Supplementary Information

Spectroscopic Signatures and Structural Motifs in Isolated and Hydrated Serotonin: A Computational Study

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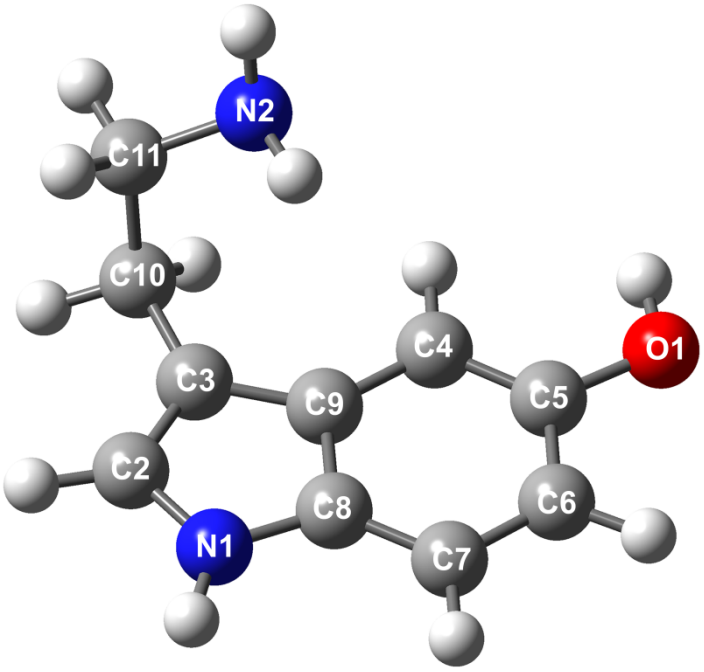

Fig. S1 Optimized geometry of the most stable conformer Gph(out)/*anti* of serotonin.

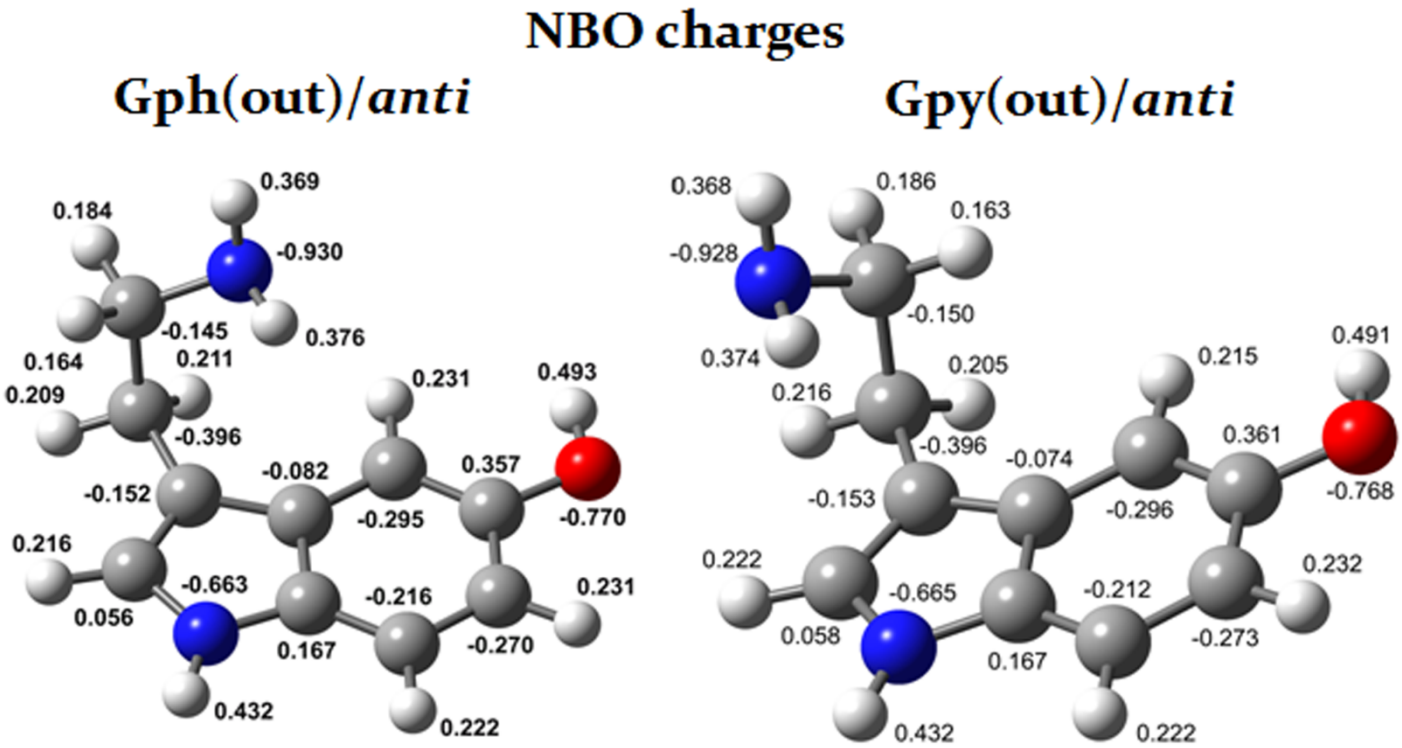

Fig. S2 Optimized geometries of the most stable conformers C and A of SERO alongwith the NBO charge distribution at the MP2/aug-cc-pVDZ level of theory.

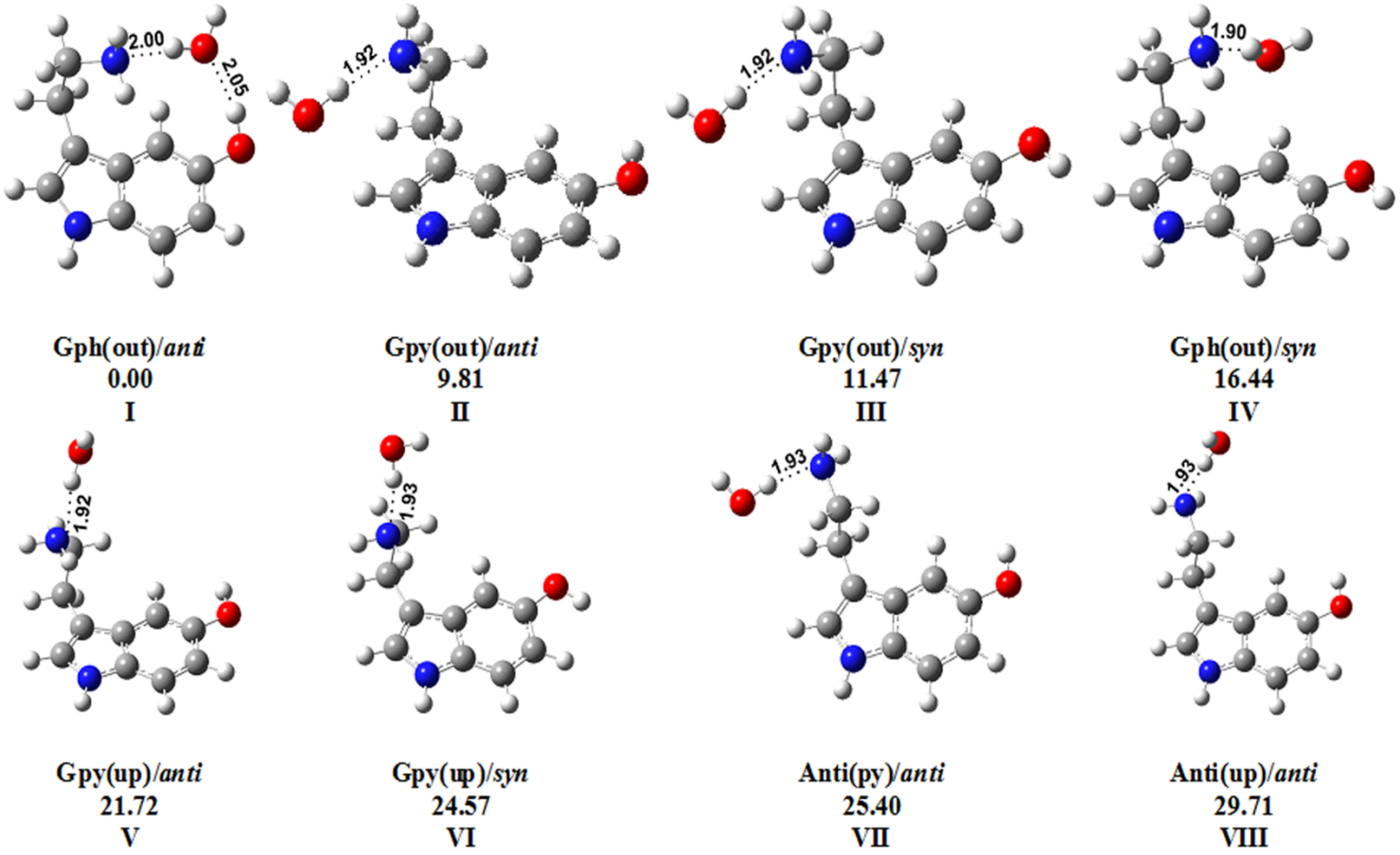

Fig. S3 Computed optimized structures and relative energy (in kJ mol^{-1}) of eight low-energy SERO-$(H_2O)_1$ clusters at MP2/6-31+G(d) level.

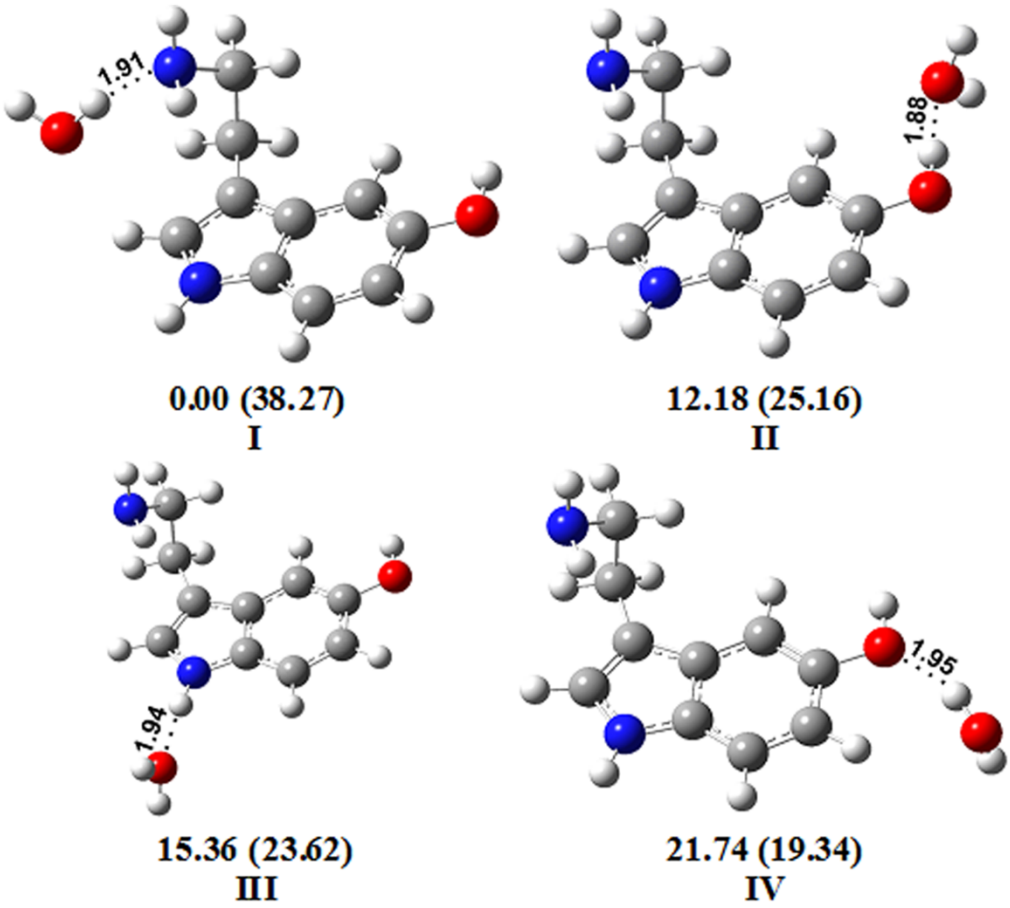

Fig. S4 Computed optimized structures, relative energies and binding energies (in parenthesis) (in kJ/mol) of SERO-$(H_2O)_1$ clusters involving Gpy(out)/*anti* conformer at MP2/6-31+G(d) level.

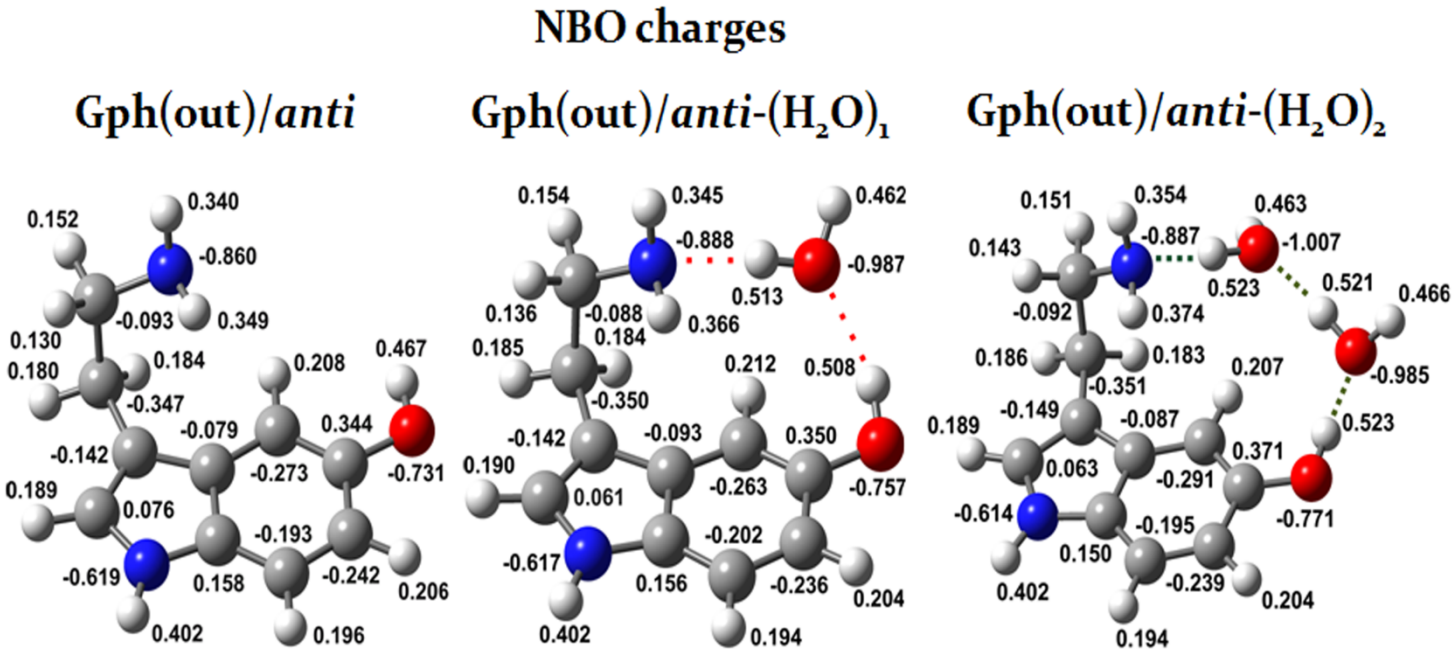

Fig. S5 NBO charge distribution of the most stable structures of isolated and hydrated serotonin involving Gph(out)/*anti* conformation at MP2/6-311++G(d,p) level.

Table S1. Selected calculated structural parameters of eight experimentally observed conformers of serotonin at the MP2/aug-cc-pVDZ level of theory.

structural parameters[a]	expt.[b]	Conf. A	Conf. B	Conf. C	Conf. D	Conf. E	Conf. F	Conf. G	Conf. H
bond lengths (Å)									
N1-C2	1.367	1.38677	1.38661	1.38572	1.38662	1.38650	1.38734	1.38724	1.38610
C2-C3	1.365	1.39483	1.39506	1.39569	1.39413	1.39436	1.39411	1.39440	1.39505
C3-C9	1.433	1.44098	1.44110	1.44201	1.44037	1.44054	1.44172	1.44181	1.44299
C9-C4	1.377	1.42012	1.42000	1.42093	1.42006	1.41995	1.41794	1.41780	1.41931
C4-C5	1.384	1.39822	1.39822	1.39771	1.39805	1.39812	1.39685	1.39684	1.39680
C5-C6	1.401	1.42145	1.42153	1.42182	1.42149	1.42157	1.42252	1.42259	1.42302
C6-C7	1.376	1.39914	1.39894	1.39907	1.39909	1.39898	1.40162	1.40147	1.40130
C7-C8	1.386	1.41022	1.41016	1.41030	1.41026	1.41024	1.40873	1.40869	1.40870
C8-C9	1.407	1.43223	1.43183	1.43251	1.43184	1.43166	1.43339	1.43301	1.43403
C8-N1	1.371	1.38410	1.38422	1.38395	1.38380	1.38385	1.38418	1.38434	1.38387
C3-C10	1.501	1.50257	1.50098	1.50476	1.50169	1.50151	1.50253	1.50088	1.50480
C10-C11	1.483	1.53813	1.54687	1.53709	1.53553	1.54372	1.53803	1.54696	1.53718
C11-N2	1.502	1.47174	1.46799	1.47363	1.47365	1.46973	1.47238	1.46833	1.47226
C5-O1	1.372	1.38749	1.38683	1.38726	1.38793	1.38732	1.38829	1.38764	1.38801
O1-H	1.010	0.96802	0.96805	0.96828	0.96797	0.96800	0.96748	0.96749	0.96748
N1-H	0.930	1.01225	1.01223	1.01225	1.01214	1.01216	1.01215	1.01214	1.01217
N2•••H	-	6.50860	6.40959	4.73101	6.37084	6.32043	7.39873	7.34131	5.91620
N2•••O1	2.896	6.69974	6.62241	5.11519	6.87967	6.83516	6.60661	6.55127	5.05713
bond angles (°)									
N1-C2-C3	109.7	109.70646	109.75083	109.77567	109.72094	109.71020	109.77746	109.81876	109.85719
C2-C3-C9	106.7	106.18479	106.13852	106.09540	106.17871	106.18370	106.20545	106.15741	106.12513
C3-C9-C8	106.8	107.56338	107.58087	107.56026	107.58437	107.57137	107.48562	107.51103	107.44215
C9-C8-N1	107.5	107.09340	107.11840	107.10717	107.07914	107.09473	107.14887	107.16753	107.18946
C8-N1-C2	109.3	109.45075	109.40993	109.46083	109.43639	109.43922	109.38123	109.34382	109.38482
C3-C9-C4	133.1	133.09246	133.05418	133.06285	133.07679	133.05593	132.91530	132.86414	132.96009
C9-C4-C5	119.0	118.30205	118.28425	118.16202	118.31468	118.29607	118.23885	118.22056	118.09139
C4-C5-C6	120.5	121.72788	121.72228	121.88344	121.72776	121.71385	121.61899	121.61077	121.76295
C5-C6-C7	121.2	120.94362	120.95434	120.88766	120.92368	120.94526	121.13336	121.14829	121.10995
C6-C7-C8	118.0	117.66108	117.64677	117.63597	117.67359	117.66291	117.45568	117.43940	117.41101
C7-C8-C9	121.2	122.02452	122.03126	122.05653	122.02481	122.01303	121.95739	121.95980	122.02996
C8-C9-C4	120.1	119.34026	119.36056	119.37381	119.33494	119.36856	119.59523	119.62068	119.59375
C7-C8-N1	131.3	130.88206	130.85027	130.83618	130.89561	130.89197	130.89373	130.87264	130.78046
C2-C3-C10	129.8	126.92161	127.25029	126.35651	126.97079	127.25013	126.97045	127.32926	126.23865
C9-C3-C10	123.4	126.78839	126.50441	127.52584	126.80115	126.48694	126.71993	126.39898	127.60786
C3-C10-C11	113.9	111.03601	111.28299	112.20894	111.66930	111.62302	111.00834	111.23330	112.09030
C10-C11-N2	110.8	109.01921	115.14856	109.87433	109.89047	115.79721	109.03045	115.11752	109.78720
C4-C5-O1	117.9	122.85564	122.87662	122.67031	122.86450	122.88266	117.09713	117.08897	117.09425
C6-C5-O1	121.6	115.41647	115.40110	115.44568	115.40769	115.40348	121.28387	121.30026	121.14267
dihedral angles (°)									
C9-C3-C10-C11	171.7	-72.46745	-70.80513	-83.31435	-72.60218	-72.08265	-72.26004	-71.15463	-84.29496
C3-C10-C11-N2	175.8	-61.67715	-59.88639	62.77152	179.42873	177.95573	-61.61271	-60.13418	63.54343

[a] See figure S1 for the atom numbering. [b] ref. 16

Table S2. Rotational constants [*A*, *B* and *C*(GHz)] and zero-point vibrational energy (a.u.) for the 24 low-energy conformers of serotonin calculated at MP2 and B3LYP levels employing 6-311++G(d,p) basis set.

conformer	MP2/6-311++G(d,p)				B3LYP/6-311++G(d,p)			
	A	*B*	*C*	ZPVE[a]	*A*	*B*	*C*	ZPVE
Gpy(out)/*anti*	1.2708981	0.5813517	0.4420128	0.207024	1.2977412	0.5569207	0.4264263	0.206785
	1.286457[b]	**0.5717580**[b]	**0.43561945**[b]					
Gpy(up)/*anti*	1.2462172	0.5866193	0.4431202	0.206851	1.2733921	0.5607364	0.4272715	0.206697
	1.2670434[b]	**0.57460393**[b]	**0.43601524**[b]					
Gpy(in)/*anti*	1.7152871	0.4664216	0.3726577	0.206887	1.7339691	0.4607784	0.3692944	0.206830
Gph(out)/*anti*	1.1622081	0.6562451	0.4530720	0.207240	1.1509448	0.6454988	0.4439913	0.206939
	1.1631523[b]	**0.6506354**[b]	**0.45007232**[b]					
Gph(up)/*anti*	1.1910038	0.6253403	0.4507190	0.207041	1.1788278	0.6153416	0.4408389	0.206645
Gph(in)/*anti*	1.0839042	0.6767164	0.4322664	0.206847	1.0711608	0.6767119	0.4276598	0.206779
Anti(py)/*anti*	1.1799120	0.5516205	0.3902360	0.206626	1.2027355	0.5365835	0.3840335	0.206481
Anti(ph)/*anti*	1.1713720	0.5578108	0.3923397	0.206665	1.1939332	0.5419118	0.3857470	0.206471
Anti(up)/*anti*	1.1710397	0.5545056	0.3909527	0.206627	1.1959175	0.5378908	0.3843083	0.206366
Gpy(out)/*syn*	1.2625801	0.5858284	0.4439339	0.206858	1.2906747	0.5602042	0.4278466	0.206603
Gpy(up)/*syn*	1.2463345	0.5875988	0.4437853	0.206705	1.2717649	0.5620955	0.4278869	0.206508
Gpy(in)/*syn*	1.7042368	0.4683741	0.3735454	0.206813	1.7277590	0.4621193	0.3698611	0.206558
Gph(out)/*syn*	1.1624249	0.6545397	0.4527216	0.206941	1.1529698	0.6422079	0.4433162	0.206613
Gph(up)/*syn*	1.1836196	0.6308938	0.4522852	0.206876	1.1719000	0.6206793	0.4422597	0.206519
Gph(in)/*syn*	1.1530843	0.6434776	0.4443253	0.206464	1.0855113	0.6688420	0.4294628	0.206281
Anti(py)/*syn*	1.1727653	0.5558409	0.3915140	0.206556	1.1948866	0.5409249	0.3853248	0.206263
Anti(ph)/*syn*	1.1695639	0.5592215	0.3926951	0.206591	1.1904437	0.5443005	0.3863098	0.206218
Anti(up)/*syn*	1.1677248	0.5567103	0.3918820	0.206500	1.1924775	0.5400519	0.3851303	0.206178
Conf. 9/*anti*	1.5393097	0.4459346	0.3478938	0.206606	1.5338672	0.4456426	0.3474246	0.206573
Conf. 9/*syn*	1.5314008	0.4476521	0.3485289	0.206367	1.5282205	0.4470333	0.3479759	0.206320
Conf. 10/*anti*	1.1915027	0.6249415	0.4506223	0.207032	1.5098188	0.4866888	0.3930131	0.206713
Conf. 10/*syn*	1.1836371	0.6308766	0.4522803	0.206878	1.1718917	0.6206529	0.4422370	0.206512
Conf. 11/*anti*	1.5169602	0.4517075	0.3506248	0.206713	1.5269831	0.4490406	0.3488347	0.206481
Conf. 11/*syn*	1.4906336	0.4563831	0.3530848	0.206559	1.5220588	0.4503682	0.3493649	0.206138

[a] Values obtained at B3LYP/6-311++G(d,p) level using MP2/6-311++G(d,p) level optimized geometries. [b] From ref 2.

Table S3. Rotational constants [*A, B,* and *C* (GHz)] and zero-point vibrational energies (a.u.) for the 24 low-energy conformers of serotonin calculated at MP2 and B3LYP levels employing aug-cc-pVDZ basis set.

conformer	MP2/aug-cc-pVDZ				B3LYP/aug-cc-pVDZ			
	A	*B*	*C*	ZPVE[a]	*A*	*B*	*C*	ZPVE
Gpy(out)/*anti*	1.2703167	0.5741047	0.4372926	0.206716	1.2977156	0.5530299	0.4236792	0.207066
	1.286457[b]	**0.5717580**[b]	**0.43561945**[b]					
Gpy(up)/*anti*	1.2493371	0.5765956	0.4372803	0.206596	1.2765820	0.5557572	0.4241091	0.206883
	1.2670434[b]	**0.57460393**[b]	**0.43601524**[b]					
Gpy(in)/*anti*	1.7144256	0.4605362	0.3685247	0.206638	1.7266675	0.4585319	0.3677336	0.206961
Gph(out)/*anti*	1.1552040	0.6521292	0.4506364	0.206988	1.1490006	0.6415996	0.4421049	0.207160
	1.1631523[b]	**0.6506354**[b]	**0.45007232**[b]					
Gph(up)/*anti*	1.1724847	0.6313426	0.4496438	0.206772	1.1716821	0.6160387	0.4393505	0.206875
Gph(in)/*anti*	1.0689997	0.6744293	0.4281742	0.206616	1.0691475	0.6710113	0.4255084	0.206962
Anti(py)/*anti*	1.1650439	0.5497340	0.3875310	0.206410	1.1963251	0.5356477	0.3828903	0.206705
Anti(ph)/*anti*	1.1576517	0.5552425	0.3893949	0.206399	1.1894261	0.5400001	0.3842951	0.206658
Anti(up)/*anti*	1.1591248	0.5510985	0.3878656	0.206332	1.1921446	0.5359967	0.3829703	0.206574
Gpy(out)/*syn*	1.2639165	0.5773044	0.4384607	0.206649	1.2926954	0.5554168	0.4246515	0.206970
Gpy(up)/*syn*	1.2471368	0.5781139	0.4378009	0.206526	1.2757429	0.5567628	0.4245457	0.206781
Gpy(in)/*syn*	1.7048427	0.4623185	0.3692023	0.206560	1.7203669	0.4598821	0.3682944	0,206874
Gph(out)/*syn*	1.1558081	0.6501907	0.4504956	0.206763	1.1508718	0.6384428	0.4414659	0.206925
Gph(up)/*syn*	1.1668283	0.6355344	0.4509586	0.206696	1.1667875	0.6198693	0.4405483	0.206815
Gph(in)/*syn*	1.1501780	0.6371469	0.4427726	0.206209	1.1142303	0.6452710	0.4308108	0.206535
Anti(py)/*syn*	1.1580613	0.5539766	0.3888155	0.206327	1.1897618	0.5393017	0.3839768	0.206602
Anti(ph)/*syn*	1.1563333	0.5563399	0.3896740	0.206282	1.1872843	0.5416439	0.3846885	0.206532
Anti(up)/*syn*	1.1556512	0.5534239	0.3888126	0.206228	1.1903037	0.5372795	0.3835514	0.206507
Conf. 9/*anti*	-	-	-	-	1.5296599	0.4439218	0.3461769	0.206783
Conf. 9/*syn*	-	-	-	-	1.5237356	0.4453463	0.3467354	0.206759
Conf. 10/*anti*	-	-	-	-	1.5572720	0.4761214	0.3851524	0.206980
Conf. 10/*syn*	-	-	-	-	1.1667794	0.6198610	0.4405436	0.206815
Conf. 11/*anti*	-	-	-	-	1.5233408	0.4471457	0.3475113	0.206800
Conf. 11/*syn*	-	-	-	-	1.5183244	0.4484766	0.3480416	0.206695

[a] Values obtained at B3LYP/aug-cc-pVDZ level using MP2/aug-cc-pVDZ level optimized geometries. [b] from ref 2.

Table S4. Natural atomic charges of the eight experimentally observed conformers of serotonin calculated at the MP2/aug-cc-pVDZ level of theory.

atom number[a]	NBO Charge							
	Conf. A	Conf. B	Conf. C	Conf. D	Conf. E	Conf. F	Conf. G	Conf. H
N1	-0.665	-0.665	-0.663	-0.664	-0.664	-0.668	-0.668	-0.666
O1	-0.768	-0.768	-0.770	-0.768	-0.768	-0.768	-0.767	-0.767
N2	-0.928	-0.913	-0.930	-0.919	-0.910	-0.928	-0.913	-0.927
C2	0.058	0.051	0.056	0.059	0.058	0.061	0.053	0.058
C3	-0.153	-0.148	-0.152	-0.143	-0.145	-0.152	-0.146	-0.150
C4	-0.296	-0.294	-0.295	-0.296	-0.296	-0.263	-0.261	-0.261
C5	0.361	0.362	0.357	0.361	0.362	0.356	0.357	0.352
C6	-0.273	-0.270	-0.270	-0.273	-0.272	-0.303	-0.300	-0.300
C7	-0.212	-0.212	-0.216	-0.211	-0.211	-0.214	-0.214	-0.218
C8	0.167	0.168	0.167	0.167	0.168	0.168	0.169	0.168
C9	-0.074	-0.075	-0.082	-0.071	-0.071	-0.071	-0.072	-0.080
C10	-0.396	-0.402	-0.396	-0.396	-0.401	-0.396	-0.402	-0.396
C11	-0.150	-0.154	-0.145	-0.150	-0.155	-0.151	-0.155	-0.144

[a] See figure S1 for the atom numbering.

Table S5. Electronic energies (a.u.) and dipole moments (D) in parenthesis of the *anti*/*syn* conformational pairs of serotonin calculated by MP2 and DFT-B3LYP methods employing 6-311++G(d,p) and aug-cc-pVDZ basis sets.

S. No.	description of the ethylamine side chain	MP2/6-311++G(d,p)		MP2/aug-cc-pVDZ		B3LYP/6-311++G(d,p)		B3LYP/aug-cc-pVDZ	
		anti-5-OH	*syn*-5-OH	*anti*-5-OH	*syn*-5-OH	*anti*-5-OH	*syn*-5-OH	*anti*-5-OH	*syn*-5-OH
1	Gph(out)	-571.5303500 (3.5547)	-571.5283381 (3.9880)	-571.4313716 (3.4172)	-571.4297226 (3.9979)	-573.1765088 (3.2219)	-573.1750384 (3.7671)	-573.0930081 (3.0694)	-573.0917648 (3.6118)
2	Gpy(out)	-571.5300959 (1.4270)	-571.5294077 (2.8797)	-571.4309162 (1.3292)	-571.4302871 (2.8762)	-573.1767624 (1.2503)	-573.1762904 (2.7944)	-573.0933049 (1.2191)	-573.0929407 (2.6650)
3	Gpy(up)	-571.5295344 (3.1864)	-571.5287048 (4.2897)	-571.4299398 (3.1398)	-571.4292465 (3.9313)	-573.1764563 (2.9144)	-573.1759153 (3.8737)	-573.0928275 (2.7854)	-573.0924106 (3.6585)
4	Gph(up)	-571.5285419 (2.7530)	-571.5277865 (3.8973)	-571.4293101 (2.7505)	-571.4288434 (3.7228)	-573.1752647 (2.4814)	-573.1749809 (3.6515)	-573.0916507 (2.4160)	-573.0914656 (3.4901)
5	Anti(ph)	-571.5276731 (3.5572)	-571.5265272 (3.9954)	-571.4281903 (3.4409)	-571.4272871 (3.9532)	-573.1758387 (3.2526)	-573.1751126 (3.7773)	-573.0924953 (3.1181)	-573.0918819 (3.6081)
6	Anti(py)	-571.5273457 (1.4570)	-571.5267945 (2.8894)	-571.4279051 (1.4012)	-571.4274274 (2.8561)	-573.1756155 (1.3352)	-573.1752692 (2.7712)	-573.0922730 (1.2749)	-573.0920344 (2.6138)
7	Anti(up)	-571.5273327 (3.1457)	-571.5266190 (4.0994)	-571.4278533 (3.0790)	-571.4272643 (3.7923)	-573.1757672 (2.8270)	-573.1753410 (3.6515)	-573.0922972 (2.7072)	-573.0919811 (3.4670)
8	Gpy(in)	-571.5265125 (3.5410)	-571.5258832 (2.5610)	-571.4272262 (3.4081)	-571.4266665 (2.4515)	-573.1748571 (3.2144)	-573.1744872 (2.2588)	-573.0914710 (3.0299)	-573.0911871 (2.1336)
9	Gph(in)	-571.5256850 (3.7612)	-571.5241415 (2.5228)	-571.4261924 (3.6238)	-571.4249858 (2.4046)	-573.1735652 (3.4308)	-573.1719802 (2.4161)	-573.0899543 (3.2628)	-573.0887017 (2.2810)
10	Conf. 9[a]	-571.5251458 (1.1419)	-571.5243540 (2.9182)	-	-	-573.1749399 (0.9963)	-573.1745309 (2.7356)	-573.0917910 (0.9674)	-573.0914776 (2.5717)
11	Conf. 10[a]	-571.5285420 (2.7525)	-571.5277865 (3.8963)	-	-	-573.1746340 (1.1272)	-573.1749809 (3.6512)	-573.0913971 (0.9475)	-573.0914656 (3.4900)
12	Conf. 11[a]	-571.5251028 (3.1694)	-571.5242892 (3.5774)	-	-	-573.1746838 (3.2005)	-573.1740637 (3.6449)	-573.0917892 (3.0464)	-573.0912914 (3.4675)

[a] ref 11.

Table S6. Vertical excitation energies (eV) and oscillator strengths (in bracket) for the low-lying excited states of macro-hydrated serotonin by PCM method.

	calculated values at TD-DFT-B3LYP/aug-cc-pVDZ level				
conformational state	^1L_b	^1L_a	$^1\pi\sigma^*_{(O-H)}$	$^1\pi\sigma^*_{(N-H)}$	^1B_b
Gph(out)/*anti*	4.189	4.457	4.876	5.084	5.525
	(0.067)	(0.130)	(0.005)	(0.021)	(0.192)
Gpy(out)/*anti*	4.193	4.463	4.885	5.130	5.501
	(0.059)	(0.134)	(0.004)	(0.017)	(0.353)
Gpy(up)/*anti*	4.191	4.464	4.878	5.118	5.507
	(0.061)	(0.137)	(0.004)	(0.020)	(0.302)
Anti(py)/*anti*	4.190	4.449	4.899	5.087	5.544
	(0.062)	(0.137)	(0.004)	(0.005)	(0.243)
Anti(up)/*anti*	4.163	4.441	4.935	5.036	5.525
	(0.064)	(0.132)	(0.006)	(0.008)	(0.362)
Gph(out)/*syn*	4.159	4.461	4.883	5.030	5.528
	(0.069)	(0.121)	(0.006)	(0.017)	(0.317)
Gpy(out)/*syn*	4.163	4.471	4.895	5.058	5.485
	(0.062)	(0.124)	(0.003)	(0.015)	(0.252)
Gpy(up)/*syn*	4.160	4.471	4.886	5.062	5.490
	(0.063)	(0.127)	(0.004)	(0.020)	(0.103)

Table S7. Optimized excited state energies (in eV, at the ground state equilibrium values of R_{N-H} and R_{O-H}) for the indole, 5- hydroxy-indole, tryptamine and 5- hydroxy-tryptamine

State	Indole		5-hydroxy-indole			Tryptamine		5-hydroxy-tryptamine		
	CAS PT2[a]	expt.[a]	CAS PT2[b]	B3LYP[c]	expt.[b]	DFT/MRCI[d]	expt.[d]	B3LYP[c]	PBE0[c]	Expt.[e]
^1L_b	4.43 (0.05)	4.43 (0.05)	4.29	4.30* (0.06)	4.08	4.32	4.33	4.02 (0.08)	4.14 (0.08)	4.04
^1L_a	4.73 (0.08)	4.77 (0.12)	5.75	4.42 (0.13)	-	4.86 (0.14)	-	4.50 (0.10)	4.65 (0.10)	
^1B_b	5.84 (0.46)	6.02 (0.60)	6.08	-	-	-	-	-	-	
$^1\pi\sigma^*_{(N-H)}$	5.15 (0.004)	-	4.95	-	-	-	-	5.23 (0.00)	5.55 (0.00)	
$^1\pi\sigma^*_{(O-H)}$	4.98 (0.00)	-	5.01	-	-	-	-	-	5.68 (0.00)	

[a] ref .47 [b] ref . 46,47 [c]This work. [d] ref .15,44 [e] ref .5