the hand movement onset (small arrow under temporal axis) in *A, B, D,* and *E,* and to eye movement onset in *C.* Thin vertical lines indicate the occurrence of an action potential; thick vertical lines define the behavioral epochs. In the Delayed Reach task, D_1 and D_2 indicate eye RT and MT; D_3 indicates the segment of the instructed delay time referring to preparation for next intended hand movement; RT and MT indicate hand reaction and movement time, respectively; THT refers to holding of combined eye-hand position at the target. *F*: color-coded maps of the frequency of neuronal discharge during inward and outward components of stimulus motion in the Visual Fixation task. These maps define the location and extent of the visual receptive field of the cell. *G*: field of global tuning. Each colored vector, represented on a circle of unit radius, is a significant ($R^2 \geq 0.7$) cell's preferred direction, computed during a given task epoch (color). The thick blue sky vector is the mean resultant vector ($P = 0.00$) of the sample ($n = 11$) of preferred directions. Its mean direction was 58°; its length, the mean resultant length, was 0.92. The angular deviation of the preferred directions was 22.7°.

Movement can be represented in many different domains, relating to dynamic, kinematic, and other aspects of motor behavior

Studies of some forms of multiarticular motion in space, such as reaching to an object of interest, have revealed the parameters coded by the CNS.

The observation that in many instances the hand follows a roughly straight-line or mildly curved path when moving between pairs of points in space (Gilman et al., 1976; Morasso, 1981; Abend et al., 1982; Flash and Hogan, 1985; Hollerbach and Atkeson, 1987) has led to the proposition that hand trajectory is one of the movement variables encoded (Morasso, 198 1; Hogan, 1984; Flash and Hogan, 1985; see Hogan, 1988, for a discussion) and that this encoding occurs within anextracorporeal Cartesian coordinate system.

Constant relationships between joint angular velocities during arm movements (Soechting and Lacquaniti, 1981; Lacquaniti and Soechting, 1982) have suggested, instead, an encoding mechanism using joint variables, and therefore occurring within a preferred intrinsic frame of reference (see Soechting and Terzuolo, 1988, for a discussion).

<u>The mechanisms by which the coordinate systems used for the planning and execution of arm movements are represented in the cerebral cortex are not known.</u>

MOTOR SYSTEMS NEUROREPORT

Three-dimensional tuning profile of motor cortical activity during arm movements

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The neural firing activity in the primary motor cortex was modulated to the direction of hand movement. In contradiction to previous reports, a recent study found a non-uniform distribution of preferred directions of neurons while monkeys made center-out reaching movements in a horizontal plane. To re-examine the distribution of preferred directions in three-dimensional space, we recorded the activity of 117 arm-related neurons in the primary motor cortex and electromyographic signals of shoulder and upper arm muscles of a monkey while it performed center-out reaching movements towards 26 target points placed on a sphere-shaped workspace. We found that the distribution of preferred directions of neurons was non-uniform and that it was correlated to muscle activity and arm joint rotations. *NeuroReport* 13:1477–1480

Key words: Arm movement; Directional tuning; Neural coding; Preferred direction; electromyography; Primary motor cortex; Shoulder and upper arm muscles; Spherical distribution

NEUROREPORT

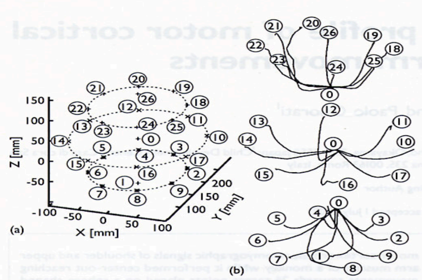
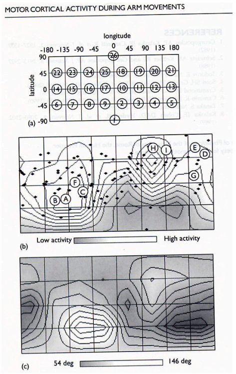


Fig. 1. (a) Perspective view of target arrangements and the Mercator projection. The target labeled 0 is the starting position of arm movement, and the other targets are the goal positions. The origin of the coordinate system (X = Y = Z = 0) is the midpoint of the plane between the monkey's eyes. (b) Hand paths during arm reaching movements.

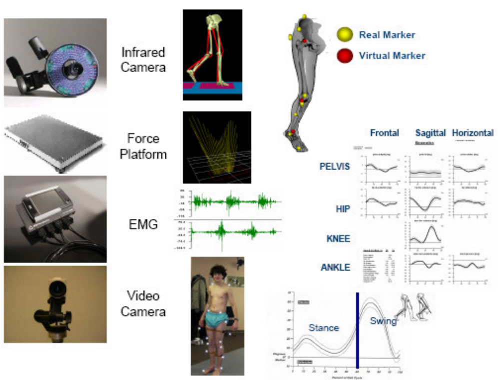


Perspective view of target locations and the Mercator projection. Target labeled 0 is a starting position. The origin of the coordinate system (X=Y=Z=0) is the center of eyes of monkey. B, Distribution of preferred direction of neural activity. Contour plot represents the average of standardized activities of all cells. Light intensity indicates high activity and the dark indicates low activity.

CONCLUSION

In contradiction to previous studies, the distribution of preferred directions of neurons in primary motor cortex was not uniform throughout three-dimensional space. The spatial distribution of preferred directions was correlated with the EMG activity of arm muscles and the joint rotations of the elbow and shoulder. These findings suggest that the directional tuning of activity of motor cortical cells is attributed to a lower-level parameter related to muscle activity rather than a higher-level parameter of hand movement.

Lower limbs and motor control



Gait analysis is the study of animal locomotions, including locomotion of humans. Gait analysis introduces the analysis of measurable parameters of gaits, as well as the interpretation of them in terms of physiological or pathological patterns.

Human movement analysis aims at gathering quantitative information about the mechanics of the musculo-skeletal system during the execution of a motor task. In particular, information is sought concerning the movement of the whole-body centre of mass; the relative movement between adjacent bones, or joint kinematics; the forces exchanged with the environment; the resultant loads transmitted across sections of body segments or between body segments, or transmitted by individual body tissues such as muscles, tendons, ligaments, and bones; and body segment energy variation and muscular work. The 3D realistic representation of the movement of the musculo-skeletal system as seen from a point of view of choice (virtual reality) is a further relevant objective.

MATERIALS AND METHODS

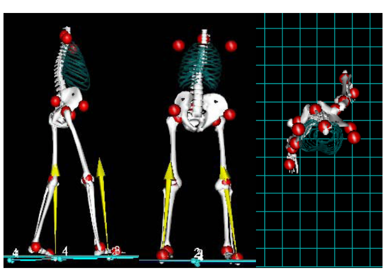
Gait trials

22 markers (Davis protocol)

Self-selected speed

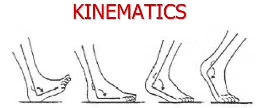
3 trials for consistency

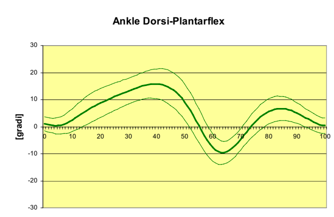
Resting time: 120 s



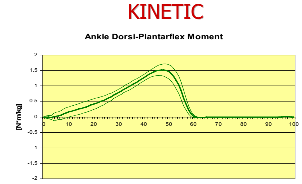
MATERIALS AND METHODS

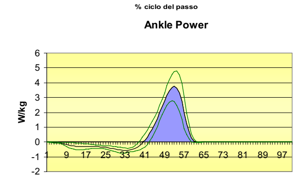
KINEMATICS





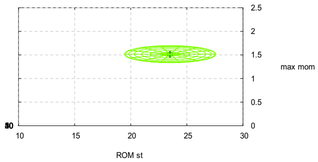
KINETIC

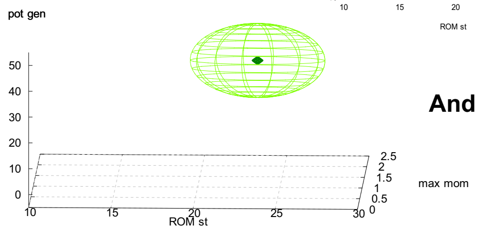




MATERIALS AND METHODS

CAVIGLIA (ankle):
x → ROM in stance
y → max momento
z → potenza generata



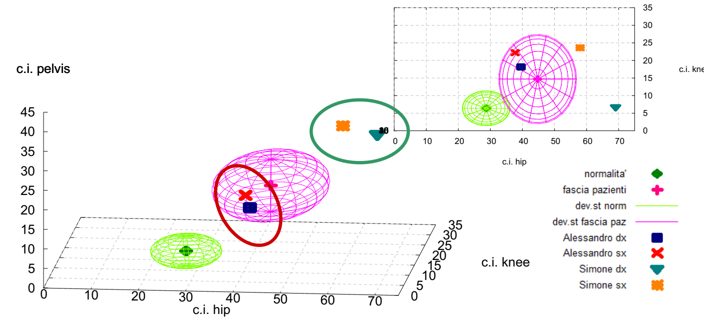


And for all joints…

RESULTS

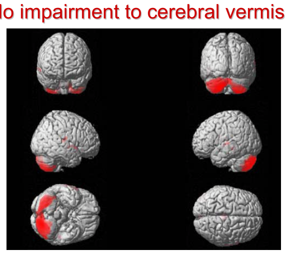
S1
More functional gait

S2
Less functional gait

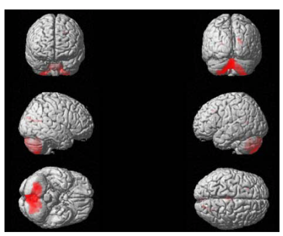


RESULTS

S1
Gray matter reduction in cerebellum;
No impairment to cerebral vermis



S2
Gray matter reduction in cerebellum,
cerebral vermis impairment



DIFFERENCES IN GRAY MATTER VOLUMES IN CEREBRAL VERMIS

CONCLUSION

There is correspondence between gait analysis data and cerebral volumes anomalies

In particular → it seems to exist a relation between gait quality and gray matter volume reduction of cerebral vermis