VIA MEDICA

REVIEW ARTICLE

Folia Morphol.
Vol. 59, No. 1, pp. 1–23

ISSN 0015–5659

Anatomic heterogeneity of the rat amygdaloid complex*

Asla Pitkänen[1,2], **Esa Jolkkonen**[1], **Samuli Kemppainen**[1]

[1]*A.I. Virtanen Institute for Molecular Sciences University of Kuopio, Finland*
[2]*Department of Neurology, Kuopio University Hospital, Finland*

*This review is a summary of the lecture presented to the 4th International Congress of the Polish Neuroscience Society in Gdansk, 2–5 September 1999.

[Received 30 November 1999; Accepted 9 December 1999]

The amygdala is a nuclear complex composed of 13 nuclei and cortical areas and their subdivisions. Tract-tracing studies performed over the past 20 years demonstrate that each nucleus is uniquely connected with other brain areas. Consistent with anatomic heterogeneity, the functions of the amygdala vary from attention to memory to formation of emotional responses to sensory stimuli. Here, we briefly review the principles of amygdaloid neuronal wiring that underlie the computations necessary to perform such complex behavioural functions.

key words: amygdala, emotion, epilepsy, temporal lobe

THE AMYGDALA IS A NUCLEAR GROUP

The rat amygdala can be partitioned into 13 nuclei and cortical areas and their subdivisions based on cytoarchitectonic and chemoarchitectonic criteria [4, 96, 102]. Therefore, the term „amygdaloid complex" rather than „amygdala" has been adopted. Connectional studies with anterograde and retrograde neuronal tracers further support the idea of the heterogeneity of the amygdaloid complex by demonstrating that each of the amygdaloid nuclei differs from the others connectionally [4,95,102].

Consistent with anatomic heterogeneity, the amygdala is involved in a large number of different behavioural functions. One of the most commonly investigated functions of the rat amygdala is the generation of appropriate motor and autonomic responses to emotionally relevant sensory stimuli in a fear-conditioning paradigm [56]. In rats, the amygdala is also a critical structure to the fear-potentiated startle response [32], modulation of memory formation in the hippocampus [20] and attention [34]. In humans, imaging studies performed over the past 5 years have initiated a renaissance in amygdala research and provided a new insight into the amygdaloid functions. A classic study by Adolphs and co-workers [1] reported that patient S.M. who had Urbach-Wiethe disease, causing bilateral amygdaloid damage, was impaired in recognising fear in facial expressions. Since then, the human amygdala has also been demonstrated to be critically involved in the recognition of emotion in auditory [117] and olfactory stimuli [153], acquisition of conditioned autonomic responses to visual or auditory stimuli [7, 55], recognition of approachability and trustworthiness in facial expressions [2], perception of body movements [14], acquisition [19] and retrieval [104] of memories for emotionally-arousing events, processing of affective aspects of dreams [63] and discrimination of stimuli based on their acquired behavioural significance [77].

These studies raise the question: How is the amygdala wired with other brain regions to allow it to perform complicated tasks that help rats to encounter and survive a predator, or humans to cope with ongoing social signalling in everyday-life situations? How are computations performed within the intra-amygdaloid circuitries? We will briefly review the major aspects of the connectivity of the amygdaloid nuclei in rats. On the basis of the anatomic findings, we speculate about the potential consequences of nucleus-specific damage to the functioning of the amygdala.

Address for correspondence: Asla Pitkänen, MD, PhD, A.I. Virtanen Institute for Molecular Sciences, University of Kuopio, POBox 1627, FIN-70 211 Kuopio, Finland. Tel: 358 17 16 3296, fax: 358 17 16 3025, e-mail: asla.pitkanen@uku.fi

EACH AMYGDALOID NUCLEUS HAS A UNIQUE SET OF AFFERENT, INTRINSIC AND OUTPUT CONNECTIONS

Nomenclature

The amygdaloid complex is partitioned into various nuclei and cortical areas based on the nomenclature described by Price et al. [102] with modifications [41,96] (Table 1). Briefly, the **deep nuclei** include the lateral nucleus, basal nucleus and accessory basal nucleus. The **superficial nuclei** include the anterior cortical nucleus, bed nucleus of the accessory olfactory tract, medial nucleus, nucleus of the lateral olfactory tract, periamygdaloid cortex and posterior cortical nucleus. The **remaining nuclei** include the anterior amygdaloid area, central nucleus, amygdalohippocampal area and the intercalated nuclei. The location of the different amygdaloid regions is shown in Figure 1. Cortical areas are partitioned according to McDonald [69] and the other brain areas according to the atlas of Paxinos and Watson [89] (Fig. 2). In the description of afferent, intrinsic and efferent connectivity, only those projections that are described in the original publications as „moderate" or „heavy" in density are summarised. The inter-amygdaloid connections that are relatively prominent in rats are also described. Based on current knowledge, however, it is difficult to judge the density of each inter-amygdaloid connection. Connectivity of the intercalated nuclei and the anterior amygdaloid area has not yet been systematically investigated and therefore these areas are excluded from the present description. For a detailed description of connections, see Pitkänen [95].

Lateral nucleus

Projections to the lateral nucleus. The connectivity of the lateral nucleus is summarised in Figure 3. The lateral nucleus receives substantial projections from the sensory-related cortical areas including the visual, auditory, somatosensory and gustatory/viscerosensory cortices. The heaviest projections from the frontal lobe originate in the infralimbic region and dorsal agranular insula. Projections from the medial temporal lobe memory system originate in the perirhinal and entorhinal cortices as well as from the temporal (*i.e.*, ventral) end of the subiculum. Other major projections originate in the midline and auditory thalamus, some hypothalamic nuclei and dorsal raphe.

Intra-amygdaloid connections. The lateral nucleus receives substantial inputs from the basal, accessory basal and medial nuclei and the periamygdaloid cortex. The intra-amygdaloid pathways originating in the lateral nucleus are more widespread than those originating in any other amygdaloid nucleus.

Table 1. Amygdaloid nuclei and nuclear divisions

Deep nuclei

Lateral nucleus (L)
    dorsolateral division (Ldl)
    ventrolateral division (Lvl)
    medial division (Lm)

Basal nucleus (B)
    magnocellular division (Bmc)
    intermediate division (Bi)
    parvicellular division (Bpc)

Accessory basal nucleus (AB)
    magnocellular division (ABmc)
    parvicellular division (ABpc)

Superficial nuclei

Nucleus of the lateral olfactory tract (NLOT)

Bed nucleus of the accessory olfactory tract (BAOT)

Anterior cortical nucleus (COa)

Medial nucleus (M)
    rostral division (Mr)
    central division
        dorsal part (Mcd)
        ventral part (Mcv)
    caudal division (Mc)

Periamygdaloid cortex
    periamygdaloid cortex (PAC)
    periamygdaloid cortex, medial subfield (PACm)
    periamygdaloid cortex, sulcal subfield (PACs)

Posterior cortical nucleus (COp)

Other amygdaloid areas

Anterior amygdaloid area (AAA)

Central nucleus (CE)
    capsular division (CEc)
    lateral division (CEl)
    intermediate division (CEi)
    medial division (CEm)

Amygdalohippocampal area (AHA)
    medial division (AHAm)
    lateral division (AHAl)

Intercalated nuclei (I)

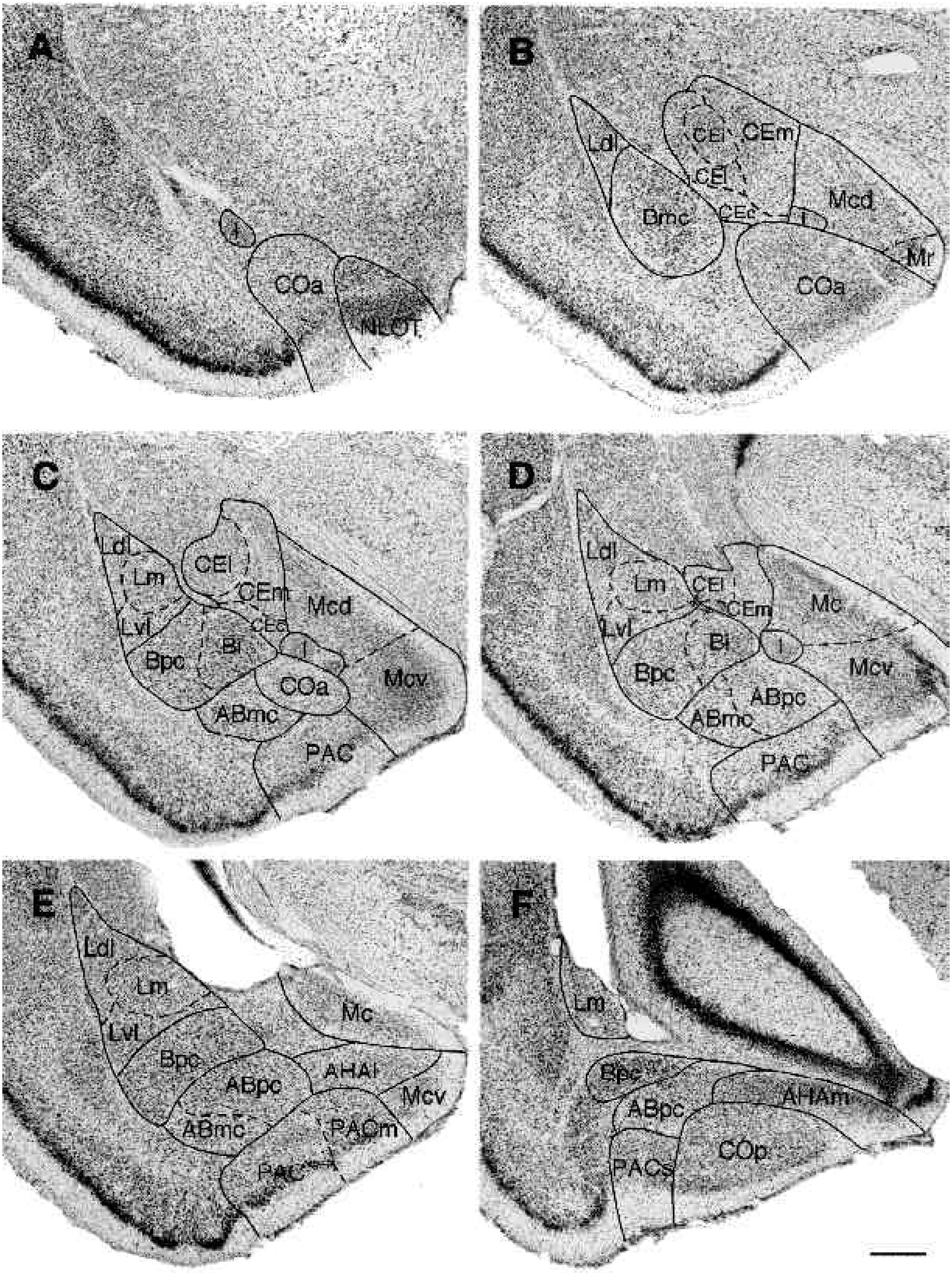


Figure 1. Brightfield photomicrographs from thionin-stained coronal sections of the rat amygdaloid complex showing the location of various amygdaloid nuclei and cortical areas and their subdivisions. Six rostrocaudal levels are presented (panel A is the most rostral and panel F the most caudal). Nuclear and divisional boundaries are indicated by continuous and dashed lines, respectively. For abbreviations, see Table 1. Scale bar equals 0.5 mm

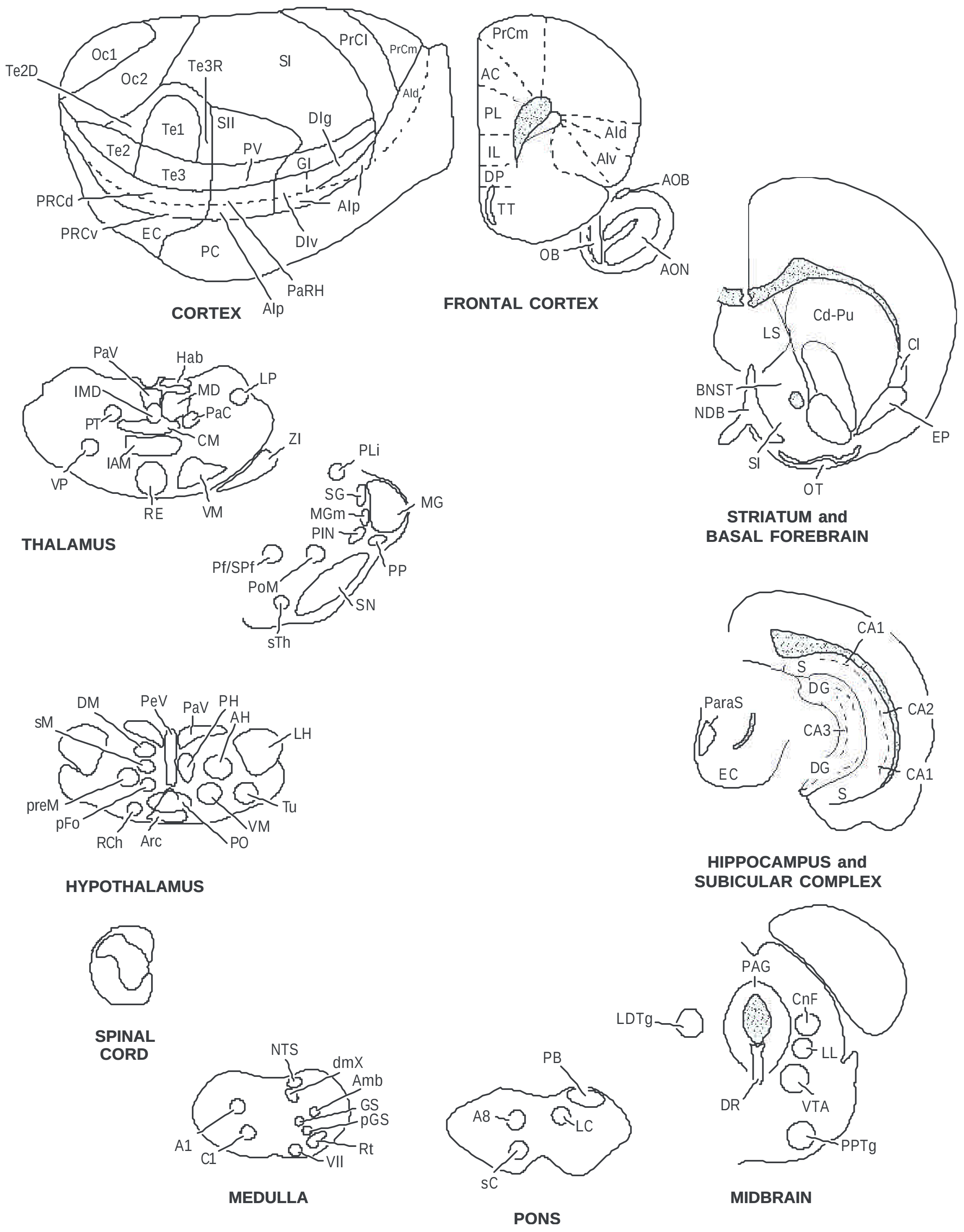


Figure 2. Schematic line-drawings describing the location of various brain areas used in the description of amygdaloid afferents and efferents in Figures 3 to 12. For the list of abbreviations, see Table 2 and for the list of references, see Table 3

CORTEX

Efferents:
Te2D[12,18,20]
Te2[6,12,18,19,21]
Te3[12,16,17,18,19,21]
PRCd[6,12,13,16,17,21]
PRCv[6,12,16,21] EC[6,21,22,98]
PaRH[12,33,114] DIv[12]
AIp[6,12,13,84]

Afferents: PRCd[38,45]
PRCv[45,89] EC[36,93,94]
AIp[38]

FRONTAL CORTEX

Efferents: AId[12,13,35,84]
IL[6,12,28,31,84]

Afferents: IL[37,42,46,66]
AIv[46]

STRIATUM and BASAL FOREBRAIN

Efferents

Afferents: Acc[30,40,83]

LATERAL NUCLEUS

THALAMUS

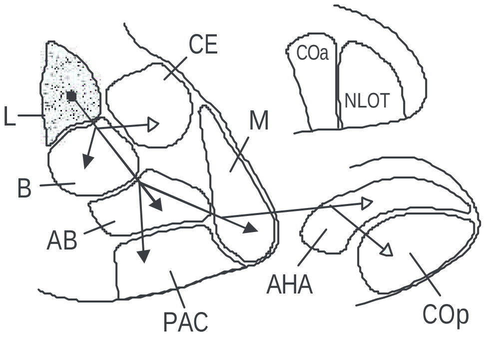
Efferents: PaV[54,59,61]
PIN[16,58,62,63] PP[53,58,63,120]

Afferents

HIPPOCAMPUS and SUBICULUM

Efferents: S[6,12,24,25,27,119]

Afferents: ParaS[36]



INTRINSIC CONNECTIONS

HYPOTHALAMUS

Efferents: pFo[74]
VM[67,73,] PH[113]

Afferents

MIDBRAIN

Efferents: DR[107,120]

Afferents

SPINAL CORD

MEDULLA

PONS

Figure 3. Afferent, intra-amygdaloid and efferent connections of the lateral nucleus. Only the moderate-to-heavy projections are indicated. In Figs. 3–12 closed arrow refers to a reciprocal connection and open arrow to an unidirectional projection

They terminate in the basal, accessory basal, medial, central and posterior cortical nuclei as well as in the periamygdaloid cortex and the amygdalohippocampal area. The lateral nucleus is not interconnected with the contralateral amygdala.

Projections from the lateral nucleus. Overall, the outputs originating in the lateral nucleus are not as widespread as the inputs. The heaviest projections to the sensory-related cortical areas terminate in the insular cortex. Within the frontal cortex, the infralimbic cortex and the ventral agranular insula receive a substantial input from the lateral nucleus. Amygdaloid outputs to the medial temporal lobe are directed to the perirhinal and entorhinal cortices as well as to the parasubiculum. Moderate-to-heavy projections to the nucleus accumbens have also been described.

Basal nucleus

Projections to the basal nucleus. The connectivity of the basal nucleus is summarised in Figure 4. Inputs to the basal nucleus from sensory related cortical areas are not as widespread as those to the lateral nucleus. There are moderate-to-heavy inputs from the dysgranular and agranular insula and the parietal rhinal cortex. In the frontal lobe, the prelimbic area and the dorsal agranular insula project substantially to the basal nucleus. Within the medial temporal lobe memory system, the basal nucleus receives inputs from the perirhinal cortex as well as from several levels of the hippocampal formation[1], including the entorhinal cortex, the temporal end of the CA1 and the subiculum. Other regions providing a moderate-to-heavy input to the basal nucleus include the paraventricular nucleus of the thalamus.

Intra-amygdaloid connections. The basal nucleus receives substantial intra-amygdaloid inputs from the lateral and anterior cortical nuclei. The basal nucleus projects to the lateral, central and anterior cortical nuclei as well as to the nucleus of the lateral olfactory tract and the amygdalohippocampal area. The basal nucleus projects to the contralateral basal nucleus as well as to the contralateral central nucleus, the nucleus of the lateral olfactory tract and the anterior amygdaloid area.

Projections from the basal nucleus. The basal nucleus projects to the infralimbic cortex in the prefrontal cortex. In addition, it provides substantial inputs to the hippocampal formation, including the entorhinal cortex, the temporal end of CA3 and CA1 subfields, the temporal subiculum and the parasubiculum. Heavy topographically-organised projections also terminate in the bed nucleus of the stria terminalis, caudate-putamen, nucleus accumbens, claustrum, substantia innominata and the olfactory tubercle.

Accessory basal nucleus

Projections to the accessory basal nucleus. The connectivity of the accessory basal nucleus is summarised in Figure 5. Sensory-related cortical areas that provide major inputs to the accessory basal nucleus include the agranular insula, the parietal rhinal cortex and the caudal piriform cortex. Within the prefrontal cortex, projections originate in the infralimbic cortex. Other major inputs originate in the medial temporal lobe memory system, including projections from the perirhinal and entorhinal cortices and the temporal end of the subiculum. Other projections originate in the paraventricular nucleus of the thalamus and the perifornical region of the hypothalamus.

Intra-amygdaloid connections. The accessory basal nucleus receives substantial inputs from the lateral and medial nuclei of the amygdala. In general, its intra-amygdaloid outputs appear more widespread than its inputs. The outputs terminate in the lateral, central, medial and posterior cortical nuclei as well as in the periamygdaloid cortex and the amygdalohippocampal area. Contralaterally, the accessory basal nucleus projects to the accessory basal and medial nuclei.

Projections from the accessory basal nucleus. The accessory basal nucleus provides substantial projections to the prefrontal cortex, particularly to the infralimbic cortex. It also provides inputs to several levels of the medial temporal lobe memory system, including the perirhinal cortex, the entorhinal cortex, the temporal end of the CA1 and the subiculum and the parasubiculum. A substantial projection to the bed nucleus of the stria terminalis, the caudate-putamen, the nucleus accumbens, the substantia innominata and the ventromedial nucleus of the hypothalamus has also been described.

Central nucleus

Projections to the central nucleus. The connectivity of the central nucleus is summarised in Figure 6. The central nucleus receives a substantial amount of sensory information from a large variety of cortical areas. These include inputs from the visual, auditory, somatosensory and visceral/gustatory cortices. The central nucleus also receives substantial inputs from the medial and lateral prefrontal cortex, including the infralimbic cortex and dorsal agranular insula, respectively. Projections from the medial temporal lobe memory system originate in the perirhinal and entorhinal cortices and the ventral subiculum. The entorhinal and perirhinal inputs terminate largely in the capsular division of the central nucleus, according to McDonald and Mascagni [72] and McDonald [69]. Terminals located in this region were considered to belong to the projection terminating in the amygdalostriatal area by Shi and Cassell [123], who state that the perirhinal cortex does not project to the central nucleus. Otherwise, the rostral part of

---

[1] The hippocampal formation includes the entorhinal cortex, dentate gyrus, hippocampus, subiculum, presubiculum, and parasubiculum according to Amaral and Witter (1989).

Table 2. Abbreviations for figures 2–12

CORTEX

AId	Dorsal agranular insular cortex
AIp	Posterior agranular insular cortex
DIg	Gustatory dysgranular insular cortex
DIv	Visceral dysgranular insular cortex
EC	Entorhinal cortex
GI	Granular insular cortex
Oc1	Primary occipital cortex
Oc2	Secondary occipital cortex
PaRh	Parietal rhinal cortex
PC	Piriform cortex
PRC	Perirhinal cortex
PRCd	Perirhinal cortex, dorsal portion
PrCl	Lateral precentral cortex
PrCm	Medial precentral cortex
PRCv	Perirhinal cortex, ventral portion
PV	Parietal ventral area
SI	Primary somatosensory area
SII	Secondary somatosensory area
Te1	Temporal cortex, area 1
Te2	Temporal cortex, area 2
Te2D	Temporal cortex, area 2, dorsal portion
Te3	Temporal cortex, area 3
Te3R	Temporal cortex, area 3, rostral portion

FRONTAL CORTEX

AC	Dorsal anterior cingulate cortex
AId	Dorsal agranular insular cortex
AIv	Ventral agranular insular cortex
AOB	Accessory olfactory bulb
AON	Anterior olfactory nucleus
DP	Dorsal peduncular cortex
IL	Infralimbic cortex
LO	Lateral orbital cortex
MO	Medial orbital cortex
OB	Olfactory bulb
PL	Prelimbic cortex
PrCm	Medial precentral cortex
TT	Tenia tecta

HIPPOCAMPUS AND SUBICULAR COMPLEX

CA1	CA1 field of the hippocampus
CA2	CA2 field of the hippocampus
CA3	CA3 field of the hippocampus
DG	Dentate gyrus
EC	Entorhinal cortex
ParaS	Parasubiculum
S	Subiculum

STRIATUM AND BASAL FOREBRAIN

Acc	Nucleus accumbens
BNST	Bed nucleus of stria terminalis
Cd-Pu	Caudate-Putamen
Cl	Claustrum
EP	Endopiriform nucleus
GP	Globus pallidus
ICa	Islands of Calleja
LS	Lateral septum
MS	Medial septum
NDB	Nucleus of the horizontal limb of the diagonal band
SI	Substantia innominata
OT	Olfactory tubercle

MIDBRAIN

bPN	Basilar pontine nucleus
CnF	Cuneiform nucleus
CS	Nucleus centralis superior
DR	Dorsal raphe nucleus
LDTg	Laterodorsal tegmental nucleus
LiC	Nucleus linearis caudalis
LL	Lateral lemniscus
PAG	Periaqueductal grey
PPTg	Pedunculopontine tegmental nucleus
R	Raphe nucleus
VTA	Ventral tegmental area

PONS

A8	A8 dopamine cells
LC	Locus coeruleus
PB	Parabrachial nucleus
RPC	Nucleus reticularis pontis caudalis
sC	Nucleus subcoeruleus
V	Mesencephalic nucleus of trigeminal nerve

MEDULLA

A1	A1 noradrenaline cells
Amb	Nucleus ambiguus
C1	C1 adrenaline cells
dmX	Dorsal motor nucleus of vagus
GS	Nucleus gigantocellularis
NTS	Nucleus of the solitary tract
pGS	Nucleus paragigantocellularis
Rt	Reticular formation
VII	Facial nucleus

THALAMUS

CM	Central medial nucleus
Hab	Habenula
IAM	Interanteromedial nucleus
IMD	Intermediodorsal nucleus
LP	Lateral posterior nucleus
LT	Lateral terminal nucleus of the accessory optic tract
MD	Mediodorsal nucleus
MG	Medial geniculate nucleus
MGm	Medial geniculate nucleus, medial part
PaC	Paracentral nucleus
PaV	Paraventricular nucleus
Pf	Parafascicular nucleus
PIN	Posterior intralaminar nucleus
PLi	Posterior limitans nucleus
PM	Posteromedian nucleus
PoM	Posterior thalamic complex, medial group
PP	Peripeduncular nucleus
PT	Paratenial nucleus
RE	Reuniens nucleus
SG	Suprageniculate nucleus
SN	Substantia nigra
SPf	Subparafascicular nucleus
sTh	Nucleus subthalamicus
VM	Ventromedial nucleus
VP	Ventral posterior nucleus
ZI	Zona inserta

HYPOTHALAMUS

Arc	Nucleus arcuatus
AH	Anterior hypothalamic area/nucleus
DM	Dorsomedial nucleus
LH	Lateral hypothalamus
PaV	Paraventricular nucleus
PeV	Periventricular nucleus
PH	Posterior hypothalamic area/nucleus
preM	Premamillary nucleus
pFo	Perifornical area
PO	Preoptic area/nucleus
RCh	Retrochiasmatic area
SCh	Suprachiasmatic nucleus
sM	Supramamillary nucleus
SO	Supraoptic nucleus
TC	Tuber cinereum
tM	Tuberomamillary nucleus
Tu	Tuberal nucleus
VM	Ventromedial nucleus

Table 3. Reference database for figures 3–12

1.	Scalia and Winans 1975
2.	de Olmos et al. 1978
3.	de Olmos et al. 1985
4.	Krettek and Price 1978b
5.	Luskin and Price 1983a
6.	Ottersen 1982
7.	Pitkänen et al. 1997
8.	Luskin and Price 1983b
9.	Swizer et al. 1985
10.	Veening 1978b
11.	Post and Mai 1978
12.	McDonald 1998
13.	Turner and Zimmer 1984
14.	Yasui et al. 1991
15.	Sun et al. 1994
16.	LeDoux et al. 1991
17.	Romanski and LeDoux 1993
18.	Mascagni et al. 1993
19.	Shi and Cassell 1997
20.	McDonald and Mascagni 1996
21.	Shi and Cassell 1999
22.	Wyss 1981
23.	Swanson and Kohler 1986
24.	Cameras and Swanson 1992
25.	Cullinan et al. 1993
26.	Van Groen and Wyss 1990b
27.	Phillips and LeDoux 1992
28.	Hurley et al. 1991
29.	Sesack et al. 1989
30.	Brog et al. 1993
31.	McDonald et al. 1996
32.	Krettek and Price 1977a
33.	McIntyre et al. 1996
34.	Christensen and Frederickson 1998
35.	Shi and Casell 1998a
36.	Pikkarainen et al. 1999
37.	Sarter and Markowitsch 1984
38.	McDonald and Jackson 1987
39.	Kita and Kitai 1990
40.	McDonald 1991a
41.	Shinonaga et al. 1994
42.	Conde et al. 1995
43.	Brindley-Reed et al. 1995
44.	Millhouse and Uemura-Sumi 1985
45.	Savander et al. 1997a
46.	Personal observation
47.	Wallace et al. 1989
48.	Kita and Oomura 1982
49.	Canteras et al. 1992a
50.	Canteras et al. 1995
51.	Petrovich et al. 1996
52.	Krettek and Price 1974
53.	Nitecka et al. 1979
54.	Ottersen and Ben-Ari 1979
55.	McDonald 1987a
56.	Van Vulpen and Verwer 1989
57.	Su and Bentevoglio 1990
58.	LeDoux et al. 1990
59.	Turner and Herkenham 1991
60.	Ray and Price 1992
61.	Moga et al. 1995
62.	Namura et al. 1997
63.	Linke et al. 1999
64.	Kemppainen and Pitkänen 1998
65.	Ottersen 1980
66.	Sarter and Markowitsch 1983
67.	Krieger et al. 1979
68.	Krettek and Price 1978a
69.	Ono et al. 1985
70.	McDonald 1987b
71.	Price et al. 1991
72.	Canteras et al. 1992b
73.	Canteras et al. 1994
74.	Risold et al. 1994
75.	Gray et al. 1989
76.	Previtt and Herman 1998
77.	Sun et al. 1991
78.	Datta et al. 1998
79.	Post and Mai 1980
80.	Weller and Smith 1982
81.	Russchen and Price 1984
82.	Schmued et al. 1989
83.	McDonald 1991b
84.	Berendse et al. 1992
85.	Wright and Groenewegen 1995
86.	Kirouac and Ganguly 1995
87.	Wright and Groenewegen 1996
88.	Wright et al. 1996
89.	Deacon et al. 1983
90.	Takagishi and Chiba 1991
91.	Kelley et al. 1982
92.	Bacon et al. 1996
93.	Krettek and Price 1977b
94.	Beckstead 1978
95.	Caffe et al. 1987
96.	Van Groen and Wyss 1990a
97.	Calderazzo et al. 1996
98.	McDonald and Mascagni 1997
99.	Luiten et al. 1985
100.	Woolf and Butcher 1982
101.	Grove 1988a
102.	Grove 1988b
103.	Ottersen 1981
104.	Gray 1990
105.	Danielson et al. 1989
106.	Rosen et al. 1991
107.	Vertes 1991
108.	Bernard et al. 1993
109.	Petrovich and Swanson 1997
110.	Bianchi et al. 1998
111.	Saper and Loewy 1980
112.	Krukoff et al. 1993
113.	Vertes et al. 1995
114.	Shi and Cassell 1998b
115.	Van Bockstaele et al. 1996
116.	Pickel et al. 1995
117.	Vankova et al. 1992
118.	Bernard et al. 1989b
119.	Veening 1978a
120.	Nitecka et al. 1980
121.	Simerly and Swanson 1986
122.	Nitecka 1981
123.	Behan and Haberly 1999
124.	Price et al. 1973

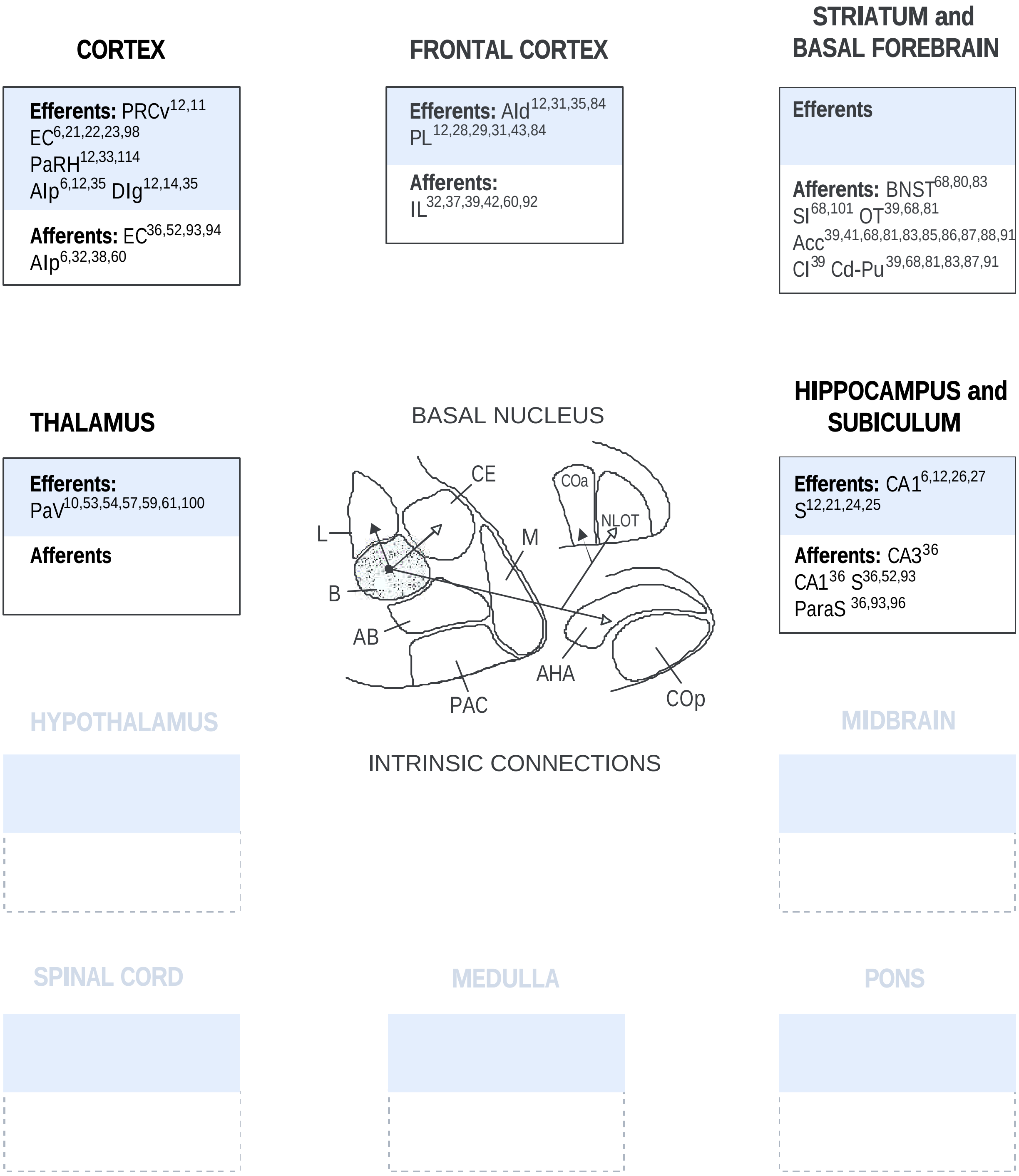


Figure 4. Afferent, intra-amygdaloid and efferent connections of the basal nucleus. Only the moderate-to-heavy projections are indicated

the entorhinal cortex, which is partly included in the AE subfield of the entorhinal cortex by Insausti et al. [40], is often considered to be the amydalopiriform transition area [89, 129]. This area provides a robust projection to the lateral division of the central nucleus [42, 72]. According to our recent observations [Jolkkonen and Pitkänen, unpublished], this area does not project to the dentate gyrus, which is considered a hallmark for the connectivity of the entorhinal cortex and this therefore suggests that the heavy input to the lateral division of the central nucleus does not originate in the entorhinal cortex. Other projections terminating in the central nucleus include inputs from the bed nucleus of the stria terminalis,

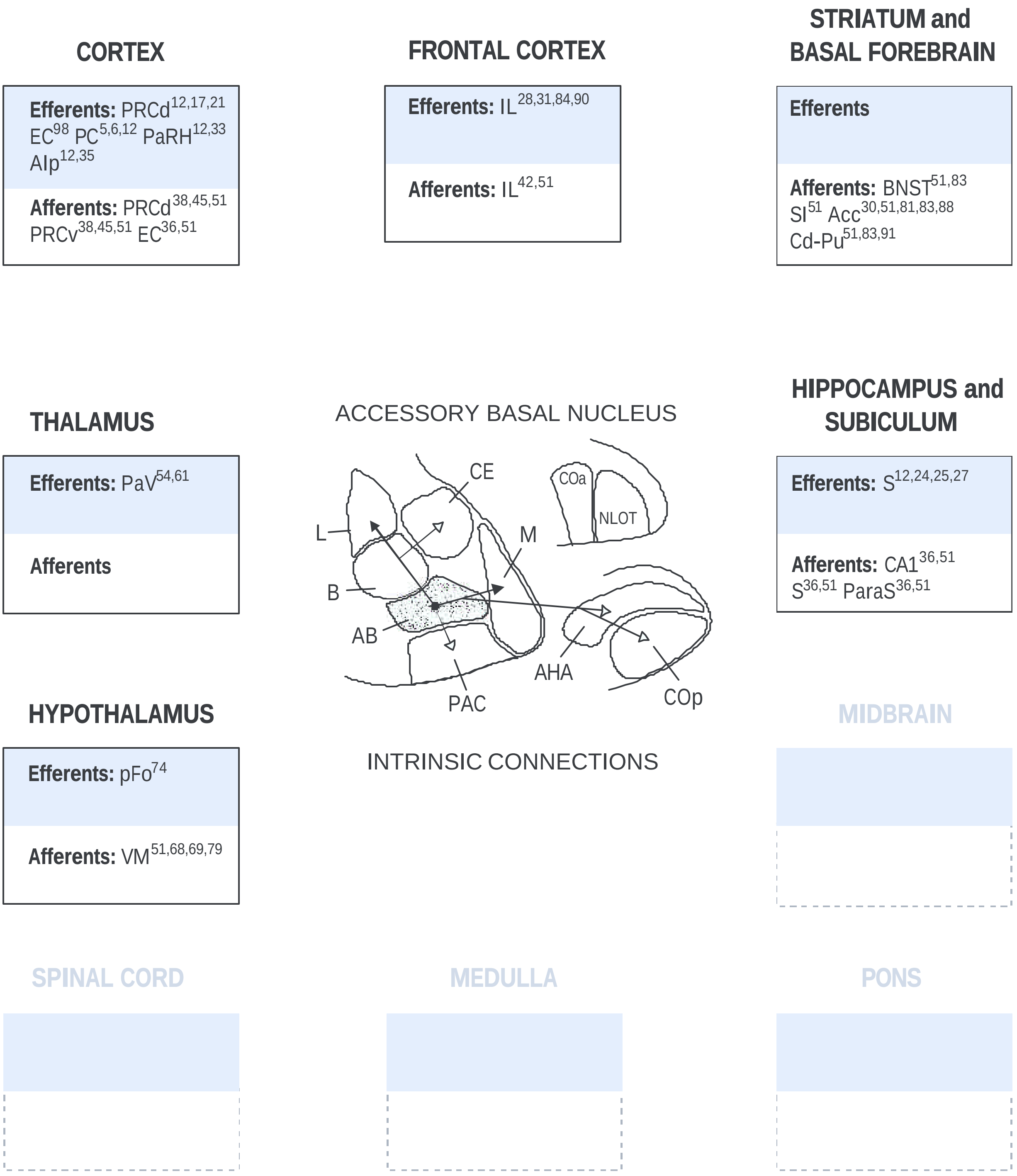


Figure 5. Afferent, intra-amygdaloid and efferent connections of the accessory basal nucleus. Only the moderate-to-heavy projections are indicated

the substantia innominata, the thalamus (paraventricular nucleus), the hypothalamus (premamillary nucleus and lateral hypothalamic area) and the pons (nucleus parabrachialis and nucleus subceruleus).

Intra-amygdaloid connections. The central nucleus converges inputs from almost all other amygdaloid nuclei. These include the lateral, basal, accessory basal, medial and anterior cortical nuclei, as well as the amygdalohippocampal area. It does not, however, provide any substantial inputs back to other amygdaloid regions. The central nucleus receives projections from the contralateral amygdala, including the basal and anterior cortical nuclei as well as the nucleus of the lateral olfactory tract.

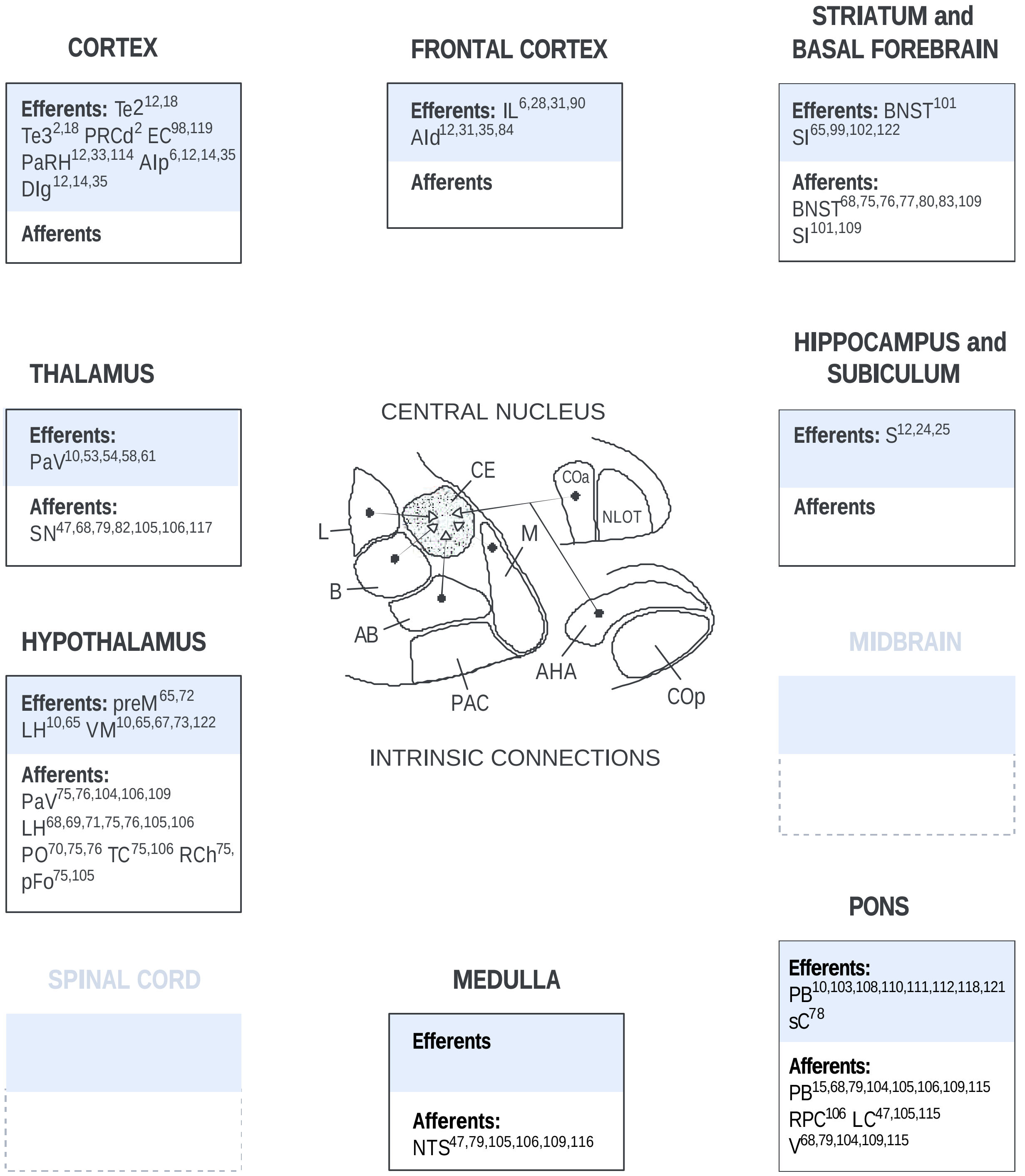


Figure 6. Afferent, intra-amygdaloid and efferent connections of the central nucleus. Only the moderate-to-heavy projections are indicated

Projections from the central nucleus. Conspicuously, the central nucleus does not project to cortical areas. It does provide substantial inputs to the bed nucleus of the stria terminalis, the substantia innominata and the substantia nigra. It provides the most prominent and widespread amygdaloid projections to the brain stem, which terminate in the parabrachial nucleus, the locus ceruleus, mesencephalic nucleus of the trigeminal nerve, the nucleus reticularis pontis caudalis and the nucleus tractus solitarius. Also, projections to many of the hypothalamic nuclei are substantial, including those to the paraventricular nucleus, the lateral hypothalamic area, the preoptic area, the perifornical region, tuber cinereum and the retrochiasmatic area.

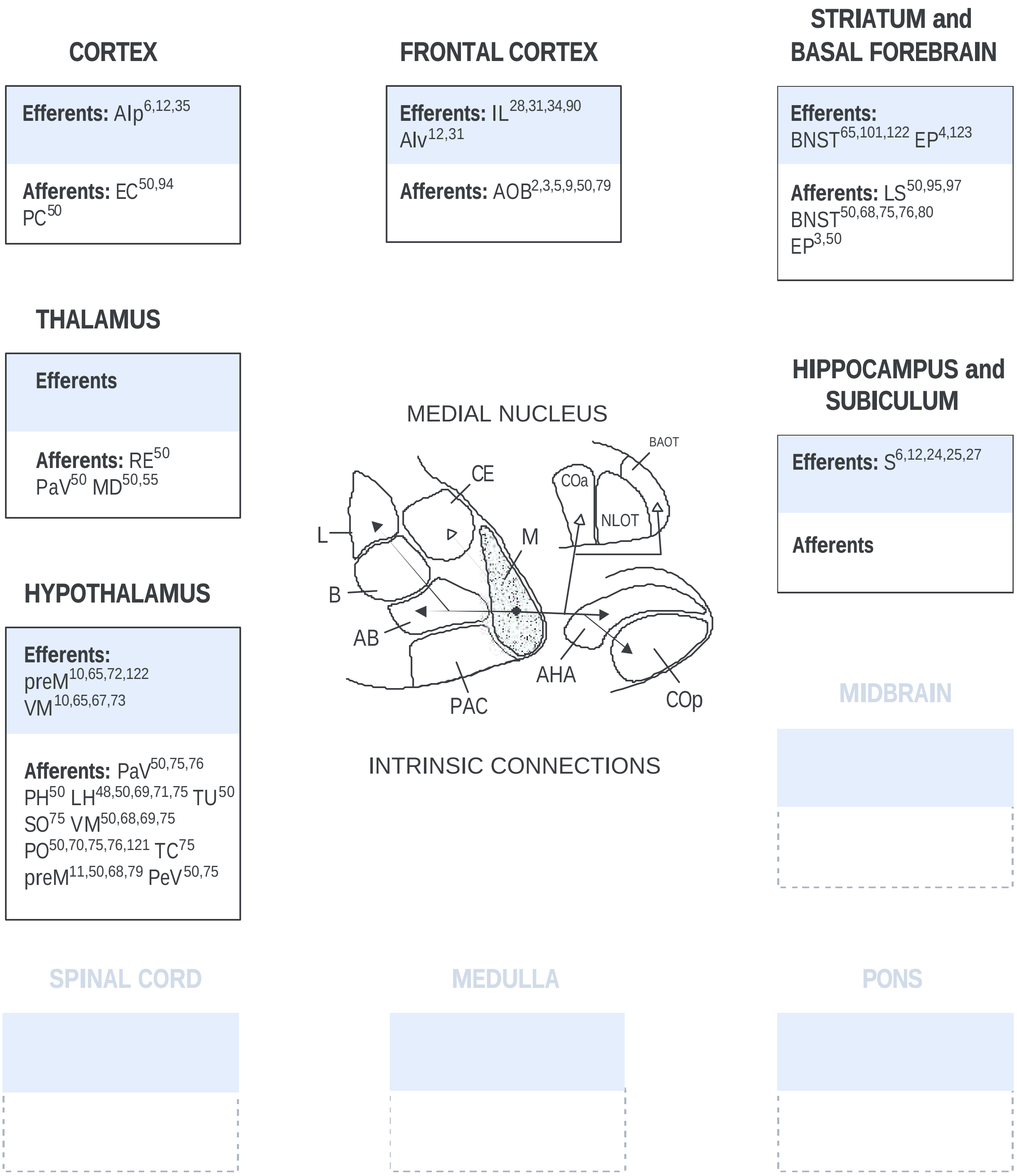


Figure 7. Afferent, intra-amygdaloid and efferent connections of the medial nucleus. Only the moderate-to-heavy projections are indicated

Medial nucleus

Projections to the medical nucleus. The connectivity of the medial nucleus is summarised in Figure 7. The heaviest cortical projections to the medial nucleus originate in the agranular insula and the infralimbic cortex. Projections from the medial temporal lobe memory system are meagre, including only a projection from the temporal subiculum. The bed nucleus of the stria terminalis and the endopiriform nucleus project to the medial nucleus. Other major inputs originate in the premamillary and ventromedial nuclei of the hypothalamus.

Intra-amygdaloid connections. The medial nucleus receives inputs from the lateral and accessory basal nuclei as well as from the amygdalohippocampal area and the posterior cortical nucleus. The intra-amygdaloid outputs are widespread and terminate in the lateral, accessory basal, central, anterior cortical and posterior cortical nuclei, as well as in the amygdalohippocampal area and the bed nucleus of the accessory olfactory tract. The medial nucleus receives inputs from several contralateral amygdaloid areas, including the nucleus of the lateral olfactory tract, the accessory basal nucleus, the periamygdaloid cortex and the posterior cortical nucleus.

Projections from the medial nucleus. The medial nucleus projects to several levels of the olfactory system including the caudal aspects of the piriform cortex, the accessory olfactory bulb and the endopiriform nucleus. The medial nucleus also projects heavily to the bed nucleus of stria terminalis and the lateral septum. The entorhinal cortex also receives a projection. Substantial projections are directed to the paraventricular, reuniens and mediodorsal nuclei of the thalamus. Finally, several hypothalamic areas are heavily innervated by the medial nucleus. These include the paraventricular nucleus, periventricular nucleus, posterior and lateral hypothalamic areas, tuberal nucleus, supraoptic nucleus, preoptic area, ventromedial nucleus, premamillary nucleus and tuber cinereum.

Anterior cortical nucleus

Projections to the anterior cortical nucleus. The connectivity of the anterior cortical nucleus is summarised in Figure 8. Inputs from the sensory-related cortex originate in the agranular and dysgranular insula. The prefrontal input originates in the infralimbic cortex and ventral agranular insula. Olfactory information comes from the piriform cortex and the endopiriform nucleus. The ventral subiculum is the only region in the hippocampal formation known to project to the anterior cortical nucleus. Other moderate-to-heavy inputs originate in the paraventricular nucleus of the thalamus and the parabrachial nucleus in the pons.

Intra-amygdaloid connections. The heaviest intra-amygdaloid inputs to the anterior cortical nucleus originate in the basal and medial nuclei. The anterior cortical nucleus projects to the central and basal nuclei. It also projects to the contralateral central nucleus.

Projections from the anterior cortical nucleus. The only cortical area that receives a substantial input from the anterior cortical nucleus is the piriform cortex. Other projections terminate in the bed nucleus of stria terminalis, substantia innominata and the lateral hypothalamus.

Periamygdaloid cortex

Projections to the periamygdaloid cortex. The connectivity of the periamygdaloid cortex is summarised in Figure 9. The agranular insula, the perirhinal cortex and the piriform cortex provide moderate inputs to the periamygdaloid cortex. Also, there are substantial projections from the infralimbic cortex. Another projection originates in the nucleus of the diagonal band and the endopiriform nucleus.

Intra-amygdaloid connections. The lateral and accessory basal nuclei provide substantial projections to the periamygdaloid cortex. The periamygdaloid cortex provides a heavy reciprocal connection back to the lateral nucleus. It also projects to the contralateral periamygdaloid cortex, the medial nucleus and the posterior cortical nucleus.

Projections from the periamygdaloid cortex. The periamygdaloid cortex provides substantial projections to several regions of the frontal cortex, including the infralimbic cortex, the dorsal peduncular cortex, the tenia tecta and the ventral agranular insula. It also provides an input to the entorhinal cortex as well as to the olfactory system, including the piriform cortex, the olfactory tubercle and the endopiriform nucleus.

Posterior cortical nucleus

Projections to the posterior cortical nucleus. The connectivity of the posterior cortical nucleus is summarised in Figure 10. The posterior cortical nucleus receives inputs from the entorhinal cortex. Substantial projections also originate in several olfactory-related areas including the piriform cortex, the accessory olfactory bulb and the endopiriform nucleus.

Intra-amygdaloid connections. The most substantial intra-amygdaloid projections come from the lateral, accessory basal and medial nuclei. The posterior cortical nucleus projects to the medial nucleus, periamygdaloid cortex and the bed nucleus of the accessory olfactory tract. It projects contralaterally to the posterior cortical nucleus, medial nucleus and the amygdalohippocampal area. The posterior cortical nucleus also receives an input from the contralateral periamygdaloid cortex.

Projections from the posterior cortical nucleus. The posterior cortical nucleus projects back to several levels of the olfactory system. These include the piriform cortex, the accessory olfactory bulb, the olfactory tubercle and the endopiriform nucleus. Other substantial projections are directed to the entorhinal cortex, the infralimbic cortex and the agranular insula. Also, the bed nucleus of the stria terminalis receives an input from the posterior cortical

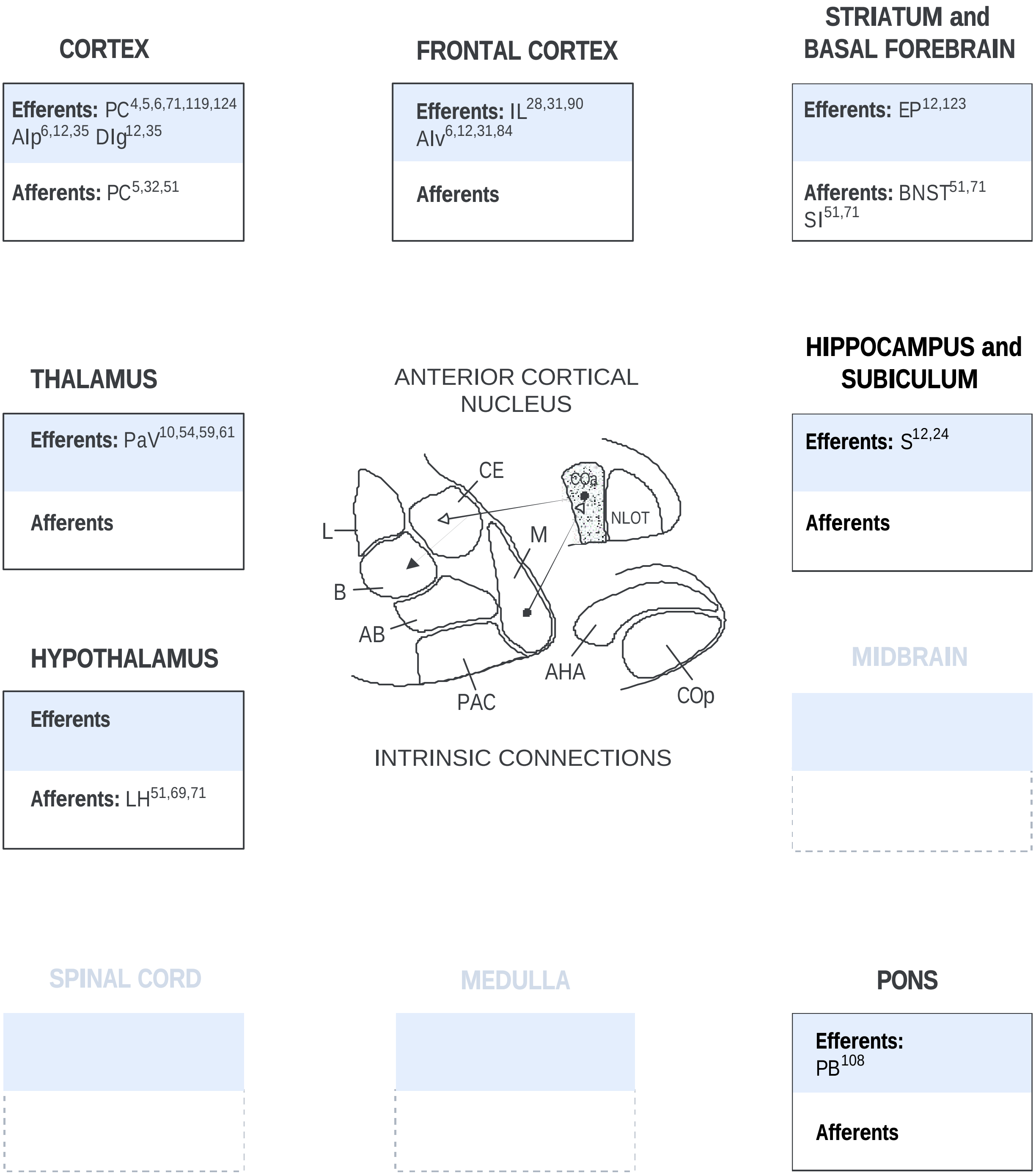


Figure 8. Afferent, intra-amygdaloid and efferent connections of the anterior cortical nucleus. Only the moderate-to-heavy projections are indicated

nucleus, as does the temporal end of the CA1 subfield of the hippocampus.

Amygdalohippocampal area

Projections to the amygdalohippocampal area. The connectivity of the amygdalohippocampal area is summarised in Figure 11. Substantial inputs originate in the medial temporal lobe memory system, including those from the temporal end of the CA1 subfield and the subiculum. Other projections originate in the hypothalamus, including the premamillary nucleus and the lateral hypothalamic area.

Intra-amygdaloid connections. The lateral, basal, accessory basal and medial nuclei as well as the bed nucleus of the accessory olfactory tract project

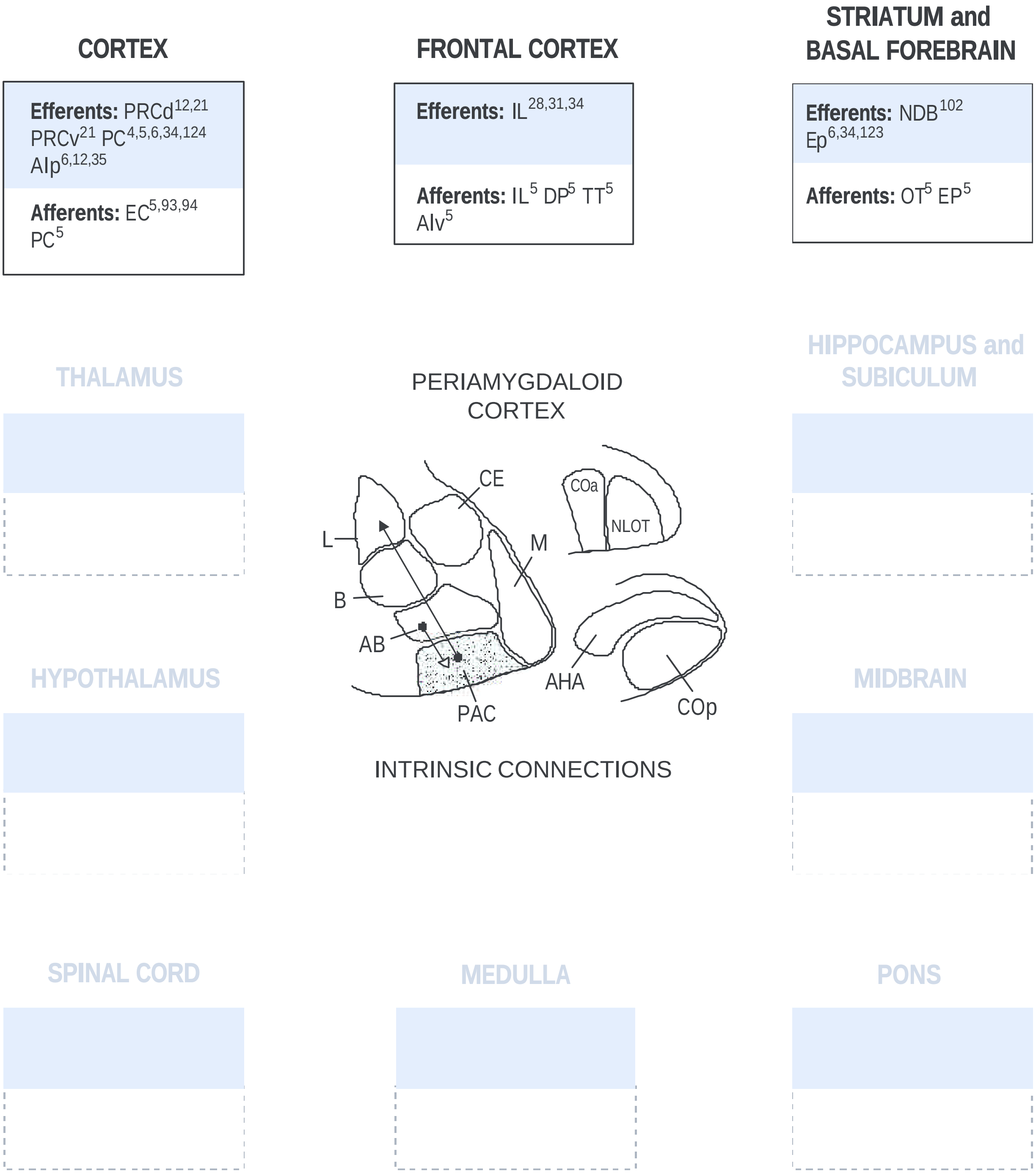


Figure 9. Afferent, intra-amygdaloid and efferent connections of the periamygdaloid cortex. Only the moderate-to-heavy projections are indicated

to the amygdalohippocampal area. It projects to the medial and central nuclei. The amygdalohippocampal area receives a contralateral input from the posterior cortical nucleus.

Projections from the amygdalohippocampal area. The amygdalohippocampal area provides substantial projections to the bed nucleus of the stria terminalis and several hypothalamic nuclei, including the premamillary nucleus, the preoptic area and the ventromedial nucleus.

Nucleus of the lateral olfactory tract

Projections to the nucleus of the lateral olfactory tract. The connectivity of the nucleus of the lateral olfactory tract is summarised in Figure 12. Overall, data about the inputs to the nucleus of the lateral olfactory tract are meagre. It receives projec-

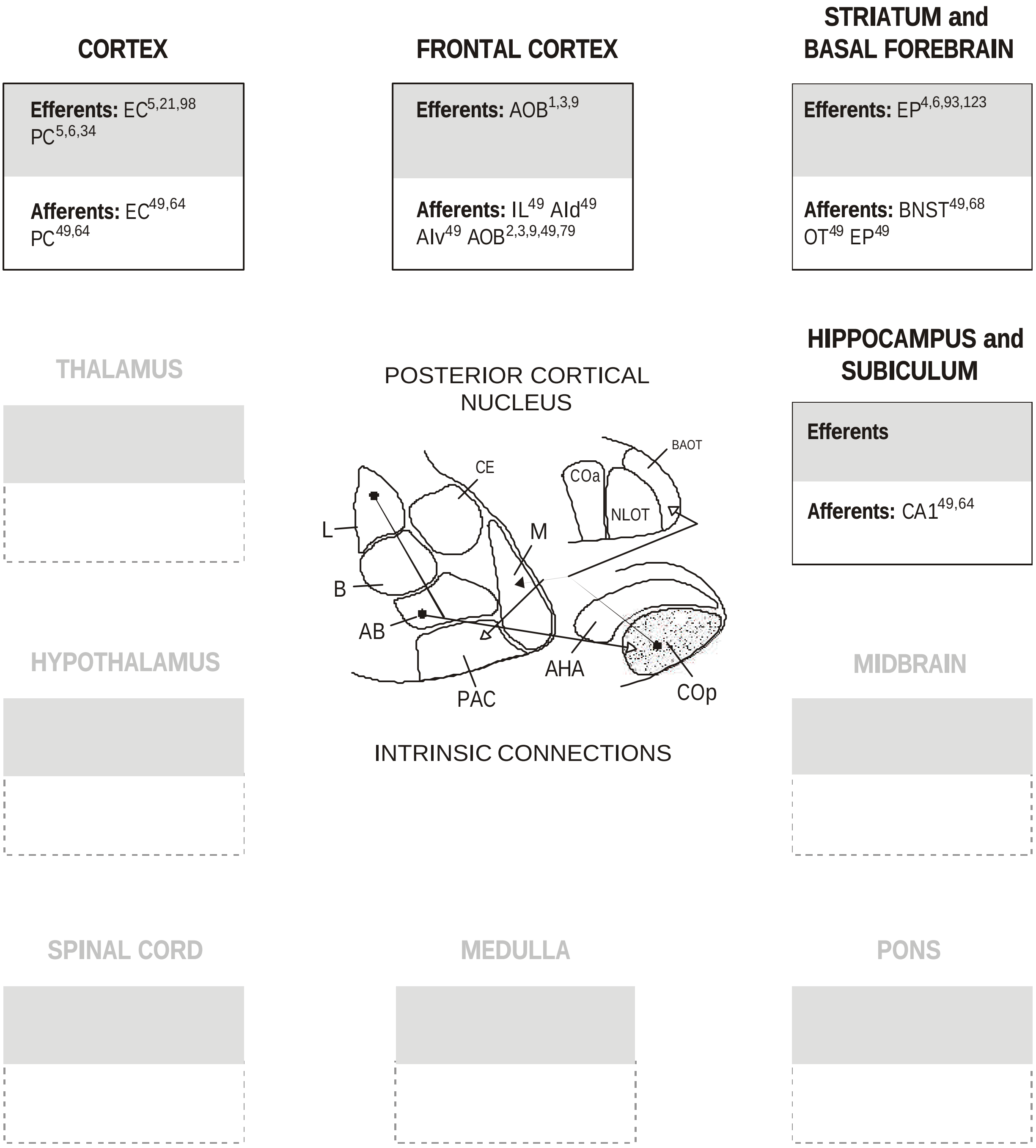


Figure 10. Afferent, intra-amygdaloid and efferent connections of the posterior cortical nucleus. Only the moderate-to-heavy projections are indicated

tions from the agranular insula, the nucleus of the diagonal band of Broca , the olfactory tubercle, the endopiriform nucleus and the temporal subiculum.

Intra-amygdaloid connections. The basal nucleus projects to the nucleus of the lateral olfactory tract. Intra-amygdaloid projections originating in the nucleus of the lateral olfactory tract are poorly described. It does, however, project contralaterally to the nucleus of the lateral olfactory tract, the medial nucleus and the central nucleus. It also receives a projection from the contralateral basal nucleus.

Projections from the nucleus of the lateral olfactory tract. The nucleus of the lateral olfactory tract provides moderate-to-heavy projections to several levels of the olfactory system, including the ol-

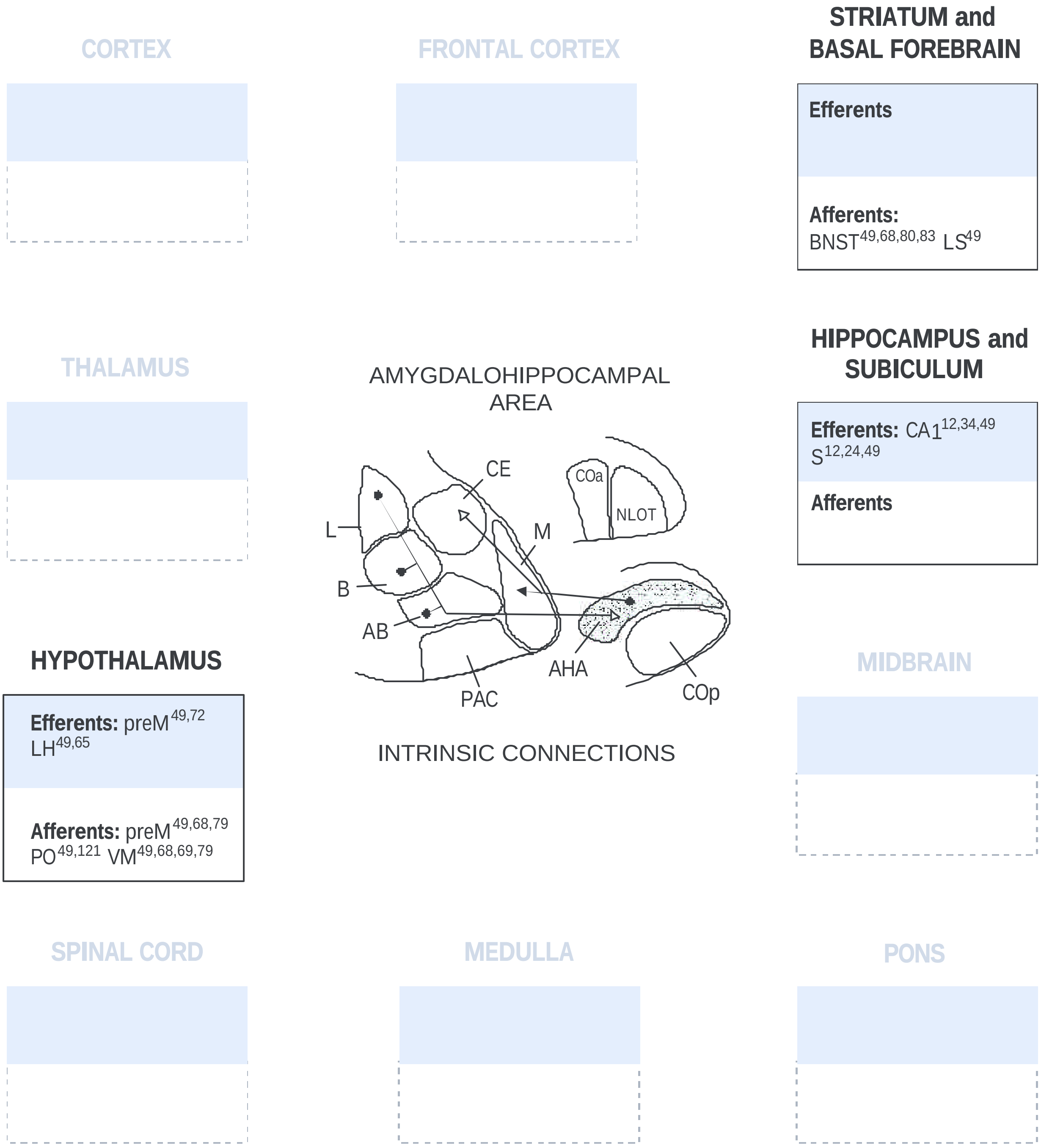


Figure 11. Afferent, intra-amygdaloid and efferent connections of the amygdalohippocampal area. Only the moderate-to-heavy projections are indicated

factory bulb, the olfactory tubercle, the endopiriform nucleus, as well as the Islands of Calleja.

PRINCIPLES OF ORGANISATION OF AMYGDALOID CONNECTIONS

Investigation of the pattern of connectivity of the amygdala with other brain areas suggests several principles in the organisation of information flow to and from the amygdala. As is evident from Figures 3 to12, each of the amygdaloid nuclei has a unique set of interconnections with other brain areas. Second, one brain area might project to several amygdaloid nuclei in parallel. Third, one amygdaloid nucleus might receive information from (a) several functional systems or (b) several levels of the same functional system. Fourth, some functional systems,

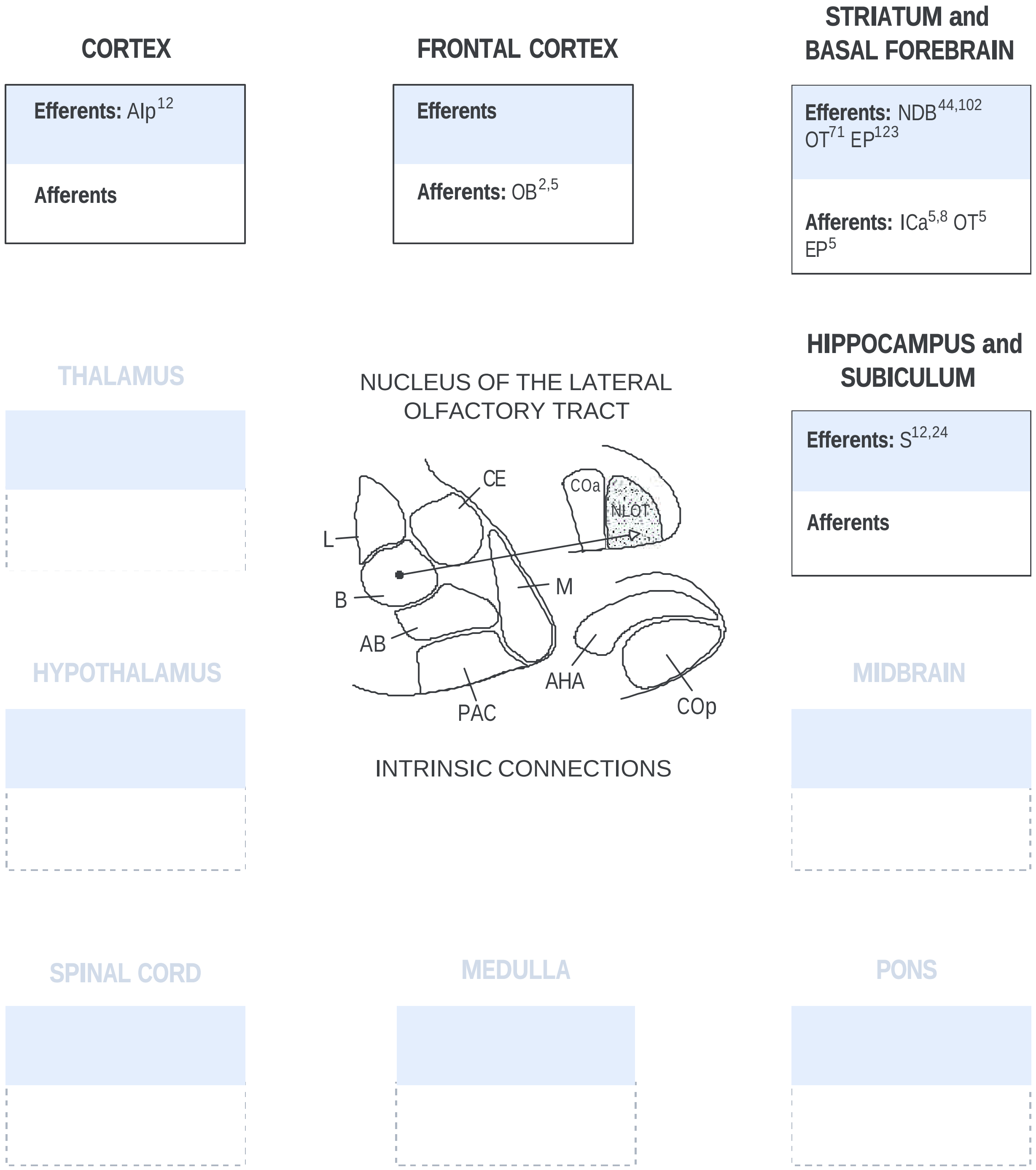


Figure 12. Afferent, intra-amygdaloid and efferent connections of the nucleus of the lateral olfactory tract. Only the moderate-to-heavy projections are indicated

however, terminate in a selective amygdaloid region. The parallel intra-amygdaloid circuitries probably multiply the number of iterations that each of the stimulus representations will have within the amygdaloid complex. The amygdaloid projections appear to obey the following principles: First, one amygdaloid nucleus might project to several functional systems or several levels of the same functional system in parallel. Second, several amygdaloid nuclei might send converging inputs to the same functional system. Third, some amygdaloid nuclei project more selectively to a few functional systems.

FUNCTIONAL IMPLICATIONS

Studies using magnetic resonance imaging volumetry, positron emission tomography, or histologic analysis of autopsy tissue demonstrate amygdaloid damage in several human brain diseases, including temporal lobe epilepsy [97], Alzheimer's disease [142], Parkinson's disease [15], schizophrenia [106], depression [119] and autism [6], to mention a few. A more detailed histologic analysis of autopsy tissue or the volumetric analysis of different amygdaloid nuclear groups using magnetic resonance imaging reveal some disease specificity in the „knock-out" of amygdaloid regions. For example, the medial division of the lateral nucleus and the parvicellular division of the basal nucleus are the most vulnerable amygdaloid regions in temporal lobe epilepsy [97]. The central nucleus and the periamygdaloid cortex contain the highest densities of Lewy bodies in Parkinson's disease [15]. The lateral, basal and accessory basal nuclei have the most prominent volume reduction in depression [119]. Finally, the basal and accessory basal nuclei have the most pronounced neuronal loss in Alzheimer's disease [142]. Considering the connectional differences of various amygdaloid nuclei with other functional systems, it is tempting to speculate that the impairments of amygdaloid functioning vary in different diseases because of the variable location of the amygdaloid lesion. One area yet to be explored is how much damage is needed and where in the amygdala to induce functional impairments; for example, the recognition of emotion in facial expressions. Further, would the same damage also impair other amygdaloid functions, such as the modulation of memory formation by emotional experiences?

ACKNOWLEDGEMENTS

This study was supported by the Academy of Finland, the Vaajasalo Foundation and the Sigrid Juselius Foundation.

REFERENCES

1. Adolphs R, Tranel D, Damasio H, Damasio A (1994) Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdala. Nature, 372: 669–672.
2. Adolphs R, Tranel D, Damasio AR (1998) The human amygdala in social judgement. Nature, 393: 470–474.
3. Amaral DG, Witter MP (1989) The three-dimensional organization of the hippocampal formation: a review of anatomical data. Neuroscience, 31: 571–591.
4. Amaral DG, Price JL, Pitkänen A, Carmichael ST (1992) Anatomical organization of the primate amygdaloid complex. In: Aggleton JP (ed.). The amygdala: Neurobiological aspects of emotion, memory and mental dysfunction. Wiley-Liss Publishers, New York, pp. 1–66.
5. Bacon SJ, Headlam AJN, Gabbott PLA, Smith AD (1996) Amygdala input to medial prefrontal cortex (mPFC) in the rat: A light and electron microscope study. Brain Res, 720: 211–219.
6. Bauman M, Kemper TL (1985) Histoanatomic observations of the brain in early infantile autism. Neurology, 35: 866–874.
7. Bechara A, Tranel D, Damasio H, Adolphs R, Rockland C, Damasio AR (1995) Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. Science, 269: 1115–1118.
8. Beckstead RM (1978) Afferent connections of the entorhinal area in the rat as demonstrated by retrograde cell-labeling with horseradish peroxidase. Brain Res, 152: 249–264.
9. Behan M, Haberly LB (1999) Intrinsic and efferent connections of the endopiriform nucleus in rat. J Comp Neurol, 408: 532–548.
10. Berendse HW, Galis-de-Graaf Y, Groenewegen HJ (1992) Topographical organization and relationship with ventral striatal compartments of prefrontal corticostriatal projections in the rat. J Comp Neurol, 316: 314–347.
11. Bernard JF, Peschanski M, Besson JM (1989) A possible spino (trigemino)-ponto-amygdaloid pathway for pain. Neurosci Lett, 100: 83–88.
12. Bernard J-F, Alden M, Besson J-M (1993) The organization of the efferent projections from the pontine parabrachial area to the amygdaloid complex: A *Phaseolus vulgaris* leucoagglutinin (PHA-L) study in the rat. J Comp Neurol, 329: 201–229.
13. Bianchi R, Corsetti G, Rodella L, Tredici G, Gioia M (1998) Supraspinal connections and termination patterns of the parabrachial complex determined by the biocytin anterograde tract-tracing in the rat. J Anat, 193: 417–430.
14. Bonda E, Petrides M, Ostry D, Evans A (1996) Specific involvement of human parietal systems and the amygdala in the perception of biological motion. J Neurosci, 16: 3737–3744.
15. Braak H, Braak E, Yilmazer D (1994) Amygdala pathology in Parkinson's disease. Acta Neuropathol (Berl.), 88: 493–500.
16. Brindley-Reed M, Mascani F, McDonald AJ (1995) Synaptology of prefrontal cortical projections to the basolateral amygdala: an electron microscopic study in the rat. Neurosci Lett, 202: 45–48.
17. Brog JS, Salyapongse A, Deutch AY, Zahm DS (1993) The patterns of afferent innervation of the core and shell in the "Accumbens" part of the rat ventral striatum: Immunohistochemical detection of retrogradely transported fluoro-gold. J Comp Neurol, 338: 255–278.
18. Caffe AR, van Leeuwen FW, Luiten PG (1987) Vasopressin cells in the medial amygdala of the rat project to the lateral septum and ventral hippocampus. J Comp Neurol, 261: 237–252.
19. Cahill L, Babinsky R, Markowitsch HJ, McGaugh JL (1995) The amygdala and emotional memory. Nature, 377: 295–296.
20. Cahill L, McGaugh JL (1998) Mechanisms of emotional arousal and lasting declarative memory. Trends Neurosci, 21: 294–299.
21. Calderazzo L, Cavalheiro EA, Macchi G, Molinari M, Bentivoglio M (1996) Branched connections to the sep-

tum and to the entorhinal cortex from the hippocampus, amygdala and diencephalon in the rat. Brain Res Bull, 40: 245–251.

22. Canteras NS, Simerly RB, Swanson LW (1992a) Connections of the posterior nucleus of the amygdala. J Comp Neurol, 324: 143–179.
23. Canteras NS, Simerly RB, Swanson LW (1992b) Projections of the ventral premammillary nucleus. J Comp Neurol, 324: 195–212.
24. Canteras NS, Simerly RB, Swanson LW (1994) Organization of projections from the ventromedial nucleus of the hypothalamus: A *Phaseolus vulgaris* - leucoagglutinin study in the rat. J Comp Neurol, 348: 41–79.
25. Canteras NS, Simerly RB, Swanson LW, (1995) Organization of projections from the medial nucleus of the amygdala: A PHAL study in the rat. J Comp Neurol, 360: 213–245.
26. Canteras NS, Swanson LW (1992) Projections of the ventral subiculum to the amygdala, septum and hypothalamus: A PHAL anterograde track-tracing study in the rat. J Comp Neurol, 324: 180–194.
27. Christensen M-K, Frederickson CJ (1998) Zinc-containing afferent projections to the rat corticomedial amygdaloid complex: A retrograde tracing study. J Comp Neurol, 400: 375–390.
28. Condé F, Maire-Lepoivre E, Audinat E, Crépel F (1995) Afferent connections of the medial frontal cortex of the rat. II Cortical and subcortical afferents. J Comp Neurol, 352: 567–593.
29. Cullinan WE, Herman JP, Watson JS (1993) Ventral subicular interaction with the hypothalamic paraventricular nucleus: Evidence for a relay in the bed nucleus of the stria terminalis. J Comp Neurol, 332: 1–20.
30. Danielson EH, Magnuson DJ, Gray TS (1989) The central amygdaloid nucleus innervation of the dorsal vagal complex in rat: A*Phaseolus vulgaris*, leucoagglutinin lectin anterograde tracing study. Brain Res Bull, 22: 705–715.
31. Datta S, Siwek F, Patterson EH, Cipolloni PB (1998) Localization of pontine PGO wave generation sites and their anatomical projections in the rat. Synapse, 30: 409–423.
32. Davis M (1992) The role of the amygdala in conditioned fear. In: Aggleton JP (ed.). The amygdala: Neurobiological aspects of emotion, memory and mental dysfuction. Wiley-Liss Publishers, New York, pp. 255–306.
33. Deacon TW, Eichenbaum H, Rosenberg P, Eckmann KW (1983) Afferent connections of the perirhinal cortex in the rat. J Comp Neurol, 220: 168–190.
34. Gallagher M, Holland PC (1994) The amygdala complex: Multiple roles in associative learning and attention. Proc Natl Acad Sci USA, 91: 11771–11776.
35. Gray TS (1990) The organization and possible function of amygdaloid corticotropin-releasing factor pathways. In: De Souza EB, Nemeroff CB (eds.). Corticotropin-releasing factor: basic and clinical studies of a neuropeptide. CRC Press, Inc., Florida.
36. Gray TS, Carney ME, Magnuson DJ (1989) Direct projections from the central amygdaloid nucleus to the hypothalamic paraventricular nucleus: Possible role in stress-induced adrenocorticotropin release. Neuroendocrinology, 50: 433–466.
37. Grove EA (1988a) Neural associations of the substantia innominata in the rat: Afferent connections. J Comp Neurol, 277: 315–346.
38. Grove EA (1988b) Efferent connections of the substantia innominata in the rat. J Comp Neurol, 277: 347–364.
39. Hurley KM, Herbert H, Moga MM, Saper CB (1991) Efferent projections of the infralimbic cortex of the rat. J Comp Neurol, 308: 249–276.
40. Insausti R, Herrero MT, Witter MP (1997) Entorhinal cortex of the rat: cytoarchitectonic subdivisions and the origin and distribution of cortical efferents. Hippocampus, 7: 146–183.
41. Jolkkonen E, Pitkänen A (1998a) Intrinsic connections of the rat amygdaloid complex: projections originating in the central nucleus. J Comp Neurol, 395: 53–72.
42. Jolkkonen E, Pitkänen A (1998b) Projections from the amygdalapiriform transition area to the central nucleus of the amygdala: A PHA-L study in the rat. Soc Neurosci Abstr, 24: 675.
43. Kelley AE, Domensick VB, Nauta WJH (1982) The amygdalostriatal projection in the rat - an anatomical study by anterograde and retrograde tracing methods. Neuroscience, 7: 615–630.
44. Kemppainen S, Pitkänen A (1998) Projections from the posterior cortical nucleus of the amygdala to other temporal lobe areas in rat. Soc Neurosci Abstr, 24: 676.
45. Kirouac GJ, Ganguly PK (1995) Topographical organization in the nucleus accumbens of afferents from the basolateral amygdala and efferents to the lateral hypothalamus. Neuroscience, 67: 625–630.
46. Kita H, Kitai ST (1990) Amygdaloid projections to the frontal cortex and the striatum in the rat. J Comp Neurol, 298: 40–49.
47. Kita H, Oomura Y (1982) An HRP study of the afferent connections of the rat lateral hypothalamic region. Brain Res Bull, 8: 63–71.
48. Krettek JE, Price JL (1974) Projections from the amygdala to the perirhinal and entrorhinal cortices and the subiculum. Brain Res, 71: 150–154.
49. Krettek JE, Price JL (1977a) Projections from the amygdaloid complex to the cerebral cortex and thalamus in the rat and cat. J Comp Neurol, 172: 687–722.
50. Krettek JE, Price JL (1977b) Projections from the amygdaloid complex and adjacent olfactory structures to the entorhinal cortex and to the subiculum in the rat and cat. J Comp Neurol, 172: 723–752.
51. Krettek JE, Price JL (1978a) Amygdaloid projections to subcortical structures in the basal forebrain and brainstem in the rat and cat. J Comp Neurol, 178: 225–254.
52. Krettek JE, Price JL (1978b) A description of the amygdaloid complex in the rat and cat with observations on intra-amygdaloid axonal connections. J Comp Neurol, 178: 255–280.
53. Krieger MS, Conrad LCA, Pfaff DW (1979) An autoradiographic study of the efferent connections of the ventromedial nucleus of the hypothalamus. J Comp Neurol, 183: 785–816.
54. Krukoff TL, Harris KH, Jhamandas JH (1993) Efferent projections from the parabrachial nucleus demonstrated with anterograde tracer *Phaseolus vulgaris* leucoagglutinin. Brain Res Bull, 30: 163–172.

55. LaBar KS, LeDoux JE, Spencer DD, Phelps EA (1995) Impaired fear conditioning following unilateral temporal lobectomy in humans. J Neurosci, 15: 6846–6855.
56. LeDoux JE (1992) Emotion and the amygdala. In: Aggleton JP (ed.). The amygdala: Neurobiological aspects of emotion, memory and mental dysfunction. Wiley-Liss Publishers, New York, pp. 339–352.
57. LeDoux JE, Farb C, Ruggiero DA (1990) Topographic organization of neurons in the acoustic thalamus that project to the amygdala. J Neurosci, 10: 1043–1054.
58. LeDoux JE, Farb C, Romanski LM (1991) Overlapping projections to the amygdala and striatum from auditory processing areas of the thalamus and cortex. Neurosci Lett, 134: 139–144.
59. Linke R, de Lima AD, Schwegler H, Pape H-C (1999) Direct synaptic connections of axons from superior colliculus with identified thalamo-amygdaloid projection neurons in the rat: Possible substrates of a subcortical visual pathway to the amygdala. J Comp Neurol, 403: 158–170.
60. Luiten PGM, Spencer DG Jr, Traber J, Gaykema RPA (1985) The pattern of cortical projections from the intermediate parts of the magnocellular nucleus basalis in the rat demonstrated by tracing with *Phaseolus vulgaris*-leucoagglutinin. Neurosci Lett, 57: 137–142.
61. Luskin MB, Price JL (1983a) The topographic organization of associational fibres of the olfactory system in the rat, including centrifugal fibres to the olfactory bulb. J Comp Neurol, 216: 264–291.
62. Luskin MB, Price JL (1983b) The laminar distribution of intracortical fibers originating in the olfactory cortex of the rat. J Comp Neurol, 216: 292–302.
63. Maquet P, Peters J, Aerts J, Delfiore G, Degueldre C, Luxen A, Franck G (1996) Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. Nature, 383: 163–166.
64. Mascagni F, McDonald AJ, Coleman JR (1993) Corticoamygdaloid and corticocortical projections of the rat temporal cortex: a *Phaseolus vulgaris* leucoagglutinin study. Neuroscience, 57: 697–715.
65. McDonald AJ (1987a) Organization of amygdaloid projections to the mediodorsal thalamus and prefrontal cortex: A fluorescence retrograde transport study in the rat. J Comp Neurol, 262: 46–58.
66. McDonald AJ (1987b) Somatostatinergic projections from the amygdala to the bed nucleus of the stria terminalis and medial preoptic-hypothalamic region. Neurosci Lett, 75: 271–277.
67. McDonald AJ (1991a) Organization of amygdaloid projections to the prefrontal cortex and associated striatum in the rat. Neuroscience, 44: 1–14.
68. McDonald AJ (1991b) Topographical organization of amygdaloid projections to the caudatoputamen, nucleus accumbens and related striatal-like areas of the rat brain. Neuroscience, 44: 15–33.
69. McDonald AJ (1998) Cortical pathways to the mammalian amygdala. Prog Neurobiol, 55: 257–332.
70. McDonald AJ, Jackson TR (1987) Amygdaloid connections with posterior insular and temporal cortical areas in the rat. J Comp Neurol, 262: 59–77.
71. McDonald AJ, Mascagni F (1996) Cortico-cortical and cortico-amygdaloid projections of the rat occipital cortex: A *phaselous vulgaris* leucoagglutinin study. Neuroscience, 71: 37–54.
72. McDonald AJ, Mascagni F (1997) Projections of the lateral entorhinal cortex to the amygdala: A *Phaseolus vulgaris* leucoagglutinin study in the rat. Neuroscience, 77: 445–460.
73. McDonald AJ, Mascagni F, Guo L (1996) Projections of the medial and lateral prefrontal cortices to the amygdala: A *Phaseolus vulgaris* leucoagglutinin study in the rat. Neuroscience, 71: 55–75.
74. McIntyre DC, Kelly ME, Staines WA (1996) Efferent projections of the anterior perirhinal cortex in the rat. J Comp Neurol, 396: 302–318.
75. Millhouse OE, Uemura-Sumi M (1985) The structure of the nucleus of the lateral olfactory tract. J Comp Neurol, 233: 517–552.
76. Moga MM, Weis RP, Moore RY (1995) Efferent projections of the paraventricular thalamic nucleus in the rat. J Comp Neurol, 359: 221–238.
77. Morris JS, Öhman A, Dolan RJ (1998) Conscious and unconscious emotional learning in the human amygdala. Nature, 393: 467–470.
78. Namura S, Takada M, Kikuchi H, Mizuno N (1997) Collateral projections of single neurons in the posterior thalamic region to both the temporal cortex and the amygdala: A fluorescent retrograde double-labeling study in the rat. J Comp Neurol, 384: 59–70.
79. Nitecka L (1981) Connections of the hypothalamus and preoptic area with nuclei of the amygdaloid body in the rat: HRP retrograde transport study. Acta Neurobiol Exp, 41: 53–67.
80. Nitecka L, Amerski L, Panek-Mikuza J, Narkiewicz O (1979) Thalamoamygdaloid connections studied by the method of retrograde transport. Acta Neurobiol Exp, 39: 585–601.
81. Nitecka L, Amerski, L, Panek-Mikula J, Narkiewicz O (1980) Tegmental afferents of the amygdaloid body in the rat. Acta Neurobiol Exp, 40: 609–624.
82. de Olmos J, Hardy H, Heimer L (1978) The afferent connections of the main and the accessory olfactory bulb formations in the rat: an experimental HRP-study. J Comp Neurol, 181: 213–244.
83. de Olmos J, Alheid GF, Beltramino CA (1985) Amygdala. In: Paxinos G (ed.). The rat nervous system. Academic Press, Sydney.
84. Ono T, Luiten PGM, Nishijo H, Fukuda M, Nishino H (1985) Topographic organization of projections from the amygdala to the hypothalamus of the rat. Neurosci Res, 2: 221–239.
85. Ottersen OP (1980) Afferent connections to the amygdaloid complex of the rat and cat: II. Afferents from the hypothalamus and the basal telencephalon. J Comp Neurol, 194: 267–289.
86. Ottersen OP, (1981) Afferent connections to the amygdaloid complex of the rat with some observations in the cat. III. Afferents from the lower brain stem. J Comp Neurol, 202: 335–356.
87. Ottersen OP (1982) Connections of the amygdala of the rat. Corticoamygdaloid and intraamygdaloid connections as studied with axonal transport of horseradish peroxidase. J Comp Neurol, 205: 30–48.
88. Ottersen OP, Ben-Ari Y (1979) Afferent connections to the amygdaloid complex of the rat and cat. J Comp Neurol, 187: 401–424.

89. Paxinos G, Watson C (1986) The rat brain in stereotaxic coordinates. Academic Press, New York.
90. Petrovich GD, Risold PY, Swanson LW (1996) Organization of projections from the basomedial nucleus of the amygdala: A PHAL study in the rat. J Comp Neurol, 374: 387–420.
91. Petrovich GD, Swanson LW (1997) Projections from the lateral part of the central amygdalar nucleus to the postulated fear conditioning circuit. Brain Research, 763: 247–254.
92. Phillips RG, LeDoux JE (1992) Overlapping and divergent projections of CA1 and ventral subiculum to the amygdala. Soc Neurosci Abstr, 18: 518.
93. Pickel VM, Van Bockstaele JC, Chan J, Cestari DM (1995) Amygdala efferents from inhibitory-type synapses with a subpopulation of catecholaminergic neurons in the rat nucleus tractus solitarius. J Comp Neurol, 362: 510–523.
94. Pikkarainen M, Rönkkö S, Savander V, Insausti R, Pitkänen A (1999) Projections from the lateral, basal and accessory basal nuclei of the amygdala to the hippocampal formation in rat. J Comp Neurol, 403: 229–260.
95. Pitkänen A (2000) Connectivity of the rat amygdaloid complex. In: Aggleton JP (ed.). The amygdala: a functional analysis. Oxford University Press.
96. Pitkänen A, Savander V, LeDoux JE (1997) Organization of intra-amygdaloid circuitries in the rat: an emerging framework for understanding functions of the amygdala. Trends Neurosci, 20: 517–523.
97. Pitkänen A, Tuunanen J, Kälviäinen R, Partanen K, Salmenperä T (1998) Amygdala damage in experimental and human epilepsy. Epilepsy Res, 328: 233–253.
98. Post S, Mai JK (1978) Evidence for amygdaloid projections to the contralateral hypothalamus and the ipsilateral midbrain in the rat. Cell Tissue Res, 191: 183–186.
99. Post S, Mai JK (1980) Contribution to the amygdaloid projection field in the rat. A quantitative autoradiographic study. J Hirnforsch, 21: 199–225.
100. Prewitt CMF, Herman JP (1998) Anatomical interactions between the central amygdaloid nucleus and the hypothalamic paraventricular nucleus of the rat: a dual tract-tracing analysis. J Chem Neuroanat, 15: 173–185.
101. Price JL (1973) An autoradiographic study of complementary laminar patterns of termination of afferent fibres to the olfactory cortex. J Comp Neurol, 15: 87–108.
102. Price JL, Russchen FT, Amaral DG (1987) Integrated systems of the CNS. The Limbic Region. II: The Amygdaloid Complex. In: Björklund A, Hökfelt T, Swanson LW (eds.). Handbook of chemical neuroanatomy. Vol. 5., Part I. Elsevier, Amsterdam.
103. Price JL, Slotnik BM, Revial M (1991) Olfactory projections to the hypothalamus. J Comp Neurol, 306: 447–461.
104. Rauch SL, van der Kolk BA, Fisler RE, Alpert NM, Orr SP, Savage CR, Fischman AJ, Jenike MA, Pitman RK (1996) A symptom provocation study of posttraumatic stress disorder using positron emission tomography and script-driven imagery. Arch Gen Psychiatry, 53: 380–387.
105. Ray JP, Price JL (1992) The organization of the thalamocortical connections of the mediodorsal thalamic nucleus in the rat, related to the ventral forebrain-prefrontal cortex topography. J Comp Neurol, 323: 167–197.
106. Reynolds GP (1992) The amygdala and the neurochemisty of schizophrenia. In: Aggleton JP (ed.). The amygdala: Neurobiological aspects of emotion, memory and mental dysfunction. Wiley-Liss, Inc., New York, pp. 561–574.
107. Risold PY, Canteras NS, Swanson LW (1994) Organization of projections from the anterior hypothalamic nucleus: A *Phaseolus vulgaris*-leucoagglutinin study in the rat. J Comp Neurol, 348: 1–40.
108. Romanski LM, LeDoux JE (1993) Information cascade from primary auditory cortex to the amygdala: Corticocortical and corticoamygdaloid projections of temporal cortex in the rat. Cereb. Cortex, 3: 515–532.
109. Rosen JB, Hitchcock JM, Sanases CB, Miserendino MJD, Davis M (1991) A direct projection from the central nucleus of the amygdala to the acoustic startle pathway: Anterograde and retrograde tracing studies. Behav Neurosci, 105: 817–825.
110. Russchen FT, Price JL (1984) Amygdalostriatal projections in the rat. Topographical organization and fiber morphology shown using the lectin PHA-L as an anterograde tracer. Neurosci Lett, 47: 15–22.
111. Saper CB, Loewy AD (1980) Efferent connections of the parabrachial nucleus in the rat. Brain Res, 197: 291–317.
112. Sarter M, Markowitsch HJ (1983) Convergence of basolateral amygdaloid and mediodorsal thalamic projections in different areas of the frontal cortex in the rat. Brain Res Bull, 10: 607–622.
113. Sarter M, Markowitsch HJ (1984) Collateral innervation of the medial and lateral prefrontal cortex by amygdaloid, thalamic and brain-stem neurons. J Comp Neurol, 224: 445–460.
114. Savander V, Miettinen M, Rönkkö S, Pitkänen A (1997) Projections from the lateral, basal and accessory basal nuclei of the amygdala to the perirhinal and posthrinal cortices: A*Phaseolus vulgaris* leucoagglutinin study in rat. Soc Neurosci Abstr, 23: 2101.
115. Scalia F, Winans SS (1975) The differential projections of the olfactory bulb and accessory olfactory bulb in mammals. J Comp Neurol, 161: 31–55.
116. Schmued L, Phermsangngam P, Lee H, Thio S, Chen E, Truong P, Colton E, Fallon J (1989) Collateralization and GAD immunoreactivity of descending pallidal efferents. Brain Res, 487: 131–142.
117. Scott SK, Young AW, Calder AJ, Hellawell DJ, Aggleton JP, Johnson M (1997) Impaired auditory recognition of fear and anger following bilateral amygdala lesions. Nature, 385: 254–257.
118. Sesack SR, Deutch AY, Roth RH, Bunney BS (1989) Topographical organization of the efferent projections of the medial prefrontal cortex in the rat: An anterograde tract-tracing study with*Phaselous vulgaris* leucoagglutinin. J Comp Neurol, 290: 213–242.
119. Sheline YI, Gado MH, Price JL (1998) Amygdala core nuclei volumes are decreased in recurrent major depression. Neuroreport, 9: 2023–2028.
120. Shi C-J, Cassell MD (1997) Cortical, thalamic and amygdaloid projections of rat temporal cortex. J Comp Neurol, 382: 153–175.

121. Shi C-J, Cassell MD (1998a) Cortical, thalamic and amygdaloid connections of the anterior and posterior insular cortices. J Comp Neurol, 399: 440–468.
122. Shi C-J, Cassell MD (1998b) Cascade projections from somatosensory cortex to the rat basolateral amygdala via the parietal insular cortex. J Comp Neurol, 399: 469–491.
123. Shi C-J, Cassell MD (1999) Perirhinal cortex projections to the amygdaloid complex and hippocampal formation in the rat. J Comp Neurol, 406: 299–328.
124. Shinonaga Y, Takada M, Mizuno N (1994) Topographic organization of collateral projections from the basolateral amygdaloid nucleus to both the prefrontal cortex and nucleus accumbens in the rat. Neuroscience, 58: 389–397.
125. Simerly RB, Swanson LW (1986) The organization of neural inputs to the medial preoptic nucleus of the rat. J Comp Neurol, 246: 312–342.
126. Su H-S, Bentivoglio M (1990) Thalamic midline cell populations projecting to the nucleus accumbens, amygdala and hippocampus in the rat. J Comp Neurol, 297: 582–593.
127. Sun N, Roberts L, Cassell MD (1991) Rat central amygdaloid nucleus projections to the bed nucleus of the stria terminalis. Brain Res Bull, 27: 651–662.
128. Sun N, Yi H, Cassell MD (1994) Evidence for a GABAergic interface between cortical afferents and brainstem projection neurons in the rat central extended amygdala. J Comp Neurol, 340: 43–64.
129. Swanson LW (1992): Brain maps: structure of the rat brain. Elsevier, Amsterdam.
130. Swanson LW, Kohler C (1986) Anatomical evidence for direct projections from the entorhinal area to the entire cortical mantle in the rat. J Neurosci, 6: 3010–3023.
131. Switzer RC, de Olmos J, Heimer L (1985) Olfactory system. In: G Paxinos (ed.). The Rat Nervous System. Academic Press, Sydney, pp. 1–35.
132. Takagishi M, Chiba T (1991) Efferent projections of the infralimbic (area 25) region of the medial prefrontal cortex in the rat: an anterograde tracer PHA-L study. Brain Res, 566: 26–39.
133. Turner BH, Herkenham M (1991) Thalamoamygdaloid projections in the rat: a test of the amygdala´s role in sensory processing. J Comp Neurol, 313: 295–325.
134. Turner BH, Zimmer J (1984) The architecture and some of the interconnections of the rat´s amygdala and lateral periallocortex. J Comp Neurol, 227: 540–557.
135. Van Bockstaele EJ, Chan J, Pickel VM (1996) Input from central nucleus of the amygdala efferents to pericoerulear dendrites, some of which contain tyrosine hydroxylase immunoreactivity. J Neurosci Res, 45: 289–302.
136. Van Groen T, Wyss JM (1990a) The connections of presubiculum and parasubiculum in the rat. Brain Res, 518: 227–243.
137. Van Groen T, Wyss JM (1990b) Extrinsic projections from area CA1 of the rat hippocampus: olfactory, cortical, subcortical and bilateral hippocampal formation projections. J Comp Neurol, 302: 515–528.
138. Vankova M, Arluison M, Leviel V, Tramu G (1992) Afferent connections of the rat substantia nigra pars lateralis with special reference to peptide-containing neurons of the amygdalo-nigral pathway. J Chem Neuroanat, 5: 39–50.
139. Van Vulpen EHS, Verwer RWH (1989) Organization of projections from the mediodorsal nucleus of the thalamus to the basolateral complex of the amygdala in the rat. Brain Res, 500: 389–394.
140. Veening JG (1978a) Cortical afferents of the amygdaloid complex in the rat: An HRP study. Neurosci Lett, 8: 191–195.
141. Veening JG (1978b) Subcortical afferents of the amygdaloid complex in the rat: an HRP study. Neurosci Lett, 8: 197–202.
142. Vereecken THLG, Vogels OJM, Nieuwenhuys R (1994) Neuron loss and shrinkage in the amygdala in Alzheimer's disease. Neurobiol Aging, 15: 45–54.
143. Vertes RP (1991) A PHA-L analysis of ascending projections of the dorsal raphe nucleus in the rat. J Comp Neurol, 313: 643–668.
144. Vertes RP, Crane AL, Colom LV, Bland BH (1995) Ascending projections of the posterior nucleus of the hypothalamus: PHA-L analysis in the rat. J Comp Neurol, 359: 90–116.
145. Wallace DM, Magnuson DJ, Gray TS (1989) The amygdalo-brainstem pathway: selective innervation of dopaminergic, noradrenergic and adrenergic cells in the rat. Neurosci Lett, 97: 252–258.
146. Weller KL, Smith DA (1982) Afferent connections to the bed nucleus of the stria terminals. Brain Res, 232: 255–270.
147. Woolf NJ, Butcher LL (1982) Cholinergic projections to the basolateral amygdala: A combined evans blue and acetylcholinesterase analysis. Brain Res Bull, 8: 751–763.
148. Wright C, Groenewegen HJ (1995) Patterns of convergence and segregation in the medial nucleus accumbens of the rat: Relationships of prefrontal cortical, midline thalamic and basal amygdaloid afferents. J Comp Neurol, 361: 383–403.
149. Wright CI, Groenewegen HJ (1996) Patterns of overlap and segregation between insular cortical, intermediodorsal thalamic and basal amygdaloid afferents in the nucleus accumbens of the rat. Neuroscience, 73: 359–373.
150. Wright CI, Beijer AVJ, Groenewegen HJ (1996) Basal amygdaloid complex afferents to the rat nucleus accumbens are compartmentally organized. J Neurosci, 16: 1877–1893.
151. Wyss JM (1981) An autoradiographic study of the efferent connections of the entorhinal cortex in the rat. J Comp Neurol, 199: 495–512.
152. Yasui Y, Breder CD, Saper CB, Cechetto DF (1991) Autonomic responses and efferent pathways from the insular cortex in the rat. J Comp Neurol, 303: 355–374.
153. Zald DH, Pardo JV (1997) Emotion, olfaction and the human amygdala: Amygdala activation during aversive olfactory stimulation. Neurobiology (Bp), 94: 4119–4124.