Localization of Area Prostriata and its Projection to the Cingulate Motor Cortex in the Rhesus Monkey

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Area prostriata is a poorly understood cortical area located in the anterior portion of the calcarine sulcus. It has attracted interest as a separate visual area and progenitor for the cortex of this modality. In this report we describe a direct projection from area prostriata to the rostral cingulate motor cortex (M3) that forms the fundus and lower bank of the anterior part of the cingulate sulcus. Injections of retrograde tracers in M3 resulted in labeled neurons in layers III, V and VI of prostriate cortex. However, injections of anterograde tracers in M3 did not demonstrate axon terminals in area prostriata. This connection was organized topographically such that the rostral part of M3 received input from the dorsal region of prostriate cortex, whereas middle and caudal levels of M3 received input from more ventral locations. Injections of retrograde and anterograde tracers in the caudal cingulate motor cortex (M4) did not produce labeling in prostriate cortex. Cytoarchitectural analysis confirmed the identity of area prostriata and further clarified its extent and borders with the parasubiculum of the hippocampal formation rostrally, and V1 of the visual cortex caudally. This linkage between cortex bordering V1 and cortex giving rise to a component of the corticofacial and corticospinal pathways demonstrates a more direct visuomotor route than visual association projections coursing laterally.

Introduction

Prefrontal projections to motor cortex represent a critical linkage in the organization of the cortical visuomotor system. The afferent visual component originates from the association areas of the lateral parieto-occipital cortex and prefrontal efferents terminate in the more rostral parts of the premotor cortices (Pandya and Kuypers, 1969; Jones and Powell, 1970; Pandya and Vignolo, 1971; Mesulam et al., 1977; Ungerleider and Mishkin, 1982; Matelli et al., 1986; Goldman-Rakic, 1987; Selemon and Goldman-Rakic, 1988; Cavada and Goldman Rakic, 1989; Fellem and Van Essen, 1991; Kurata, 1991; McGuire et al., 1991; Bates and Goldman-Rakic, 1993; Morecraft and Van Hoesen, 1993; Lu et al., 1994). In addition to these classical pathways, other visuomotor projections have been recently described which directly link various parts of the parietal lobe with the lateral premotor cortex (Tanne et al., 1995; Caminiti et al., 1996; Johnson et al., 1996; Wisc et al., 1997; Graziano and Gross, 1998).

Another important feature of the cortical motor system as it relates to visuomotor control is the recent recognition of several somatotopically organized motor areas located on the medial wall of the hemisphere. These include the supplementary (M2 – area 6m), pre-supplementary (preSMA – area F6), rostral cingulate (M3 – area 24c) and caudal cingulate (M4 – area 23c) motor cortices (Woolsey et al., 1952; Biber et al., 1978; Muakkassa and Strick, 1979; Murray and Coulter, 1981; Hutchins et al., 1988; Dum and Strick, 1991, 1996; Luppino et al., 1991, 1994; Preuss and Goldman-Rakic, 1991; Shima et al., 1991; Morecraft and Van Hoesen, 1992, 1998; Galea and Darian-Smith, 1994; Tanji, 1994; West and Larson, 1995; Nimchinsky et al., 1996; Van Hoesen et al., 1996; Morecraft et al., 1996, 1997, 1999; Picard and Strick, 1996; Shen and Alexander, 1997; Tokuno et al., 1997; Geyer et al., 1998; Shima and Tanji, 1998; Deiber et al., 1999). Although the anatomical relationship between the various medial motor areas and other frontal cortices has been relatively well documented, other possible visual-related connections may exist. For example, pathways that link the medial motor areas with the medial visual areas seem likely. Such connections would contribute to shaping the distinguishing functional features that characterize the medial and lateral motor cortices during visually guided movements (Shima et al., 1991; Mushiake et al., 1997; Shima and Tanji, 1998; Sakai et al., 1999).

In experiments exploring the neural connections of the monkey cingulate motor cortex, we have consistently found labeling in the cortex adjoining V1 in the anterior part of the calcarine sulcus following injections of retrograde tracers in M3. The cortex in the calcarine sulcus corresponded to ‘area prostriata’ (Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967, Sanides, 1969, 1970), which is known to be responsive to visual stimuli (Gergen and MacLean, 1964; Cuendol et al., 1965; MacLean, 1967; Allman and Kaas, 1971; Rosa et al., 1997). In this report, we analyze the extent of this projection field and the organization of area prostriata.

Materials and Methods

The results from 13 injection sites involving various parts of the cingulate motor cortex (M3 and M4) were studied in 11 rhesus monkeys (Macaca mulatta) (Fig. 1, Table 1). The midline cortex was exposed after opening the interhemispheric fissure (Morecraft and Van Hoesen, 1998, Morecraft et al., 1996, 1997), and pressure injections of retrograde fluorescent tracers (fast blue, FB; diamidino-yellow, DY) or a tracer that labels bidirectionally (biotinylated dextran amine, BDA) were made into the cortex lining the fundus and lower bank of the calcarine sulcus (Fig. 1, Table 1). This location corresponded to either M3 or M4. After survival periods of 8–14 days for fluorescent and TAA cases and 21–28 days for BDA cases, each monkey was perfused with saline, followed by fixative (4% paraformaldehyde in 0.1 M phosphate buffer, PB) and then cryoprotectant (30% solution of sucrose or glycerol in 0.1 M PB). In all cases, the brain was removed, frozen sectioned and processed for visualization of each tracer according to specific protocols outlined in previous reports (Vetier and Van Hoesen, 1978; Morecraft and Van Hoesen, 1992, Morecraft et al., 1992, 1999, 1997). Tissue sections spaced at 400 or 500 µm intervals through the calcarine sulcus were evaluated for transported label. For cytoarchitectural validation, each tissue section reacted for transported label was paired with an adjacent section stained with thionin for Nissl substance.

Sections were charted through the cingulate injection site and calcarine fissure using an Olympus BX-60 microscope with an x,y plotter attached to the microscope stage. Labeling was superimposed onto the detailed drawings of cytoarchitecture using Nissl-stained sections, and anatomical and surface landmarks as guides. The cingulate cortex (injection site) and calcarine sulcus (transported label) were reconstructed using illustrations of each hemisphere generated from metrically...
calibrated photographs of the medial wall of the hemisphere in combination with plotted serial sections.

The cingulate motor area is formed by the rostral cingulate (M3 — area 24c) and the caudal cingulate (M4 — area 23c) motor cortices, which are somatotopically organized and line the fundus and lower bank of the cingulate sulcus (Biber et al., 1978; Muakkassa and Strick, 1979; Murray and Coudler, 1981; Morecraft and Van Hoesen, 1988, 1992, 1998; Dum and Strick, 1991; Luppino et al., 1991, 1994; Shima et al., 1991; Morecraft et al., 1996, 1997; Nimchinsky et al., 1996; Geyer et al., 1998; Hurovich et al., 1998; Shima and Tanji, 1998). Area 24c is agranular and extends from coronal levels 1–2 mm rostral to the genu of the corpus callosum to coronal levels that include the spur of the arcuate sulcus laterally and anterior commissure medially (Vogt et al., 1987; Dum and Strick, 1991; Morecraft and Van Hoesen, 1992, 1998; Nimchinsky et al., 1996; Geyer et al., 1998). The cortex located adjacent and anterior to area 24c was defined as area 2hb, which spreads from the interhemispheric surface into the depths of the cingulate sulcus (Carmichael and Price, 1994). Area 23c is characterized, in part, by an incipient layer IV (Vogt et al., 1987). It abuts the posterior border of area 24c and extends posteriorly to coronal levels approximating the posterior extent of the central sulcus. Area PECi forms the remainder of the posterior cingulate sulcus and is characterized in part by a well-demarcated layer IV (Pandya and Seltzer, 1982). Standard cytoarchitectural criteria for the hippocampal formation (Blackstead, 1956; Rosene and Van Hoesen, 1987), prostriate cortex (Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967; Sanides, 1969, 1970) and striate cortex (Brodmann, 1909; Bonin and Bailey, 1947) were employed to re-evaluate the organization of the anterior calcarine region.

Results

Cytoarchitecture of the Anterior Calcarine Region

At the most rostral levels of the calcarine sulcus, the presubiculum arches dorsally and medially, and becomes continuous with the retrosplenial cortex (Fig. 2A,B). In contrast, the parasubiculum deviates ventrally and medially into the calcarine sulcus. The presubiculum is distinguishable by the prominent cell clusters in the inner border of layer I, and the parasubiculum can be recognized by its simple laminar organization and prominent lamina dissecans. Cells superficial to the lamina dissecans are densely packed, while those deep to the lamina are more loosely organized. At this rostral junction, area prostriata lies adjacent to the parasubiculum, and the lamina dissecans of the latter is a reliable marker for distinguishing the two cytoarchitectonic areas (Fig. 2A–E). The cytoarchitectural features of area prostriata include an accentuated layer II, incipient layer IV, lightly stained layer V, a poorly defined border between layers V and VI and an absence of sublamination within layers IV, V and VI (Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967; Sanides, 1969, 1970). More caudally, area prostriata maintains continuity with the parasubiculum and visual association cortex [area OA (Bonin and Bailey, 1947)] in the ventral fundus of the calcarine fissure (Fig. 2B,C). The ventral portion of area OA possibly corresponds to area VTF (Boussouad et al., 1991). Further caudally, area prostriata shifts dorsally in the depths of the calcarine fissure and becomes interposed between visual association cortex above (area OA) and below (V2 or area OB) (Fig. 2D,E). Most caudally, area prostriata is in direct continuity with V1, and is flanked on both sides by visual association cortex (area OA and below (V2 or area OB) (Fig. 2D,E). Most caudally, area prostriata is in direct continuity with V1, and is flanked on both sides by visual association cortex (area OA and below (V2 or area OB) (Fig. 2D,E). Area prostriata was found to span ~5.5 mm in its rostrocaudal extent.

Recognizing the separation of the pre- and parasubiculum at the most anterior portion of the calcarine sulcus is key to understanding the location of area prostriata. In this respect, an important feature is the lamina dissecans of the parasubiculum, that extends into the calcarine fissure and forms the key dorsal limit in the fundus of the anterior calcarine sulcus (Figs 1, 2A,B).

Some early reports (Cajal, 1955; Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967; Sanides, 1969, 1970) did not discriminate between the laminae dissecans of the parasubiculum and that of the entorhinal cortex, yielding the erroneous impression that the latter was in continuity posteriorly with the calcarine fissure and V1.
**Injection Site Locations**

All injections were confined to cytoarchitectural area 24c (M3) or area 23c (M4) (Fig. 1, Table 1). The criteria of Conde (Conde, 1987) was used to assess the fluorescent injection sites (cases 1–4). Zones 0–II correspond to the effective uptake site and zone III its periphery. Injection sites 1, 2A, 2B and 4 have been characterized in former reports (Morecraft and Van Hoesen, 1993, 1998). In all cases, the effective injection site was confined to the gray matter of the lower bank of the cingulate sulcus with the exception of case 3A. Case 3A received a single injection of FB into mid-levels of area 24c. This location corresponded to the arm representation of M3 based upon the heavy labeling found in the arm representation of the primary motor cortex (M1). The solid deposit of the FB injection site (zone I) and zones II and III.

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**Figure 2A–B**
involved layers I–VI. In the coronal plane, the injection coursed diagonally from medial to lateral across all gray matter layers of the lower bank, ending in the ventral portion of the fundus, including −300 µm of subcortical white matter. The white matter penetration did not involve the cingulum bundle. Case 3B received a single injection of DY in the caudal one-third of area 24c where zones 0–III were all confined to the gray matter. This location corresponded to the leg representation of M3 based upon the heavy labeling found in the leg representation of M1. In the coronal plane, the injection was located in the middle of the lower bank of the cingulate sulcus. Cases 5 and 6 received multiple injections of tritiated amino acids in area 24c, whereas cases 7 and 8 received multiple injections of the same tracer into area 23c. In all cases, the isotope was confined to cortex lining the lower bank of the cingulate sulcus. The injection site in case 5 was extensive in the rostrocaudal direction involving most of area 24c. Case 6 involved the caudal one-half of area 24c. The injection site in case 7 involved the rostral two-thirds of area 23c and case 8 the caudal half of this same field. The BDA injections in cases 9–11, and their somatotopical affiliation have also been described previously (Morecraft et al., 1996). Briefly, the injection in case 9 involved the face representation of M3 and labeled terminals in the facial nucleus, whereas the injection in case 10 involved the arm representation of M3 and labeled terminals in the brachial spinal cord. The injection in case 11 involved the face and arm representations of M4 and labeled terminals in the facial nucleus and brachial spinal cord.

**Cingulate Motor Cortex Connections with Area Prostriata**

In all retrograde labeling experiments (fluorescent and BDA cases) labeled neurons were found in prostriate cortex when the injection involved M3 (injections 1, 2A, 3A, 3B, 9 and 10) (Figs 1–3). The cytoarchitectural field containing retrogradely labeled neurons bordered upon but did not include cortex identified
as V1 and V2 in adjacent Nissl-stained sections. In these cases, retrograde labeling in prostriate cortex occupied layers III, V, and VI, and was more prominent in an infragranular location (Figs 2, 3). For example, the ratio of supragranular to infragranular labeled neurons in case 2A was 0.44 and in case 3A it was 0.28.

In case 9, which had a single injection of BDA in rostral levels of M3, retrograde labeling occurred throughout rostrocaudal levels of area prostriata with the exception of the caudal most level directly abutting V1 (Figs 1, 3). This field was ∼3.5 mm in length in the rostrocaudal dimension. In accord with our cytoarchitectonic evaluation of area prostriata, retrograde labeling occupied cortex dorsal to the parasubiculum at rostral levels, and maintained this general position at more caudal levels when parasubiculum disappeared (Fig. 3B–F).

Cases 2A and 3A each had a single injection of FB into mid-levels of M3 (Figs 1, 2). In the rostrocaudal direction, retrograde labeling occurred over a distance of ∼3.5 mm in both cases, extending to the most caudal levels of area prostriata (Fig. 2E,F). In terms of dorsoventral topography, labeling occurred ventral to parasubiculum (Fig. 2C), shifted to mid-levels of area prostriata more caudally (Fig. 2E), and at the most posterior levels of area prostriata moved dorsally (Fig. 2F).

Case 3B had an injection of DY in the caudal most part of M3. Very few labeled cells were found in area prostriata. In the same animal, the small number of neurons labeled with DY were intermingled among numerous neurons labeled with FB (injection 3A). No double-labeled neurons were detected.

None of the area 23c injections resulted in labeled neurons in area prostriata (Fig. 1, Table 1). Finally, none of the experiments with anterograde tracers (TAA cases and BDA cases) produced labeled axons in area prostriata (injections 5-11).

The above results suggest a general topography in the dorso-
ventral dimension such that anterior levels of M3 received input from the dorsal to mid-levels of area prostriata (Fig. 4B–F), whereas caudal levels of M3 received input from ventral and mid-levels of area prostriata (Fig. 2C–E). In the rostrocaudal direction there was considerable overlap in the projection to caudal (case 3B) middle (cases 1, 2A 3A) and rostral (case 9) parts of M3. However, rostral M3 received projections from very rostral levels of prostriate cortex (Fig. 4A), whereas caudal and middle levels of M3 received input from the most caudal part of prostriata (Fig. 2E,F). Comparisons among the various cases indicate that the prostriate projection to M3 increases in intensity as it targets the middle and more rostral levels of M3, corresponding to the upper limb and face representations respectively.

Discussion
Our results demonstrate a direct projection arising from the cortex along the anterior part of the calcarine fissure to a localized part of the cingulate motor cortex involved in mediating higher-order motor behaviors (Shima et al., 1991; Shima and
Figure 3. (A–G) A rostral to caudal series of line drawings depicting area prostriata in relation to bordering areas in case 9 which had an injection of biotinylated dextran amine in rostral levels of MD. The location of individual retrogradely labeled neurons in area prostriata are identified by the black dots. The dashed line in area prostriata of the line drawings indicate the location of an incipient layer IV. The lamina dissecans of the parasubiculum is depicted in the line drawings by a flattened sphere with hatching. For conventions, see List of Abbreviations.
Tanji, 1998). This projection originates from cortex which borders the peripheral visual representation within V1 and it itself is responsive to visual stimuli (Cuenod et al., 1965; Rosa et al., 1997). It terminates directly in cortex that gives rise to upper motor neuron pathways that directly target the facial nucleus (injection 9) and the upper spinal cord (injection 10). Our cytoarchitectural analysis of the anterior part of the calcarine fissure, aided by retrograde labeling patterns, indicates that area prostriata spans approximately 3.5 mm in the rostrocaudal dimension and it borders the caudal extension of the parasubicular component of the hippocampal formation anteriorly (Fig. 2A), and the rostral extension of V1 posteriorly (Fig. 2F).

**Cortical Connections of Area Prostriata**

Very little is known about the cortical connections of area prostriata. However, in addition to our observations, which demonstrate prostriate projections to the rostral cingulate motor cortex, a few visual-related areas of the occipital and temporal lobes appear to be connected with prostriate cortex. For example, injections of retrograde tracers in cortex involving the peripheral visual field representation of V1, middle temporal area (MT) and the middle superior temporal area (MST) label neurons in area prostriata (Sousa et al., 1991; Rosa et al., 1993). Injections of tritiated leucine and proline in cortex corresponding to the peripheral upper visual field of V2 have been found to label axon terminals in area prostriata (Gattass et al., 1997). Finally, inferior parietal (Wellman et al., 1997) and temporal association cortices project to area prostriata in a topographical manner (unpublished observations).

**Cytoarchitectural Organization of the Anterior Calcarine Region of the Monkey**

A continuity between limbic and visual cortices was noted in early cytoarchitectural studies (Brodmann, 1909; von Economo, 1929; Lorente de No, 1934; Rose, 1935; Cajal, 1955). For example, Cajal had named the entornithal cortex the 'sphenoc-occipital ganglion' (Cajal, 1955). However, no evidence exists that the entornithal cortex proper extends as far caudally as the calcarine fissure in primates despite the fact that Sanides alluded to such a relationship (Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967; Sanides, 1969, 1970). It appears from our observations that the presence of the lamina dissecans, a characteristic feature of the entornithal cortex, as a guide for arriving at this deduction. However, Sanides did not take into consideration the adjacent parasubiculum, as described by Blackstead (Blackstead, 1956), which is cytoarchitecturally similar to the entornithal cortex but more simply organized and actually extends to the caudal most tip of the hippocampal formation (Rose, 1935; Rosene and Van Hoesen, 1987). Our cytoarchitectonic analysis, which follows the lamina dissecans of the parasubiculum more caudally, clarifies the limbic-occipital junction within the anterior part of the calcarine sulcus. This organization is characterized from rostral to caudal by the parasubiculum more caudally, clarifies the limbic-occipital sulcus (Berger et al., 1997). Our report adds to our understanding of this complex transitional region in two major respects. First, we localize area prostriata in the depth of the calcarine fundus: interposed between the parasubiculum dorostrilaterally and extrastriate visual association cortex medially (Fig. 2A,B). Second, we have followed the parasubiculum caudally within the calcarine fissure, where it is in continuity with prostriate cortex dorsally as well as ventrally (Figs 2C, 3A). With the exception of the parasubiculum, our observations are in agreement with Sanides' original cytoarchitectonic interpretation of area prostriata (Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967; Sanides, 1969, 1970). Our observations are also in agreement with the work of others indicating the general location of area prostriata in the anterior calcarine region (Allman and Kaas, 1971; Sousa et al., 1991; Hof and Morrison, 1995; Gattass et al., 1997; Rosa et al., 1993, 1998), and the suggestion that area prostriata is in direct continuity with the rostral extension of V1 (Fig. 2F) (Sanides and Vitzthum, 1965; Vitzthum and Sanides, 1967; MacLean, 1967; Sanides, 1969, 1970; Gattass et al., 1997).

**Functional Considerations**

Visual influence on motor behavior has long been known to be mediated, in part, by prefrontal cortex (Myers et al., 1962; Ungerleider and Mishkin, 1982; Goldman-Rakic, 1987; Sasaki et al., 1989; Funahasi et al., 1991, 1993; Fuster, 1997; Rao et al., 1997). Many behavioral and anatomical studies have demonstrated that there are at least two major projection systems originating from the occipitoparietal cortices that end in the prefrontal cortex (Mesulam et al., 1977; Pandya and Kuypers, 1969; Jones and Powell, 1970; Pandya and Vignolo, 1971; Haaxma and Kuypers, 1974; Selemon and Goldman-Rakic, 1988; Cavada and Goldman Rakic, 1989; Van Essen et al., 1990; Fellemann and Van Essen, 1991; Van Hoesen et al., 1996). The first, known as the dorsal pathway, originates from the parieto-occipital region and terminates in the dorsolateral part of the prefrontal cortex. The second projection, known as the ventral pathway, originates from the ventral part of the temporoo-occipital region and ends in the ventrolateral part of the prefrontal cortex. Highly transformed visual-related information is then advanced from the prefrontal cortex to the premotor cortices. More recently, additional projection systems arising from parietal cortex which converge directly on the lateral premotor cortices have been implicated in visuomotor control.
(Caminiti et al., 1996; Johnson et al., 1996; Wise et al., 1997; Graziano and Gross, 1998). Although these visual-related projection systems are critical for appropriate execution of cortically controlled movements, the prostriate projection to M3 may represent a subcomponent of a potential 'medial' visuo-motor projection system. In contrast to the visuomotor behaviors mediated by prefrontal cortex, which are task-oriented and problem-based, and the lateral premotor cortices, which appear to be involved the preparation and execution of movement, the prostriate projection to M3 may be involved in potentiating motor responses, including orientation and reaching, to stimuli detected in the peripheral visual field. This inference is based upon area prostriata’s proximate association with the peripheral visual field representation in V1 (Gergen and MacLean, 1964; Casey et al., 1965; Cuenod et al., 1965; MacLean, 1966; Sanides, 1970; Allman and Kaas, 1971; Hof and Morrison, 1995; Gattass et al., 1997) as well as the direct neural connections between area prostriata and the peripheral visual field representations of V1 and V2 (Sousa et al., 1991; Gattass et al., 1997).

The behavioral implications of this projection system are unclear because little is known of the functional characteristics of area prostriata. However, several studies indicate that area prostriata is influenced by visual-related stimuli. Recording studies in monkeys demonstrate that neurons in V1 and the adjoining prostriate cortex are responsive to visual stimuli (Cuenod et al., 1965; Rosa et al., 1997). In addition, regional cerebral blood flow studies in humans have shown that the anterior cingulate and anterior caudal calcarine regions may be coupled on a functional basis. For example, during mental imagery tasks significant increases in activity occur in the anterior calcarine region as well as anterior cingulate gyrus (Kosslyn et al., 1995). The anterior cingulate activation site possibly corresponds, in part, to the human rostral cingulate motor field (Paus et al., 1993; Picard and Strick, 1996, Nimchinsky et al., 1997; Deiber et al., 1999). Within the anterior calcarine region two specific foci occur, one in V1 and the other immediately anterior to V1, in a location that may correspond to area prostriata as described in the human brain by Sanides (Sanides, 1970). Finally, a more recent study has shown that cortex in the anterior calcarine and anterior cingulate regions may be concomitantly involved in rapid visual tasks that require a manual response (Kinomura et al., 1996).

Potential Prostriate Influence on Facial Movements

The above, in conjunction with the descending projection to the facial nucleus from M3, may be of particular significance from a behavioral and clinical viewpoint. The injection site in the rostral part of M3 reported here as receiving direct non-reciprocal prostriate input (injection 9) also issues descending corticobulbar projections that end in the facial nucleus in a highly organized manner (case 2) (Morecraft et al., 1996). Specifically, the face representation of M3 preferentially targets the dorsal and intermediate subnuclei of the facial nucleus (Morecraft et al., 1996, 1999) which, in turn, contain lower motoneurons innervating the frontalis and orbicularis oculi muscles respectively (Jenny and Saper, 1987; Satoda et al., 1987; Porter et al., 1989; Welt and Abbas, 1990; VanderWerf et al., 1998; Morecraft et al., 1999). Both muscles act to close the eyelid rapidly and forcefully (Anderson and Patrinely, 1988; Goodmurphy and Ovalle, 1999). There is a growing body of evidence suggesting that the medial motor cortices may play a role in the manifestation of focal dystonia (Tempel and Perlmutter, 1993; Ceballos-Baumann et al., 1997; Naumann and Reiners, 1997; Playford et al., 1998; Feilwell et al., 1999). Blepharospasm is the second most common focal cranial-cervical dystonia characterized by sustained contraction of the frontalis, corrugator supercilii and orbicularis oculi muscles of the upper face (Jankovic, 1985; Grandas et al., 1988; Jankovic and Fahn, 1998; Sankhla et al., 1998). It has been reported that bright flashes of light can selectively trigger the spasmodic contractions in the upper facial musculature (Jankovic, 1985; Koster, 1988; Holds et al., 1991; Hallett and Daroff, 1996). Therefore, the pathways we describe in this report may be used to construct a testable hypothesis suggesting that the non-reciprocal prostriate-cingulate motor projection system may, in part, play a role in the expression of blepharospasm.

Conclusion

We report a direct, non-reciprocal projection from area prostriata to M3 of the cingulate motor cortex (Fig. 4). The origin of this projection suggests that this corticocortical pathway may be responsive to and mediated by peripheral visual-related events. The termination of the projection in cortex giving rise to axons ending in many subcortical motor centers including the facial nucleus and spinal cord indicates a potential role in motor behavior. The functional significance of the projections originating from area prostriata is less certain, but evidence suggests they may convey some type of visual information to representations of the face and upper extremity in M3.

Notes

This work was supported by NIH grants NS 33003 and NS 36397 and a grant from the Benign Essential Blepharospasm Research Foundation (R.J.M.). NIH grant NS19632 (K.S.R. and G.V.H.) and NIH grant NS 14944 (G.V.H.).

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List of Abbreviations

CA caudate nucleus
CA1,2,3,4 cornu ammonis (Lorente de No, 1934)
CF calcarine fissure
CGS cingulate sulcus
DY diamidino-yellow
DG dentate gyrus
EC entorhinal cortex
FB Fast Blue
Flu fluorescent
FX fornix
HF hippocampal fissure
HP hippocampus
IG indusium griseum
M3 rostral cingulate motor area (area 24c)
M4 caudal cingulate motor area (area 25c)
OA cytoarchitectonic area (Bonin and Bailey, 1947)
OTS occipito-temporal sulcus
ParaS parasubiculum
POMS medial parieto-occipital sulcus
PreS-Ipc presubiculum, lamina principalis externa
PreS-Ipi presubiculum, lamina principalis interna
ProS presubiculum
Prostriata cytoarchitectonic area (Sanides, 1969)
PUL pulvinar
ROS rostral sulcus
RS rhinal sulcus
RSpC retrosplenial cortex
References


