NEURAL CONNECTIVITY OF THE AMYGDALA IN THE HUMAN BRAIN: A DIFFUSION TENSOR IMAGING STUDY

Sung Ho Jang, Hyeok Gyu Kwon**

Abstract: Several diffusion tensor imaging (DTI) studies have reported on the anatomical neural tracts between the amygdala and specific brain regions. However, no study on the neural connectivity of the amygdala has been reported. In the current study, using probabilistic DTI tractography, we attempted to investigate the neural connectivity of the amygdala in normal subjects. Forty eight healthy subjects were recruited for this study. A seed region of interest was drawn at the amygdala using the FMRIB Software Library based on probabilistic DTI tractography. Connectivity was defined as the incidence of connection between the amygdala and each brain region at the threshold of 1 and 5 streamlines. The amygdala showed 100% connectivity to the hippocampus, thalamus, hypothalamus, and medial temporal cortex regardless of the thresholds. In contrast, regarding the thresholds of 1 and 5 streamlines, the amygdala showed high conncetivity (over 60%) to the globus pallidus (100% and 92.7%), brainstem (83.3% and 78.1%), putamen (72.9% and 63.5%), occipito-temporal cortex (72.9% and 67.7%), orbitofrontal cortex (70.8 and 43.8%), caudate nucleus (63.5% and 45.8%), and ventromedial prefrontal cortex (63.5% and 31.3%), respectively. The amygdala showed high connectivity to the hippocampus, thalamus, hypothalamus, medial temporal cortex, basal ganglia, brainstem, occipito-temporal cortex, orbitofrontal cortex, and ventromedial prefrontal cortex. We believe that the methods and results of this study provide useful information to clinicians and researchers studying the amygdala.

Key words: *Amygdala, neural connectivity, diffusion tensor imaging, emotion, memory*

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1. Introduction

Amygdala, a large mass of deep nuclei located in the medial temporal lobe, is a part of the limbic system [2, 37]. The amygdala has widespread connectivity with various

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brain regions [13, 16, 20, 21, 27, 37]. The connected brain regions and their related functions can be summarized as follows: hippocampal formation-emotional memory, thalamus-sensory and memory, hypothalamus-autonomic function and defense reaction, brainstem-autonomic response and defense reaction, striatum-integrated motor response and goal-directed behavior, occipito-temporal cortex-attention and visual perception, orbitofrontal and anterior cingulate cortex-aggression and violence, motor cortex-complex motor behavior, insular cortex-mediation of heart rate and gustatory processing, ventromedial prefrontal cortex (vmPFC)-anxiety, and the basal forebrain-aggression and motivation [1, 2, 12, 13, 16, 20, 21, 27, 31, 37]. As a result, the amygdala is known to be involved in the pathogenetic mechanism of various neurological diseases, including anxiety disorder, schizophrenia, Alzheimer's disease, and autism [8, 20, 37, 39]. Therefore, elucidation of the neural connectivity of the amygdala would be an important topic for research on these neurological diseases in terms of diagnosis, treatment, and prognosis prediction.

Many animal studies have reported on the neural connectivity of the amygdala using electrophysiologic and tracing techniques [3-7, 15, 24-26, 32]. By contrast, use of these methods in the live human brain is limited [20]. In addition, deep location in the white matter and widespread connectivity of the amygdala with various brain regions also cause more difficulty in investigation of the neural connectivity of the amygdala [6, 20]. Development of diffusion tensor imaging (DTI) enables evaluation of white matter tracts by virtue of its ability to image water diffusion characteristics [9]. At the early stage of DTI, deterministic DTI tractography, which estimates the only primary orientation of diffusion in each MR imaging voxel, was commonly used [9, 33]. However, due to the crossing fibers, this method cannot trace all connected brain regions from seed voxels [9, 33]. In contrast, probabilistic DTI tractography, which is a reflection of the multiple orientations of diffusion and estimation of more than one fiber population in each MR imaging voxel, enables tracing of the crossing fibers [9, 29, 33]. Accordingly, probabilistic DTI tractography has been widely used for investigation of the neural connectivity of a neural structure in the human brain, including the fornix, lateral geniculate body, red nucleus, and so on [17, 18, 23, 28]. However, no study on the neural connectivity of the amygdala has been reported, although several DTI studies have reported on the anatomical neural tracts between the amygdala and specific brain regions [11, 16, 19, 21, 22, 30].

In the current study, using probabilistic DTI tractography, we attempted to investigate the neural connectivity of the amygdala in normal subjects.

2. Methods

2.1 Subjects

Forty eight healthy subjects (males: 26, females: 22, mean age: 331 years, range: 20–50 years) with no previous history of neurological, physical, or psychiatric illness were recruited for this study. All subjects understood the purpose of this study and provided written, informed consent prior to participation. The study protocol was approved by our local Institutional Review Board.

2.2 Data acquisition

DTI data were acquired using a 6-channel head coil on a 1.5 T Philips Gyroscan Intera (Philips, Ltd, Best, The Netherlands) with single-shot echo-planar imaging (EPI). For each of the 32 non-collinear, diffusion-sensitizing gradients, we acquired 67 contiguous slices parallel to the anterior commissure-posterior commissure line. Imaging parameters were as follows: acquisition matrix = 96×96; reconstructed to matrix = 128×128; field of view = 221×221 mm; repetition time (TR) = 10,726 ms; echo time (TE) = 76 ms; parallel imaging reduction factor (SENSE factor) = 2; EPI factor = 49; $b = 1000$ s/mm^2; number of excitations (NEX) = 1; and a slice thickness of 2.3 mm (acquired voxel size $1.73 \times 1.73 \times 2.3$ mm).

2.3 Probabilistic fiber tracking

Analysis of DTI data was performed using the Oxford Centre for Functional Magnetic Resonance Imaging of the Brain (FMRIB) Software Library (FSL: `www.fmrib.ox.ac.uk/fsl`). Head motion effect and image distortion due to eddy current were corrected using affine multi-scale two-dimensional registration. Fiber tracking was performed using a probabilistic DTI tractography method based on a multifiber model, and applied in the current study utilizing tractography routines implemented in FMRIB Diffusion (5000 streamline samples, 0.5 mm step lengths, curvature thresholds = 0.2) [9, 29]. A seed region of interest was placed on the known anatomical location of the amygdala on the axial image for the connectivity [34, 37]. Out of 5000 samples generated from each seed voxel, results for each connection were visualized at a threshold of 1 and 5 streamlines through each voxel for analysis. Connectivity represented the percentage of connection in all hemispheres of 48 subjects.

2.4 Determination of connections between the amygdala and target brain regions

Connectivity was defined as the incidence of connection between the amygdala and each brain region: the primary motor cortex (M1), premotor cortex (PMC), primary somatosensory cortex (S1), posterior parietal cortex (PPC), lateral prefrontal cortex (lPFC), vmPFC, orbitofrontal cortex (OFC), anterior cingulate cortex, insular cortex, occipito-temporal cortex, medial temporal cortex, caudate nucleus, putamen, globus pallidus, basal forebrain, thalamus, hippocampus, hypothalamus, and brainstem.

2.5 Statistical analysis

SPSS software (v.15.0; SPSS, Chicago, IL) was used for the analysis. The chi-square test was used for determination of the difference in connectivity of the amygdala between the right and left hemispheres Statistical significance was accepted for p values of <0.05.

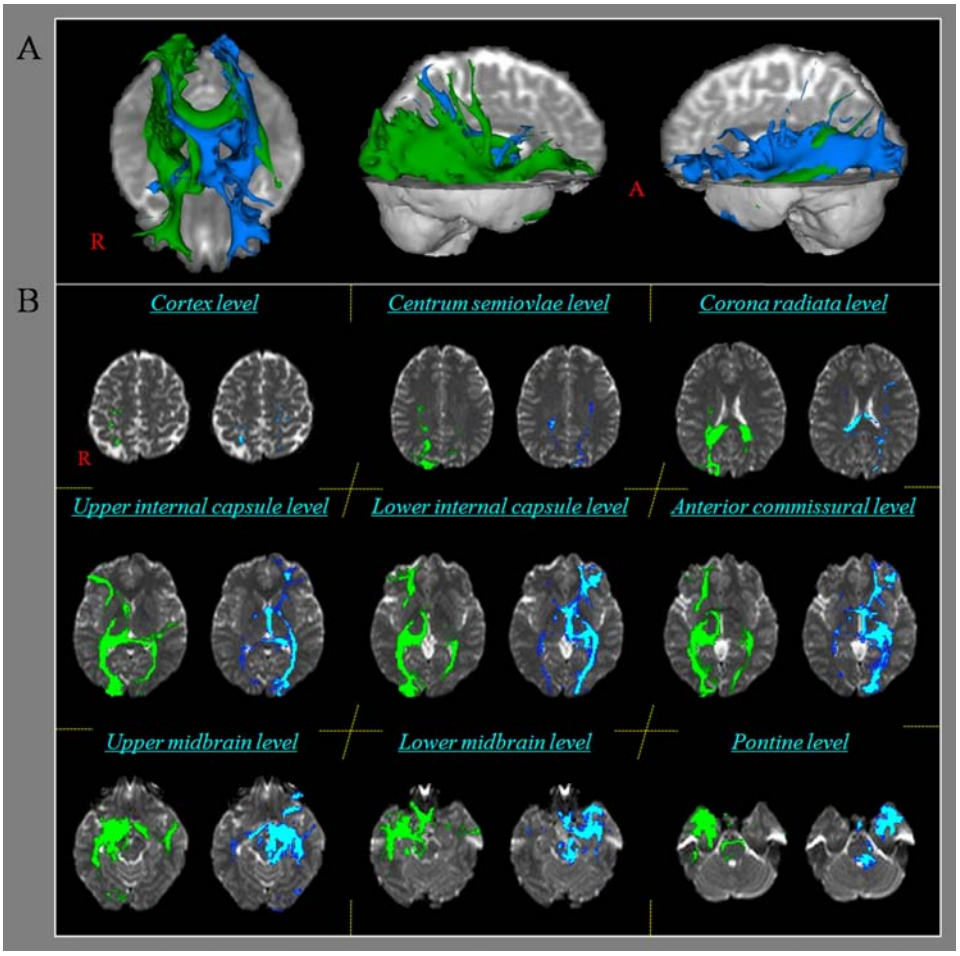

Fig. 1 *(A) Results of diffusion tensor tractography of the neural connectivity between the amygdala and the target brain regions (right: green, left: blue). (B) The amygdala shows connectivity with each brain region at each level.*

3. Results

The neural connectivities of the amygdala are summarized in Tab. I. In all subjects, the amygdala showed 100% connectivity to the hippocampus, thalamus, hypothalamus, and medial temporal cortex regardless of the thresholds. In addition, regarding the thresholds of 1 and 5, the amygdala showed high conncetivity (over 60%) to the globus pallidus (100% and 92.7%), brainstem (83.3% and 78.1%), putamen (72.9% and 63.5%), occipito-temporal cortex (72.9% and 67.7%), OFC (70.8 and 43.8%), caudate nucleus (63.5% and 45.8%), and vmPFC (63.5% and 31.3%), respectively. By contrast, other brain regions showed low connectivity (below 50%) to the PPC (47.9% and 34.4%), S1 (31.3% and 13.5%), insular cortex (28.1% and

17.7%), M1 (28.1% and 13.5%), lPFC (26.1% and 13.5%), basal forebrain (25.0% and 18.8%), PMC (9.4% and 5.2%), and anterior cingulate cortex (5.2% and 4.2%), respectively. In all target brain regions, no significant differences in connectivity were observed between right and left hemispheres ($p > 0.05$).

Target brain regions	1 threshold			5 threshold		
	Rt [%]	Lt [%]	Total average of Rt/Lt [%]	Rt [%]	Lt [%]	Total average of Rt/Lt [%]
Hippocampus	100	100	100	100	100	100
Thalamus	100	100	100	100	100	100
Hypothalamus	100	100	100	100	100	100
Medial temporal cortex	100	100	100	100	100	100
Globus pallidus	100	100	100	91.7	93.8	92.7
Brainstem	83.3	83.3	83.3	79.2	77.1	78.1
Putamen	77.1	68.8	72.9	64.6	62.5	63.5
Occipito-temporal cortex	77.1	68.8	72.9	72.9	62.5	67.7
OFC	64.6	77.1	70.8	41.7	45.8	43.8
Caudate nucleus	66.7	60.4	63.5	52.1	39.6	45.8
vmPFC	62.5	64.6	63.5	33.3	29.2	31.3
PPC	52.1	43.8	47.9	39.6	29.2	34.4
S1	35.4	27.1	31.3	16.7	10.4	13.5
Insular cortex	25.0	31.3	28.1	16.7	18.8	17.7
M1	29.2	27.1	28.1	14.6	12.5	13.5
lPFC	25.0	27.1	26.1	16.7	10.4	13.5
Basal forebrain	27.1	22.9	25.0	18.8	18.8	18.8
PMC	8.3	10.4	9.4	4.2	6.3	5.2
Cingulate cortex	4.2	6.3	5.2	2.1	6.3	4.2

Connectivity (%), Rt: right, Lt: left, OFC: orbitofrontal cortex, vmPFC: ventromedial prefrontal cortex, PPC: posterior parietal cortex, S1: primary somatosensory cortex, M1: primary motor cortex, lPFC: lateral prefrontal cortex, PMC: premotor cortex.

Tab. I *Incidence of connectivity between the amygdala and the target brain regions.*

4. Discussion

In the current study, using probabilistic DTI tractography, we investigated the neural connectivity of the amygdala in the normal human brain. Many animal studies have reported on the neural connectivity of the amygdala [3-7, 15, 24-26, 32]. In 1977, Llamas et al. found projections from the amygdala to the prefrontal, premotor, and motor cortices using a tracing technique in 34 cats [24]. Subsequently, Aggleton et al. [1980, 1984, and 1986] reported on the neural connectivity of the amygdala to the hippocampus, thalamus, hypothalamus, midbrain, OFC, and anterior insular cortex using a horseradish peroxidase tracing technique in monkey [3-5]. In 1981, using a tracing axonal technique in nine monkeys, Price and Amaral found that the central nucleus of the amygdala had connectivity to the basal fore-

brain, hypothalamus, thalamus, and brainstem [32]. In 1984, using an H-amino acid tracing technique in 12 monkeys, the same authors reported on the connectivity of the amygdala to the frontal, insular, temporal, and occipital cortices; however, the dorsolateral PFC cortex showed very low connectivity with the amygdala [6]. Subsequently, using a tracing technique in 26 monkeys, Ghashghaei and Barbas [2002] demonstrated that the amygdala was heavily connected to the OFC and medial prefrontal cortex, whereas connectivity with the ventrolateral PFC was poor [25]. They also suggested that connectivity between the OFC and the amygdala might play an important role in emotion.

According to our findings, the connectivity of the amygdala was as follows: 1) hippocampus (100%), thalamus (100%), hypothalamus (100%), medial temporal cortex (100%), globus pallidus (100%), brainstem (83.3%), putamen (72.9%), occipito-temporal cortex (72.9%), OFC (70.8%), caudate nucleus (63.5%), and vmPFC (63.5%) showed high connectivity with the amygdala at the threshold of 1 streamline and 2) somatosensori-motor related cortexes (PPC: 47.9%, S1: 31.3%, M1: 28.1%, and PMC: 9.4%), insular cortex (28.1%), lPFC (26.1%), basal forebrain (25.0%), and anterior cingulate cortex (5.2%) showed low connectivity with the amygdala at the threshold of 1 streamline. Considering our results, in general, the high connectivity to hippocampus, thalamus, hypothalamus, basal ganglia, brainstem, occipito-temporal cortex, OFC, and vmPFC, and the low connectivty to somatosensori-motor related cortexes and lPFC appears to be in agreement with the results of previous studies [8, 10, 11, 14, 20, 25, 31, 32, 35, 37]. However, the low connectivity to the anterior cingulate cortex, insular cortex, and basal forebrain, which are known to have high relevance with the amygdala, according to previous studies, should be considered with regard to whether these results were ascribed to the limitations of DTI such as crossing fibers [6, 19, 25, 30-32, 35-38]. Therefore, we believe that conduct of further studies on this topic should be encouraged.

Regarding the human studies, several studies reported on the anatomical neural connectivity of the amygdala with specific brain regions [11, 16, 19, 21, 22, 30]. In 2003, using DTI in 11 normal healthy subjects, Catani et al. demonstrated the connectivity between the amygdala and the occipital cortex via inferior longitudinal fasciculus [11]. In 2005, Pezawas et al. reported on interconnection of the amygdala to the vmPFC in 208 normal healthy subjects [30]. Subsequently, two studies [2008, Johansen-Berg et al. – 17 normal healthy subjects using DTT and 2009, Kim and Whalen – 12 normal healthy subjects using combined functional MRI and DTT] identified the pathway between the amygdala and the vmPFC and OFC, respectively [19, 21]. In 2011, using DTT in 30 normal healthy subjects, Kwon and Jang identified the stria terminalis which was connected from amygdala to the anterior hypothalamus through the hippocampal regions and thalamus [22]. In a recent study, using probabilistic DTT in 40 normal healthy subjects, Grčzes et al. [2014] investigated the direct projections from the amygdala to motor-related cortical regions (M1, S1, supplementary motor area, and mid cingulate) [16]. They found direct projections from the amygdala to motor-related cortical regions, which might influence the complex motor behaviors compared to the direct projections of emotion-related regions (superior temporal sulcus, fusiform gyrus, inferior frontal gyrus, and OFC). These previous studies investigated and focused on the connectivity between the amygdala and specific brain regions. By contrast, our study

investigated the whole connectivity between the amygdala and almost all brain regions. As a result, to the best of our knowledge, this is the first study to investigate the whole neural connectivity of the amygdala in the human brain.

In conclusion, we investigated the anatomical neural connectivity of the amygdala in normal subjects and the amygdala showed high connectivity to the hippocampus, thalamus, hypothalamus, medial temporal cortex, brainstem, basal ganglia, occipito-temporal cortex, OFC, and vmPFC. We believe that the methods and results of this study provide useful information for clinicians and researchers studying the amygdala. However, several limitations of DTI should be considered [9, 38]. First, we could not quantify the strength of the connectivity between the amygdala and each brain region. Second, despite the fact that the amygdala is composed of several subnuclei, we could not find the connectivity from specific subnuclei of the amygdala to each brain region [2, 37]. Third, use of probabilistic DTT tractography can result in false positive and negative findings due to fiber complexity or partial volume effect throughout the white matter of the brain [36, 38]. Therefore, in order to overcome these limitations, conduct of further studies should be encouraged.

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References

[1] ADOLPHS R., BARON-COHEN S., TRANEL D. Impaired recognition of social emotions following amygdala damage. *Journal of cognitive neuroscience.* 2002, 14(8), pp. 1264-1274, doi:10.1162/089892902760807258.

[2] AGGLETON J.P., ed. *The Amygdala: Neurobiological aspects of emotion, memory, and mental dysfunction.* 1st ed. New York: Wiley-Liss, 1992.

[3] AGGLETON J.P. A description of intra-amygdaloid connections in old world monkeys. *Experimental brain research.* 1985, 57(2), pp. 390-399, doi: 10.1007/BF00236545.

[4] AGGLETON J.P. A description of the amygdalo-hippocampal interconnections in the macaque monkey. *Experimental brain research.* 1986, 64(3), pp. 515-526, doi: 10.1007/BF00340489.

[5] AGGLETON J.P., BURTON M.J., PASSINGHAM R.E. Cortical and subcortical afferents to the amygdala of the rhesus monkey (*Macaca mulatta*). *Brain research.* 1980, 190(2), pp. 347-368, doi: 10.1016/0006-8993(80)90279-6.

[6] AMARAL D.G., PRICE J.L. Amygdalo-cortical projections in the monkey (*Macaca fascicularis*). *The Journal of comparative neurology.* 1984, 230(4), pp. 465-496, doi:10.1002/cne.902300402.

[7] AMARAL D.G., VEAZEY R.B., COWAN W.M. Some observations on hypothalamo-amygdaloid connections in the monkey. *Brain research.* 1982, 252(1), pp. 13-27, doi: 10.1016/0006-8993(82)90974-X.

[8] ANTICEVIC A., TANG Y., CHO Y.T., et al. Amygdala connectivity differs among chronic, early course, and individuals at risk for developing schizophrenia. *Schizophrenia bulletin.* 2014, 40(5), pp. 1105-1116, doi:10.1093/schbul/sbt165.

[9] BEHRENS T.E., BERG H.J., JBABDI S., et al. Probabilistic diffusion tractography with multiple fibre orientations: What can we gain? *NeuroImage.* 2007, 34(1), pp. 144-155, doi:10.1016/j.neuroimage.2006.09.018.

[10] BLAIR R.J. The amygdala and ventromedial prefrontal cortex: Functional contributions and dysfunction in psychopathy. *Philosophical Transactions of the Royal Society B: Biological sciences.* 2008, 363(1503), pp. 2557-2565, doi:10.1098/rstb.2008.0027.

[11] CATANI M., JONES D.K., DONATO R., et al. Occipito-temporal connections in the human brain. *Brain: A Journal of Neurology.* 2003, 126(9), pp. 2093-2107, doi:10.1093/brain/awg203.

[12] DAVIDSON R.J., PUTNAM K.M., LARSON C.L. Dysfunction in the neural circuitry of emotion regulation–a possible prelude to violence. *Science.* 2000, 289(5479), pp. 591-594, doi: 10.1126/science.289.5479.591.

[13] EICHENBAUM H. *The cognitive neuroscience of memory: an introduction.* 2nd ed. New York: Oxford University Press, 2002.

[14] GHASHGHAEI H.T., HILGETAG C.C., BARBAS H. Sequence of information processing for emotions based on the anatomic dialogue between prefrontal cortex and amygdala. *NeuroImage.* 2007, 34(3), pp. 905-923, doi:10.1016/j.neuroimage.2006.09.046.

[15] GLOOR P. Electrophysiological studies on the connections of the amygdaloid nucleus in the cat Part I: The neuronal organization of the amygdaloid projection system. *Electroencephalography and clinical neurophysiology.* 1955, 7(2), pp. 223-242, doi: 10.1016/0013-4694(55)90037-7.

[16] GREZES J., VALABREGUE R., GHOLIPOUR B., et al. A direct amygdala-motor pathway for emotional displays to influence action: A diffusion tensor imaging study. *Human brain mapping.* 2014, 35(12), pp. 5974-5983, doi:10.1002/hbm.22598.

[17] HABAS C., CABANIS E.A. Cortical projections to the human red nucleus: A diffusion tensor tractography study with a 1.5-T MRI machine. *Neuroradiology.* 2006, 48(10), pp. 755-762, doi:10.1007/s00234-006-0117-9.

[18] JANG S.H., KWON H.G. Neural connectivity of the posterior body of the fornix in the human brain: Diffusion tensor imaging study. *Neuroscience letters.* 2013, 549, pp. 116-119, doi:10.1016/j.neulet.2013.06.017.

[19] JOHANSEN-BERG H., GUTMAN D.A., BEHRENS T.E., et al. Anatomical connectivity of the subgenual cingulate region targeted with deep brain stimulation for treatment-resistant depression. *Cereb Cortex.* 2008, 18(6), pp. 1374-1383, doi:10.1093/cercor/bhm167.

[20] KIM M.J., LOUCKS R.A., PALMER A.L., et al. The structural and functional connectivity of the amygdala: From normal emotion to pathological anxiety. *Behavioural brain research.* 2011, 223(2), pp. 403-410, doi:10.1016/j.bbr.2011.04.025.

[21] KIM M.J., WHALEN P.J. The structural integrity of an amygdala-prefrontal pathway predicts trait anxiety. *The Journal of neuroscience: The official journal of the Society for Neuroscience.* 2009, 29(37), pp. 11614-11618, doi:10.1523/JNEUROSCI.2335-09.2009.

[22] KWON H.G., BYUN W.M., AHN S.H., et al. The anatomical characteristics of the stria terminalis in the human brain: A diffusion tensor tractography study. *Neuroscience letters.* 2011, 500(2), pp. 99-102, doi:10.1016/j.neulet.2011.06.013.

[23] KWON H.G., JANG S.H. Neural connectivity of the lateral geniculate body in the human brain: Diffusion tensor imaging study. *Neuroscience letters.* 2014, 578, pp. 66-70, doi:10.1016/j.neulet.2014.06.033.

[24] LLAMAS A., AVENDANO C., REINOSO-SUAREZ F. Amygdaloid projections to prefrontal and motor cortex. *Science.* 1977, 195(4280), pp. 794-796, doi: 10.1126/science.836591.

[25] LLAMAS A., AVENDANO C., REINOSO-SUAREZ F. Amygdaloid projections to the motor, premotor and prefrontal areas of the cat's cerebral cortex: A topographical study using retrograde transport of horseradish peroxidase. *Neuroscience.* 1985, 15(3), pp. 651-657.

[26] MEHLER W.R. Subcortical afferent connections of the amygdala in the monkey. *The Journal of comparative neurology.* 1980, 190(4), pp. 733-762, doi:10.1002/cne.901900407.

[27] MESULAM M.M, ed. *Principles of behavioral and cognitive neurology.* New York: Oxford University Press, 2000.

[28] NUCIFORA P.G., VERMA R., LEE S.K., et al. Diffusion-tensor MR imaging and tractography: Exploring brain microstructure and connectivity. *Radiology.* 2007, 245(2), pp. 367-384, doi:10.1148/radiol.2452060445.

[29] PARKER G.J., ALEXANDER D.C. Probabilistic anatomical connectivity derived from the microscopic persistent angular structure of cerebral tissue. *Philosophical transactions of the Royal Society B: Biological sciences.* 2005, 360(1457), pp. 893-902, doi:10.1098/rstb.2005.1639.

[30] PEZAWAS L., MEYER-LINDENBERG A., DRABANT E.M., et al. 5-HTTLPR polymorphism impacts human cingulate-amygdala interactions: A genetic susceptibility mechanism for depression. *Nature neuroscience.* 2005, 8(6), pp. 828-834, doi:10.1038/nn1463.

[31] PRICE J.L. Comparative aspects of amygdala connectivity. *Annals of the New York Academy of Sciences.* 2003, 985, pp. 50-58, doi: 10.1111/j.1749-6632.2003.tb07070.x.

[32] PRICE J.L., AMARAL D.G. An autoradiographic study of the projections of the central nucleus of the monkey amygdala. *The Journal of neuroscience: The official journal of the Society for Neuroscience.* 1981, 1(11), pp. 1242-1259.

[33] SMITH S.M., JENKINSON M., WOOLRICH M.W., et al. Advances in functional and structural MR image analysis and implementation as FSL. *NeuroImage.* 2004, 23, Supplement 1, pp. 208-219, doi:10.1016/j.neuroimage.2004.07.051.

[34] SOLANO-CASTIELLA E., ANWANDER A., LOHMANN G., et al. Diffusion tensor imaging segments the human amygdala in vivo. *NeuroImage.* 2010, 49(4), pp. 2958-2965, doi:10.1016/j.neuroimage.2009.11.027.

[35] STEFANACCI L., AMARAL D.G. Some observations on cortical inputs to the macaque monkey amygdala: An anterograde tracing study. *The Journal of comparative neurology.* 2002, 451(4), pp. 301-323, doi:10.1002/cne.10339.

[36] WEDEEN V.J., WANG R.P., SCHMAHMANN J.D., et al. Diffusion spectrum magnetic resonance imaging (DSI) tractography of crossing fibers. *NeuroImage.* 2008, 41(4), pp. 1267-1277, doi:10.1016/j.neuroimage.2008.03.036.

[37] WHALEN P.J., PHELPS E.A., eds. *The human amygdala.* 1st ed. New York: Guilford Press, 2009.

[38] YAMADA K., SAKAI K., AKAZAWA K., et al. MR tractography: A review of its clinical applications. *Magnetic resonance in medical sciences : MRMS : an official journal of Japan Society of Magnetic Resonance in Medicine.* 2009, 8(4), pp. 165-174.

[39] ZALLA T., SPERDUTI M. The amygdala and the relevance detection theory of autism: an evolutionary perspective. *Frontiers in human neuroscience.* 2013, 7, pp. 894, doi:10.3389/fnhum.2013.00894.