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SCIENCE DIRECT

Brain Research 1041 (2005) 181 – 197

BRAIN RESEARCH

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Research report

Cerebellar thalamic activity in the macaque monkey encodes the duration but not the force or velocity of wrist movement

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Accepted 1 February 2005
Available online 10 March 2005

Abstract

The way in which the cerebellum influences the output of the motor cortex is not known. The aim of this study was to establish whether information about force, velocity or duration of movement is encoded in cerebellar thalamic discharge and could therefore be involved in the modulation of motor cortical activity. Extracellular single cell recordings were made from the cerebellar thalamus (66 neurones) and VPLc (49 neurones) of four conscious macaques performing simple wrist movements with various load and gain conditions imposed. A significant correlation (Spearman's; $P < 0.05$) was found between movement duration and the duration of neuronal discharge of most cerebellar thalamic neurones (65%), the velocity of movement and rate of neuronal discharge of some cerebellar thalamic neurones (23%), but not between force of movement and rate of neuronal discharge of any cerebellar thalamic neurones. Similar relationships were found between the activity of VPLc neurones and these movement parameters. The strength of the correlations increased when many cells were grouped and analysed as an ensemble, suggesting that populations of cerebellar thalamic (and VPLc) neurones can encode a signal with higher fidelity than single neurones alone. The ensemble data confirmed that the most robust association was between the duration of neuronal discharge and movement duration. We propose that the cerebellum does not provide the motor cortex with specific information about movement force or velocity, but rather that its major role is in activating many motor cortical regions for a specific duration, thus influencing the timing of complex movements involving many muscles and joints.

Theme: Motor systems and sensorimotor integration
Topic: Control of posture and movement

Keywords: Cerebellum; Motor thalamus; Motor control; Electrophysiology; Population analysis

1. Introduction

Early descriptions of humans with cerebellar lesions led to the conclusion that the cerebellum was required for the production of smooth and accurate voluntary movements [8,18,24,35]. The cerebellum can influence movement at multiple levels through projections via descending tracts as well as the motor cortex. In primates, the enlargement of the lateral cerebellar hemispheres and the cerebello–thalamo–cortical pathway have made the thalamus an ideal location for examining the nature of the cerebellar influence on cortical control of movement. The precise nature of this influence has remained elusive but numerous studies suggest that it provides the motor cortex with information pertinent to the timing, velocity or force of movement (see [37] for a review and [8,9,18,24,27,32,35,36,45,46]). Previously, we investigated the influence of the cerebellum on the motor cortex by recording the activity of neurones along the cerebello–thalamo–cortical pathway (CTC) of

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doi:10.1016/j.brainres.2005.02.005

conscious monkeys whilst they performed simple wrist movements so as to determine the relationship between neuronal discharge and movement. We showed that the discharge of cells in the cerebellar thalamus[1] seems to best encode information about the duration of movement [12–15]. In addition, some cerebellar thalamic neurones encoded information pertaining to movement velocity in their discharge pattern. However, a correlation between discharge patterns and any single kinematic parameter of movement (except movement duration) was found in only a small proportion individual neurones. Thach et al. [56] speculated that deep cerebellar nuclear (DCN) output may not encode parameters of movement as such, but rather some other aspect of movement or a certain parameter only in specific circumstances. Possibilities include control of multijointed movements or a limb with reference to a point in space, a neighbouring joint, or to the measurement of an error such as the difference between the intended and actual velocity of movement [56–59]. Nevertheless, it is a common view that the cerebellar hemispheres have a role in regulating specific parameters or kinematics of movement. The DCN are the major source of afferents projecting onto the cerebellar thalamus and it would seem likely that the cerebellar thalamus would reflect the information encoded in the discharge patterns in these nuclei. Thus, a major aim of this paper was to resolve the question of whether the discharge patterns of cerebellar thalamic neurones do indeed have a biologically meaningful correlation with kinematic parameters such as velocity that has been obscured by methodological and statistical factors or whether alternatively, the few neurones that do have a correlation reflect enthusiastic statistical massaging of data.

There are a number of possible explanations as to why the discharge patterns of relatively few cerebellar thalamic neurones were correlated with movement kinematics. In typical movement tasks, the net force operating on the limb (a fixed mass) must increase if the limb is to move with a greater velocity: in other words, force will covary with velocity. Because force may have covaried with velocity in those studies, the possibility that force may also be signalled by neuronal discharge could not be excluded. This issue was addressed in this study by requiring movements to be made against a number of different inertial loads (masses). Another factor confounding the interpretation of many of these studies was that data were pooled and averaged [12–14]. The conventional approach is to average the neuronal activity associated with several attempts at movement but this may obscure biologically significant relationships that would be apparent if neuronal activity was correlated with individual movements. There have been few studies that have examined the relationships between cerebellar thalamic discharge and movement kinematics during single movement trials and this issue was addressed in this study.

A further, more general concern relates to the way in which neuronal discharge is identified as being related to movement. Conventionally, analyses of single cell recordings have been hampered by methods of defining a burst: in particular its offset, its onset and its peak, especially if this relates to the activity associated with a single performance of a movement. Visual inspection by experienced scientists is the most favoured technique but this introduces bias, fatigue, and inter-observer variability, any of which may obscure relationships between neuronal discharge and movement kinematics. In this study, we used a previously described fuzzy-logic-based program (Knowledge Based Spike Train Analysis system; KBSTA) to automate our analysis and to eliminate some of these problems [63]. It was expected that if a relationship between velocity or force and cerebellar thalamic discharge did indeed exist, then it would become clearer using such an objective method. A fourth factor that may obscure a biologically meaningful correlation of neuronal discharge with kinematic parameters is the possibility that the information is encoded by the discharge of a population of neurones and not just a single neurone.

Thus, the aim of this paper was to primarily address the question as to whether the signal content of cerebellar thalamic neurones could be more clearly identified: in particular whether the signal content of cerebellar thalamic neurones does encode a kinematic such as velocity. This will be achieved using: (1) fuzzy-logic techniques to identify individual bursts of neuronal activity; (2) a movement paradigm that produced movement forces and velocities that did not covary; (3) analysis of single movement and neuronal trials rather than pooled or averaged data; and (4) neuronal ensembles to investigate the influence of multiple cells on the signal fidelity.

2. Methods

Extracellular single cell recordings were made from the cerebellar thalamus and ventro-posterior lateralis pars caudalis (VPLc) of four adult monkeys (one *Macaca mulatta*, one *Macaca fascicularis* and two *Macaca nemestrina*) performing simple movements of the wrist. The methods conform to the published code of practice for the use of animals in research (Australian National Health and Medical Research Council) and were approved by the Monash University Animal Experimentation and Ethics Committee (#94-059 and #MMCB/1999/25).

One animal was trained to produce wrist movements against three different inertial loads and with two amplitudes, thus producing a range of forces, velocities, and durations of movement. Three animals were trained to produce movements of varying amplitudes but without changes in force or load. This paradigm also provided a range of movement velocities and movement durations.

[1] We refer to the thalamic nuclei receiving cerebellar afferents as the cerebellar thalamus. These include VPLo, VLc, VLps and Area X of Olszewski [48]. It is through the efferent projections of these nuclei that the cerebellum influences the motor cortex and hence movement.