

ONLINE SUPPLEMENTARY INFORMATION

Mood, season and light within the amygdala

Islay Campbell^{1*}, Jose Fermin Balda Aizpurua^{1*}, Roya Sharifpour¹, Ilenia Paparella¹, Elise Beckers¹, Nasrin Mortazavi¹, John Read¹, Christophe Phillips¹, Fabienne Collette¹, Puneet Talwar¹, Laurent Lamalle¹, Mikhail Zubkov¹, Gilles Vandewalle^{1**}

Short Title: Mood, season, light and the amygdala

¹GIGA-CRC-Human Imaging, University of Liège, Liège, 4000 Belgium

* shared first authorship

****Corresponding author:** Gilles Vandewalle, GIGA-Cyclotron Research Centre-In Vivo Imaging, Bâtiment B30, 8 Allée du Six Août, University of Liège-Sart Tilman, 4000 Liège, Belgium.

Email: gilles.vandewalle@uliege.be

Supplementary Table S1. Characteristics of the participants included in the analyses.

	Mean (SD)
Number of Participants	29
Age	24y $\pm$ 3.1
Sex (M)	11
Affective state (BDI-II)	7.9 $\pm$ 7.0
Number of participants per month (January to December)	j:1; f:1; m:3; a:4; m:4; j:2; j:1; a:3; s:1; o:2; n:5; d:2
Anxiety (BAI)	5.1 $\pm$ 4.2
Sleep quality (PSQI)	4.1 $\pm$ 2.6
Seasonality (SPAQ)	1.2 $\pm$ 0.9
Chronotype (HO)	48.3 $\pm$ 7.6
Daytime sleepiness (ESS)	6.2 $\pm$ 2.9
Years of Education	14.2 $\pm$ 3.1
Sleep duration (night before fMRI protocol)	7.9 $\pm$ 0.7

BDI-II, Beck Depression Inventory-II ¹; BAI, Beck Anxiety Inventory ²; PSQI, Pittsburgh Sleep Quality Index ³; SPAQ, Seasonal Pattern Assessment Questionnaire ⁴; HO, Horne and Östberg ⁵; ESS, Epworth Sleepiness Scale ⁶.

Supplementary Table 2. Characteristics of the four light conditions used in fMRI protocol

	Low BEL	Mid BEL	High BEL	Monochromatic light (589nm)
Lux	47	116	240	7.5
Peak Spectral Irradiance (nm)	460	460	460	590
Melanopic EDI (lux ; ipRGCs)	37	92	190	0.16
Rhodopic EDI (lux ; Rods)	39	97	201	0.94
Cyanopic EDI (lux ; S-cones)	32	79	163	0
Chloropic EDI (lux; M-cones)	44	110	227	5
Erythropic EDI (lux ; L-cones)	46	113	233	8
Irradiance ($\mu\text{W}/\text{cm}^2$)	15	36	75	1.4
Photon flux($1/\text{cm}^2/\text{s}$)	$4.12^{\text{E}+13}$	$1.02^{\text{E}+14}$	$2.10^{\text{E}+14}$	$4.24^{\text{E}+12}$
Log Photon Flux ($\log_{10} (1/\text{cm}^2/\text{s})$)	13.61	14.01	14.32	12.63
Narrowband peak	-	-	-	589
Narrowband FWHM	-	-	-	10

Blue enriched light (BEL) (low, mid, and high) and monochromatic light (589nm).

Supplementary Table S3. Impact of the emotional content to the auditory stimuli on amygdala subparts.

Main GLMM				
Effect	DF	F	P	Partial R ²
Stimulus type	1, 27.74	9.93	<.0039	0.26
Amygdala subpart	9, 499.9	2.13	<.0256	0.04
Amygdala subparts x stimulus type	9, 499.9	0.56	0.85	-
Age	1, 24.98	2.20	0.15	-
Sex	1, 25	0.69	0.41	-
BMI	1, 24.97	1.69	0.20	-
Least Squares Means				
Amygdala subpart	t Value	P-value		
1	1.99	0.0494		
2	0.71	0.4787		
3	3.46	0.0008		
4	1.75	0.0834		
5	3.64	0.0005		
6	1.59	0.1155		
7	4.08	<.0001		
8	2.92	0.0044		
9	3.18	0.0020		
10	2.17	0.0327		

Amygdala subpart (refer to Fig. 2): (1) Lateral nucleus, (2) Intermediate and dorsal basolateral nucleus, (3) Basomedial nuclei, (4) Central nucleus, (5) Medial and Cortical nuclei, (6) Ventral basolateral nucleus and Paralaminar nucleus, (7) amygdala transition area composed of Amygdalocortical area, Amygdalohippocampal area, Periamygdaloid cortex, (8) Amygdalostriatal, (9) Anterior amygdaloid area, (10) Intercalated nuclei.

BMI: body mass index

Supplementary Table S4. Impact of season and affective state on the activity of amygdala subparts.

GLMM				
Effect	DF	F	P	Partial R ²
Stimulus type	1, 23.85	8.85	0.0066	0.27
Amygdala subpart	6, 272.7	1.58	0.15	-
Affective state	1, 17.81	17.46	0.0006	0.495
Affective state * Amygdala subpart	6, 272.4	2.99	0.0076	0.062
Season #	1, 17.85	12.62	0.0023	0.41
Season * Amygdala subpart	6, 272.6	4.66	0.0002	0.09
Affective state * Season	1, 17.79	12.18	0.0027	0.41
Affective state * Season * Amygdala subpart	6, 272.4	4.03	0.0007	0.08
Age	1, 17.84	7.77	0.0122	0.3
Sex	1, 17.88	2.66	0.12	-
BMI	1, 17.82	1.37	0.26	-
<u>Season</u>				
Amygdala subpart	T	P	P _{corrected}	
1	2.22	0.0287	0.1570	
3	3.54	0.0006	0.0040	
5	2.13	0.0356	0.1917	
7	1.68	0.0963	0.4555	
8	-0.96	0.3384	0.9219	
9	4.96	<.0001	<.0001	
10	2.06	0.0417	0.2211	
<u>Season * amygdala subpart</u>				
Amygdala subpart contrast	T	P	P _{corrected}	
1 vs. 3	-1.11	0.2665	0.9261	
1 vs. 5	0.08	0.9401	1.0000	
1 vs. 7	0.42	0.6720	0.9992	
1 vs. 8	2.68	0.0078	0.1073	
1 vs. 9	-2.32	0.0210	0.2348	
1 vs. 10	0.13	0.8951	1.0000	
3 vs. 5	1.19	0.2356	0.9000	
3 vs. 7	1.52	0.1291	0.7305	
3 vs. 8	3.80	0.0002	0.0037	
3 vs. 9	-1.21	0.2268	0.8925	
3 vs. 10	1.25	0.2141	0.8796	
5 vs. 7	0.35	0.7269	0.9998	
5 vs. 8	2.61	0.0096	0.1269	
5 vs. 9	-2.40	0.0172	0.2021	
5 vs. 10	0.06	0.9548	1.0000	
7 vs. 8	2.22	0.0271	0.2817	

7 vs. 9	-2.71	0.0071	0.0992
7 vs. 10	-0.29	0.7692	0.9998
8 vs. 9	-5.00	<.0001	<.0001
8 vs. 10	-2.55	0.0113	0.1457
9 vs. 7	2.45	0.0148	0.1806
<u>Affective state</u>			
Amygdala subpart	T	P	P_{corrected}
1	1.85	0.0668	0.3350
3	2.17	0.0328	0.1764
5	4.28	<.0001	0.0002
7	4.64	<.0001	<.0001
8	0.40	0.6881	0.9994
9	2.60	0.0107	0.0614
10	2.46	0.0156	0.0879
<u>Affective state * amygdala subpart</u>			
Amygdala subpart contrast	T	P	P_{corrected}
1 vs. 3	-0.26	0.7926	0.9999
1 vs. 5	-2.05	0.0416	0.3814
1 vs. 7	-2.36	0.0190	0.2163
1 vs. 8	1.22	0.2224	0.8823
1 vs. 9	-0.64	0.5243	0.9940
1 vs. 10	-0.51	0.6086	0.9979
3 vs. 5	-1.78	0.0755	0.5583
3 vs. 7	-2.10	0.0370	0.3503
3 vs. 8	1.49	0.1384	0.7519
3 vs. 9	-0.38	0.7079	0.9997
3 vs. 10	-0.25	0.8032	0.9999
5 vs. 7	-0.32	0.7518	0.9998
5 vs. 8	3.27	0.0012	0.0198
5 vs. 9	1.40	0.1613	0.7987
5 vs. 10	1.53	0.1261	0.7218
7 vs. 8	3.58	0.0004	0.0083
7 vs. 9	1.72	0.0871	0.6051
7 vs. 10	1.85	0.0658	0.5123
8 vs. 9	-1.86	0.0643	0.5051
8 vs. 10	-1.74	0.0838	0.5925
9 vs. 7	0.13	0.8997	1.0000

Amygdala subparts (refer to Fig. 2): (1) Lateral nucleus, (3) Basomedial nuclei, (5) Medial and Cortical nuclei, (7) amygdala transition area composed of Amygdalocortical area, Amygdalohippocampal area, Periamygdaloid cortex, (8) Amygdalostriatal, (9) Anterior amygdaloid area, (10) Intercalated nuclei.

BMI: body mass index

Supplementary Table S5. Impact of light illuminance on the activity of amygdala subparts.

GLMM				
Effect	DF	F	P	Partial R ²
Stimulus type	1, 27.24	6.32	0.0181	0.19
Amygdala subpart	6, 331.4	7.05	<.0001	0.11
Stimulus type * Amygdala subpart	6, 331.4	1.42	0.21	-
Age	1, 25.06	1.23	0.28	-
Sex	1, 25.05	1.41	0.25	-
BMI	1, 25.12	0.11	0.74	-
Illuminance - Least Squares Means				
Amygdala subpart	T	P		
1	-1.90	0.0623		
3	-4.12	0.0001		
5	-4.47	<.0001		
7	-3.68	0.0005		
8	-0.30	0.7675		
9	-3.92	0.0002		
10	-0.63	0.5283		
Illuminance * amygdala subpart				
Amygdala subpart contrast	T	P	P _{corrected}	
1 vs. 3	2.39	0.0172	0.2087	
1 vs. 5	2.77	0.0059	0.0893	
1 vs. 7	1.92	0.0561	0.4693	
1 vs. 8	-1.72	0.0873	0.6069	
1 vs. 9	2.2	0.0283	0.2978	
1 vs. 10	-1.36	0.1741	0.8205	
3 vs. 5	0.38	0.7072	0.9998	
3 vs. 7	-0.48	0.6329	0.9993	
3 vs. 8	-4.1	<.0001	0.0005	
3 vs. 9	-0.16	0.8765	1	
3 vs. 10	-3.76	0.0002	0.0025	
5 vs. 7	-0.85	0.3937	0.98	
5 vs. 8	-4.47	<.0001	0.0002	
5 vs. 9	-0.53	0.5995	0.9988	
5 vs. 10	-4.13	<.0001	0.0005	
7 vs. 8	-3.62	0.0003	0.005	
7 vs. 9	0.32	0.7529	0.9998	
7 vs. 10	-3.28	0.0012	0.0206	
8 vs. 9	3.89	0.0001	0.0011	
8 vs. 10	0.36	0.7191	0.9998	
9 vs. 7	-3.54	0.0005	0.0074	

Amygdala subpart (refer to Fig. 2): (1) Lateral nucleus, (3) Basomedial nuclei, (5) Medial and Cortical nuclei, (7) amygdala transition area composed of Amygdalocortical area, Amygdalohippocampal area, Periamygdaloid cortex, (8) Amygdalostriatal, (9) Anterior amygdaloid area, (10) Intercalated nuclei.
BMI: body mass index

Supplementary Table S6. Impact of each illuminance on the activity of the amygdala subparts affected by light exposure.

GLMM				
Effect	DF	F	P	Partial R ²
Stimulus type	1, 244.1	9.12	0.0028	0.04
Illuminance	4, 244.1	6.09	0.0001	0.09
Illuminance * Stimulus type	4, 244.2	1.65	0.1617	-
Amygdala subpart	3, 813.4	0.1	0.9587	-
Stimulus type * Amygdala subpart	3, 813.6	3.08	0.0269	0.01
Illuminance * Amygdala subpart	12, 813.5	0.48	0.9294	-
Stimulus type * Illuminance * Amygdala subpart	12, 813.5	0.26	0.9942	-
Age	1, 24.98	2.9	0.1008	-
Sex	1, 24.99	0.3	0.5885	-
BMI	1, 24.98	1.84	0.187	-
<u>Illuminance per amygdala subpart</u>				
Amygdala subpart	Contrast	T	P	P _{corrected}
3	0 vs. 0.16	-0.59	0.55	0.97
3	0 vs. 37	1.01	0.31	0.85
3	0 vs. 92	-0.07	0.94	1
3	0 vs. 190	2.76	0.0059	0.046
3	0.16 vs. 37	1.6	0.11	0.5
3	0.16 vs. 92	0.51	0.61	0.97
3	0.16 vs. 190	3.35	0.0008	0.0075
3	37 vs. 92	-1.09	0.28	0.81
3	37 vs. 190	1.74	0.083	0.41
3	92 vs. 190	2.84	0.0047	0.0375
5	0 vs. 0.16	-0.07	0.94	1
5	0 vs. 37	0.69	0.49	0.96
5	0 vs. 92	0.35	0.72	0.99
5	0 vs. 190	3.07	0.0022	0.019
5	0.16 vs. 37	0.76	0.45	0.94
5	0.16 vs. 92	0.42	0.67	0.99
5	0.16 vs. 190	3.14	0.0018	0.015
5	37 vs. 92	-0.33	0.74	0.99
5	37 vs. 190	2.38	0.0175	0.12
5	92 vs. 190	2.69	0.0072	0.056
7	0 vs. 0.16	0.19	0.85	0.99
7	0 vs. 37	1.01	0.31	0.85
7	0 vs. 92	0.34	0.74	0.99
7	0 vs. 190	2.53	0.0116	0.085
7	0.16 vs. 37	0.82	0.41	0.93
7	0.16 vs. 92	0.15	0.88	0.99
7	0.16 vs. 190	2.34	0.0195	0.13

7	37 vs. 92	-0.67	0.50	0.96	
7	37 vs. 190	1.51	0.13	0.55	
7	92 vs. 190	2.19	0.029	0.18	
9	0 vs. 0.16	0.28	0.78	0.99	
9	0 vs. 37	-0.04	0.97	1	
9	0 vs. 92	0.62	0.54	0.97	
9	0 vs. 190	3.55	0.0004	0.0038	
9	0.16 vs. 37	-0.32	0.75	0.99	
9	0.16 vs. 92	0.34	0.73	0.99	
9	0.16 vs. 190	3.23	0.0013	0.011	
9	37 vs. 92	0.66	0.51	0.97	
9	37 vs. 190	3.58	0.0004	0.0033	
9	92 vs. 190	2.91	0.0038	0.031	

Activity of the 4 subparts showing a significant impact of overall illuminance changes (cf. Table S5 and Fig. 3C-D) was extracted from a separate analysis of the fMRI data which considered separately each illuminance (cf. methods). As in the main analysis, the GLMM including these activity estimates as dependent variable confirmed that there was a significant impact of stimulus type and light level. The 4 subparts did not differ between each other and their changes in responses with illuminance change were not different, which is not surprising given the fact that the four subparts were selected based on their overall response to illuminance change.

Post hoc contrasts indicate that the activity of the four subparts significantly decreased under the highest illuminance (190 mel EDI) when compared to darkness (0 mel EDI lux) and the lowest illuminance level (.16 mel EDI lux) and with 37 mel EDI illuminance in some cases (though significance was not surviving correction for multiple comparisons in some cases). Together with the visual inspection of Figure 3C, the overall impression is of linear decrease in activity with increasing illuminance (in line with the output of the analyses considering illuminance variation as a whole – cf. Table S5).

Amygdala subpart (refer to Fig. 2): (3) Basomedial nuclei, (5) Medial and Cortical nuclei, (7) amygdala transition area composed of Amygdalocortical area, Amygdalohippocampal area, Periamygdaloid cortex, (9) Anterior amygdaloid area.

BMI: body mass index

Supplementary Table S7. Impact of season and affective state on the impact of light exposure on the activity of amygdala subparts.

GLMM				
Effect	DF	F	P	Partial R ²
Stimulus type	1, 23.13	9.01	0.0063	0.28
Amygdala subpart	6, 272	5.63	<.0001	0.11
Affective state	1, 18	1.23	0.28	-
Affective state * Amygdala subpart	6, 272	2.24	0.04	0.05
Season #	1, 18	0.02	0.89	-
Season * Amygdala subpart	6, 272	2.94	0.0085	0.06
Affective state * Season	1, 18.01	0.25	0.62	-
Affective state * Season * Amygdala subpart	6, 272	0.87	0.52	-
Age	1, 18.07	0.97	0.34	-
Sex	1, 18.02	0.6	0.45	-
BMI	1, 18.05	0.09	0.77	-
<u>Season</u>				
Amygdala subpart	T	P	P _{corrected}	
1	0.58	0.56	0.98	
3	0.27	0.79	0.99	
5	1.06	0.29	0.76	
7	-1.71	0.096	0.32	
8	-0.92	0.36	0.85	
9	1.14	0.26	0.70	
10	0.36	0.72	0.99	
<u>Season * amygdala subpart</u>				
Amygdala subpart contrast	T	P	P _{corrected}	
1 vs. 3	0.36	0.72	0.99	
1 vs. 5	-0.56	0.58	0.99	
1 vs. 7	2.64	0.0089	0.12	
1 vs. 8	1.73	0.085	0.6	
1 vs. 9	-0.65	0.52	0.99	
1 vs. 10	0.26	0.8	0.99	
3 vs. 5	-0.92	0.36	0.97	
3 vs. 7	2.27	0.0237	0.26	
3 vs. 8	1.37	0.17	0.83	
3 vs. 9	-1.01	0.31	0.95	
3 vs. 10	-0.11	0.92	1	
5 vs. 7	3.19	0.0016	0.0244	
5 vs. 8	2.29	0.023	0.26	
5 vs. 9	-0.09	0.93	1	
5 vs. 10	0.81	0.42	0.98	
7 vs. 8	-0.9	0.37	0.97	

7 vs. 9	-3.28	0.0012	0.0185	
7 vs. 10	-2.38	0.018	0.2167	
8 vs. 9	-2.38	0.0182	0.218	
8 vs. 10	-1.48	0.1413	0.7691	
9 vs. 7	0.91	0.3662	0.9732	
<u>Affective state</u>				
Amygdala subpart contrast	T	P	P_{corrected}	
1	0.66	0.51	0.96	
3	1.73	0.091	0.29	
5	1.53	0.14	0.41	
7	0	0.99	1	
8	-0.21	0.84	1	
9	2.21	0.033	0.12	
10	0.47	0.64	0.99	
<u>Affective state * amygdala subpart</u>				
1 vs. 3	-1.23	0.22	0.87	
1 vs. 5	-0.99	0.32	0.95	
1 vs. 7	0.77	0.44	0.99	
1 vs. 8	1	0.32	0.95	
1 vs. 9	-1.78	0.077	0.56	
1 vs. 10	0.23	0.819	1	
3 vs. 5	0.24	0.81	1	
3 vs. 7	2	0.046	0.42	
3 vs. 8	2.23	0.027	0.29	
3 vs. 9	-0.55	0.58	0.99	
3 vs. 10	1.46	0.15	0.76	
5 vs. 7	1.76	0.079	0.57	
5 vs. 8	1.99	0.0475	0.42	
5 vs. 9	-0.79	0.43	0.99	
5 vs. 10	1.22	0.22	0.88	
7 vs. 8	0.24	0.81	1	
7 vs. 9	-2.54	0.0116	0.15	
7 vs. 10	-0.54	0.58	0.99	
8 vs. 9	-2.77	0.006	0.084	
8 vs. 10	-0.77	0.44	0.99	
9 vs. 7	2	0.046	0.41	

Amygdala subparts (refer to Fig. 2): (1) Lateral nucleus, (3) Basomedial nuclei, (5) Medial and Cortical nuclei, (7) amygdala transition area composed of Amygdalocortical area, Amygdalohippocampal area, Periamygdaloid cortex, (8) Amygdalostriatal, (9) Anterior amygdaloid area, (10) Intercalated nuclei.

BMI: body mass index

References

1. Beck, A. T., Ward, C. H., Mendelson, M., Mock, J. & Erbaugh, J. An inventory for measuring depression. *Arch Gen Psychiatry* **4**, 561–571 (1961).
2. Beck, A. T., Epstein, N., Brown, G. & Steer, R. A. An inventory for measuring clinical anxiety: Psychometric properties. *J Consult Clin Psychol* **56**, 893–897 (1988).
3. Buysse, D. J., Reynolds, C. F. 3rd, Monk, T. H., Berman, S. R. & Kupfer, D. J. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res* **28**, 193–213 (1989).
4. Rosenthal, N. E. & Bradt, G. W. T. Seasonal pattern assessment questionnaire (SPAQ). *National Institute of Mental Health, Bethesda, MD, USA* (1984).
5. Horne, J. A. & Ostberg, O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int J Chronobiol* **4**, 97–110 (1976).
6. Johns, M. W. Daytime sleepiness, snoring, and obstructive sleep apnea; The Epworth Sleepiness Scale. *Chest* **103**, 30–36 (1993).