

Supplementary Material

Listening to their nights: Sleep disruptions in captive housed chimpanzees affect their daytime behavior

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Table S1. Characteristics of the study population.

Name	ID	Sex	Age category	Group
Africa	AFR	F	Adult	Mutamba
Bongo	BON	M	Adult	Mutamba
Juanito	JUA	M	Adult	Mutamba
Marco	MAR	M	Senior	Mutamba
Waty	WAT	F	Adult	Mutamba
Bea	BEA	F	Senior	Bilinga
Cheeta	CHE	F	Senior	Bilinga
Coco	COC	F	Adult	Bilinga
Nico	NIC	M	Adult	Bilinga
Tico	TIC	M	Senior	Bilinga
Tom	TOM	M	Senior	Bilinga
Victor	VIC	M	Senior	Bilinga

Abbreviations: F = Female; M = Male

Table S2. This table show the ethogram we used to record daytime behavioral data.

Type of Behavior	Name of behavior	Definition
Solitary	Abnormal	This includes: (a) Atypical Behaviors, i.e. behaviors not typically seen in wild populations; (b) behaviors exhibited in an excessive manner or as an inadequate, non-adaptive response to a specific situations. SELF SCRATCH: invariable, rhythmic and repetitive movement of the hand fingers or with an object (e.g. stick) rubbing some part of its own body. SELF POKE: insert or press fingers or objects (e.g. sticks) repeatedly or continuously in a part of the body (only mark when actively manipulating or maintaining contact). SELF CLAP: hitting (soft or hard) some part of the body with hands or feet rhythmically and repetitively. ROCKING: Repetitive and invariable swinging of the body while sitting (they can hug or grab objects at the same time, e.g. pile of straw). OVER GROOMING: excessive self-cleaning behavior of the skin / coat with hands or mouth, which may include pulling and ingesting hair. The behavior can also be focused on wounds or damage to the skin, deteriorating its condition. They usually do it on the same areas of the body with a visible lack of hair. COPROPHAGY: handling and/or ingestion of feces (both own and others). OTHER ABNORMAL: other abnormal or stereotyped behaviors not described above. The majority can be identified due to its rhythmically, repetitiveness and/or excessive frequency.
Solitary	Locomotion	Displacement from a point A to a point B on a vertical or horizontal surface, while not doing any other behavior from the catalogue.
Solitary	Alimentation	All behaviors related to food. FOOD: ingest or handle solid or liquid food in a stationary position. FOODING: active search and/or transport of food (the animal keeps its eyes focused on possible food sources). It can include punctual food intake without interrupting gathering food. FOOD EXTRACTION: The chimpanzee is working an enrichment device/item (provided by care givers) which contains food items. This may include longer periods of manipulation in order to bring out the food items which are occasionally ingested. The chimpanzee might use feet, hands, mouth or tools.
Solitary	Manipulation	Inspecting elements of the environment or enrichment that are not food with the upper or lower extremities.
Solitary	Inactivity	RESTING: the individual remains stationary without actively interacting with himself, other individuals, nor does VIGILANCE or RELAXED behavior. VIGILANCE BEHAVIOR: described as the fixed gazing of something concrete or scanning the distant environment in a fixed, immobile position, either seated or bipedal standing. It does not include looking at parts of your own body, objects in close proximity, or other individuals within a 5m radius. It includes looking at distant group members, other groups, and the surrounding area. RELAXED RESTING: dozing or sleeping in an upward-facing or lateral position with either elongated or bent limbs (without hugging oneself). The individual does not show any indication of being focused on any other individual or their general environment. The individual is not defined as RELAXED RESTING if it is goes into a fetal position (may include hugging limbs and/or patting oneself with fingers on various parts of the body), nor any other behavior categorized as abnormal, such as: self-poking or self-clasping, etc.

Solitary	Self Directed	Behaviors directed towards the individual, such as self-cleaning (auto grooming), masturbation, scratching, scrubbing, body inspection, etc.
Solitary	Other Individual	Individual behaviors that are not better defined by any other category of the "Solitary Behavior" group. Does include behaviors such as individual tension or excretion. SOLITARY BLURRED: mark only when the individual can be located performing an individual behavior but the behavior the individual performs is not identified due to lack of vision.
Solitary	Solitary Play	All Solitary Play behaviors have to be either accompanied by either laughs or a "play face". (In the absence of laughter or a play face this would be recorded as "Manipulation"). For all categories, be careful not to include abnormal behaviors such as self-clasping, self-patting, pacing, self-poking, body rocking, or any other abnormal or stereotypical behaviors. LOCOMOTOR SOLITARY PLAY: An active game played by a single individual that includes swinging, hanging, jumping, pivoting, sliding, jumping and moving quickly without any indication of external motivation (social or nutritional, for example). STATIONARY SOLITARY PLAY: the individual plays silently with the hands, the fingers and toes, or other parts of one's own body. OBJECT SOLITARY PLAY: the individual plays individually while carrying or using one or several objects.
Other	Not visible	The individual cannot be located or is out of the view of the observer. INTERIORS: mark when the individual is in the bedrooms while having access to the observed group exteriors.
Other	Human Positive	Interaction, or looking for interaction, with humans of a neutral type, or without showing clear signs of antagonism. HUMAN AFFILIATIVE INTERACTION: search, action, or mutual influence with or without physical contact between animal and human of non-agonistic type. It can be initiated by animals or by humans. OBSERVING HUMAN CLOSE UP: the individual remains less than 1.5 meters from the fence observing humans in close proximity. FOLLOW HUMAN: locomotion in parallel to the fence following the path that people make around the enclosure.
Other	Human Negative	Agonistic-like interaction or looking for it towards humans. HUMAN AGGRESSION: chimpanzees show threatening behavior and/or perform an agonistic display directed at humans in close proximity. It may include attempts to come into physical contact, throw items, or spit. HUMAN SUBMISSIVE: Chimpanzees are agitated with a scared face can include behaviors such as asking for support, crying or yelling directed at a human.
Social	Grooming	Body-cleansing behavior (grooming) from one individual to another (includes mutual grooming), performed with the upper extremities or with the mouth.
Social	Agonistic Dominance	Behaviors relating to the agonistic/display threat, direct aggression, displacement and resource appropriation (including object and social resources) It can be accompanied by vocalizations.
Social	Agonistic Submission	The chimpanzee shows signs of fear directed at another individual in an aggressive context. It may include approaching and presenting vulnerable body parts in an attempt to appease or attempt to avoid or flee from an individual displaying aggressive behavior. It can include actions such as genital presenting, extending limbs, hand to mouth, finger to mouth, running away, avoiding, and is typically accompanied by a scared face and vocalizations such as yelling, screaming, crying or pant-grunting.
Social	Other Agonistic	Other aggression-related behaviors that cannot be defined by the Agonistic Dominance or Agonistic Submission categories. AGONISTIC BLURRED: the individual can be located performing or receiving agonistic social behavior, but the behavior the individual performs or receives is not identified due to lack of vision.

Social	Social Play	Playful behavior between two or more individuals punctually accompanied by playful indicators (eg, play face, laugh, gallop, cartwheels and pirouettes). Tag, catch and grab limbs or objects, tickles, muzzling, rough-and-tumble. These interactions do not require permanent physical contact.
Social	Other Affiliative	Other affiliative-like behaviors that cannot be defined by the “Social Play” or “Grooming” categories. Any of the following 3 subcategories are marked if they fit the following definitions: FOLLOW: Synchronized movement following the trajectory of another individual locomotion following the trajectory of another individual, moving beside or behind (always mark mutual). EMBRACE: An individual hugs or tries to hug another with one or both arms. FEED TOGETHER Two individuals eat from the same food source or forage in close proximity allowing the collection of food within their reach by another individual, sharing the food in a passive way (always marking it mutual). AFFILIATIVE BLURRED: the individual can be located performing or receiving an affiliative social behavior but the behavior he / she performs or receives is not identified due to lack of vision.
Social	Socio Sexual	Sexual interaction, or search for sexual interaction, between two individuals that includes behaviors such as: copulation, attempted copulation, genital presentation, and other behaviors directed towards the genitals of another individual.
Distance	Social proximity	Sharing a space during inactivity, or associated with other individual behaviors, while the distance between individuals is less than the length of the upper extremity. (Includes physical contact). Social Proximity is only recorded between animals that do not interact socially.

Table S3. Minimum, maximum, average and standard deviation values of the sample used in the analysis for the different variables recorded.

	Minimum	Maximum	Average	Standard deviation
Average T^a (°C)	16.6	28.6	22.0	5.5
Max Humidity (%)	49	99	78.1	9.2
Min Humidity (%)	27	91	58.7	13.7
N° events	1	6	2.2	1.1
Max Events (seconds)	286	4771	1065.4	452.2

Table S4. Categories of variables used for data analysis: number of events (N° Events) and duration of the longest event (Max Duration).

Variable	Category	Range
N° events	one	1
	two	2
	three or more	3 - 6
Max Events (seconds)*	short	< 870
	medium	870 – 1150
	long	> 1150

* The cut-off values between categories have been assigned to achieve an equal distribution of the data in the three categories.

Table S5. Results of Kendall's rank correlation test for all measured abiotic factor variables (adjusted p values with Holm-Bonferroni method).

Night disruption	Abiotic factor	tau	Z	p
Nº events	T^a average	0.2717223	5.553	2.808e-08 **
	T^a min	0.3015013	6.1065	1.018e-09 **
	T^a max	0.23958	4.8745	1.091e-06 **
	H average	-0.05452151	-1.1154	0.2647
	H min	-0.002396573	-0.048865	0.961
	H max	-0.1376107	-2.7921	0.005237 **
Max Events	T^a average	0.1169002	2.7095	0.006739 **
	T^a min	0.1236477	2.8403	0.004506 **
	T^a max	0.1137081	2.6239	0.008694 **
	H average	-0.01373435	-0.31867	0.75
	H min	0.000268284	0.006204	0.995
	H max	-0.04058961	-0.93404	0.3503

Signif. codes: p <0.05 ' * ' / p<0.01 ' ** ' ,

Anova Type III Analysis of Variance Table with Satterthwaite's method																		
				Nº Events			Max Event				Sex				Age Category			
Model	ΔAIC	p	SumSq	Mean Sq	Fvalue	p	SumSq	Mean Sq	Fvalue	p	SumSq	Mean Sq	Fvalue	p	SumSq	Mean Sq	Fvalue	p
Inactivity	57.5	5.221e-13 **	0.163633	0.081816	26.3382	8.258e-10 **	0.122320	0.061160	19.6885	7.203e-08 **	0.003445	0.003445	1.1090	0.31296	0.019007	0.019007	6.1186	0.02924 *
Abn - Self	16.15	8.798e-05 **	0.0013494	0.0006747	0.6774	0.5104	0.0312790	0.0156395	15.7027	1.306e-06 **	0.0000074	0.0000074	0.0075	0.9326	0.0000722	0.0000722	0.0725	0.7923
Aff - Prox	44	2.911e-10**	0.111800	0.055900	15.6418	1.342e-06 **	0.131204	0.065602	18.3566	1.817e-07 **	0.013621	0.013621	3.8114	0.07459	0.001056	0.001056	0.2954	0.59674

Table S7. Post hoc test results of the linear mixed models. Multiple comparison of means with Tukey contrasts (adjusted p values with Holm-Bonferroni method).

Model	Fixed Factor		Estimate	Std. Error	Z value	p value
Inactivity	N° Events	one two	0.06250	0.01324	4.720	4.73e-06 **
		one three	0.09530	0.01335	7.141	2.78e-12 **
		two three	0.03280	0.01324	2.476	0.0133 *
	Max Event	short medium	-0.02817	0.01314	-2.144	0.032 *
		short long	0.05446	0.01335	4.079	9.03e-05 **
		medium long	0.08263	0.01335	6.189	1.81e-09 **
	Age Category	adult senior	0.10030	0.04055	2.474	0.0134 *
Abn - Self	Max Event	short medium	0.001556	0.007439	0.209	0.834
		short long	0.037632	0.007559	4.978	1.92e-06 **
		medium long	0.036076	0.007559	4.772	3.64e-06 **
Aff - Prox	N° Events	one two	0.05980	0.01420	4.210	5.11e-05 **
		one three	0.07543	0.01420	5.310	3.28e-07 **
		two three	0.01563	0.01409	1.109	0.267
	Max Event	short medium	-0.01016	0.01409	-0.721	0.471
		short long	0.06912	0.01420	4.866	2.27e-06 **
		medium long	0.07928	0.01420	5.581	7.15e-08 **

Table S8. Post hoc test (emmeans function) results of the LMM regarding Inactivity, including fixed factor interaction between Max Duration and N° Events, based on pairwise comparison of means. Results are averaged over the levels of Sex and Age Category with Tukey contrast for comparing a family of 9 estimates (adjusted p-values with Bonferroni method)

Interaction Max duration : N° events		estimate	SE	df	t ratio	p value
short + one	medium + one	0.0282	0.0134	98.2	2.0980	0.4808
short + one	long + one	-0.0545	0.0136	98.2	-3.9910	0.0039**
short + one	short + two	-0.0625	0.0135	98.2	-4.6180	0.0004***
short + one	medium + two	-0.0343	0.0191	98.2	-1.8010	0.6814
short + one	long + two	-0.1170	0.0191	98.2	-6.1350	<.0001***
short + one	short + three or more	-0.0953	0.0136	98.2	-6.9860	<.0001***
short + one	medium + three or more	-0.0671	0.0191	98.2	-3.5070	0.0189*
short + one	long + three or more	-0.1498	0.0193	98.2	-7.7620	<.0001***
medium + one	long + one	-0.0826	0.0136	98.2	-6.0550	<.0001***
medium + one	short + two	-0.0907	0.0191	98.2	-4.7560	0.0002***
medium + one	medium + two	-0.0625	0.0135	98.2	-4.6180	0.0004***
medium + one	long + two	-0.1451	0.0191	98.2	-7.6130	<.0001***
medium + one	short + three or more	-0.1235	0.0191	98.2	-6.4510	<.0001***
medium + one	medium + three or more	-0.0953	0.0136	98.2	-6.9860	<.0001***
medium + one	long + three or more	-0.1779	0.0193	98.2	-9.2220	<.0001***
long + one	short + two	-0.0080	0.0194	98.2	-0.4150	1.0000
long + one	medium + two	0.0201	0.0194	98.2	1.0390	0.9810
long + one	long + two	-0.0625	0.0135	98.2	-4.6180	0.0004***
long + one	short + three or more	-0.0408	0.0193	98.2	-2.1170	0.4684
long + one	medium + three or more	-0.0127	0.0193	98.2	-0.6570	0.9992
long + one	long + three or more	-0.0953	0.0136	98.2	-6.9860	<.0001***
short + two	medium + two	0.0282	0.0134	98.2	2.0980	0.4808
short + two	long + two	-0.0545	0.0136	98.2	-3.9910	0.0039**
short + two	short + three or more	-0.0328	0.0135	98.2	-2.4230	0.2835
short + two	medium + three or more	-0.0046	0.0191	98.2	-0.2430	1.0000

short + two	long + three or more	-0.0873	0.0194	98.2	-4.5040	0.0006***
medium + two	long + two	-0.0826	0.0136	98.2	-6.0550	<.0001***
medium + two	short + three or more	-0.0610	0.0191	98.2	-3.1980	0.0466
medium + two	medium + three or more	-0.0328	0.0135	98.2	-2.4230	0.2835
medium + two	long + three or more	-0.1154	0.0194	98.2	-5.9580	<.0001***
long + two	short + three or more	0.0217	0.0191	98.2	1.1360	0.9671
long + two	medium + three or more	0.0498	0.0191	98.2	2.6140	0.1944
long + two	long + three or more	-0.0328	0.0135	98.2	-2.4230	0.2835
short + three or more	medium + three or more	0.0282	0.0134	98.2	2.0980	0.4808
short + three or more	long + three or more	-0.0545	0.0136	98.2	-3.9910	0.0039**
medium + three or more	long + three or more	-0.0826	0.0136	98.2	-6.0550	<.0001***

Signif. codes: p <0.05 ' * ' / p<0.01 ' ** ' p<0.001 ' *** ' ,

Table S9: Post hoc test (emmeans function) results of the LMM regarding Inactivity, including fixed factor interaction between Age Category and N° Events, based on pairwise comparison of means. Results are averaged over the levels of Sex and Max Duration with Tukey contrast for comparing a family of 6 estimates (adjusted p-values with Bonferroni method)

Interaction: Age Category : N° events		estimate	SE	df	t ratio	p value
adult + one	senior + one	-0.1003	0.0764	9.55	-1.3140	0.7721
adult + one	adult + two	-0.0625	0.0135	98.21	-4.6180	0.0002***
adult + one	senior + two	-0.1628	0.0775	11.62	-2.1000	0.3498
adult + one	adult + three or more	-0.0953	0.0136	98.24	-6.9860	<.0001***
adult + one	senior + three or more	-0.1956	0.0775	11.72	-2.5230	0.1934
senior + one	adult + two	0.0378	0.0776	11.76	0.4870	0.9957
senior + one	senior + two	-0.0625	0.0135	98.21	-4.6180	0.0002***
senior + one	adult + three or more	0.00501	0.0776	11.72	0.0650	1.0000
senior + one	senior + three or more	-0.0953	0.0136	98.24	-6.9860	<.0001***

adult + two	senior + two	-0.1003	0.0764	9.55	-1.3140	0.7721
adult + two	adult + three or more	-0.0328	0.0135	98.21	-2.4230	0.1585
adult + two	senior + three or more	-0.1331	0.0775	11.76	-1.7170	0.5472
senior + two	adult + three or more	0.06751	0.0775	11.62	0.8710	0.9465
senior + two	senior + three or more	-0.0328	0.0135	98.21	-2.4230	0.1585
adult + three or more	senior + three or more	-0.1003	0.0764	9.55	-1.3140	0.7721

Signif. codes: p <0.05 ' * ' / p<0.01 ' ** ' p<0.001 ' *** ' ,

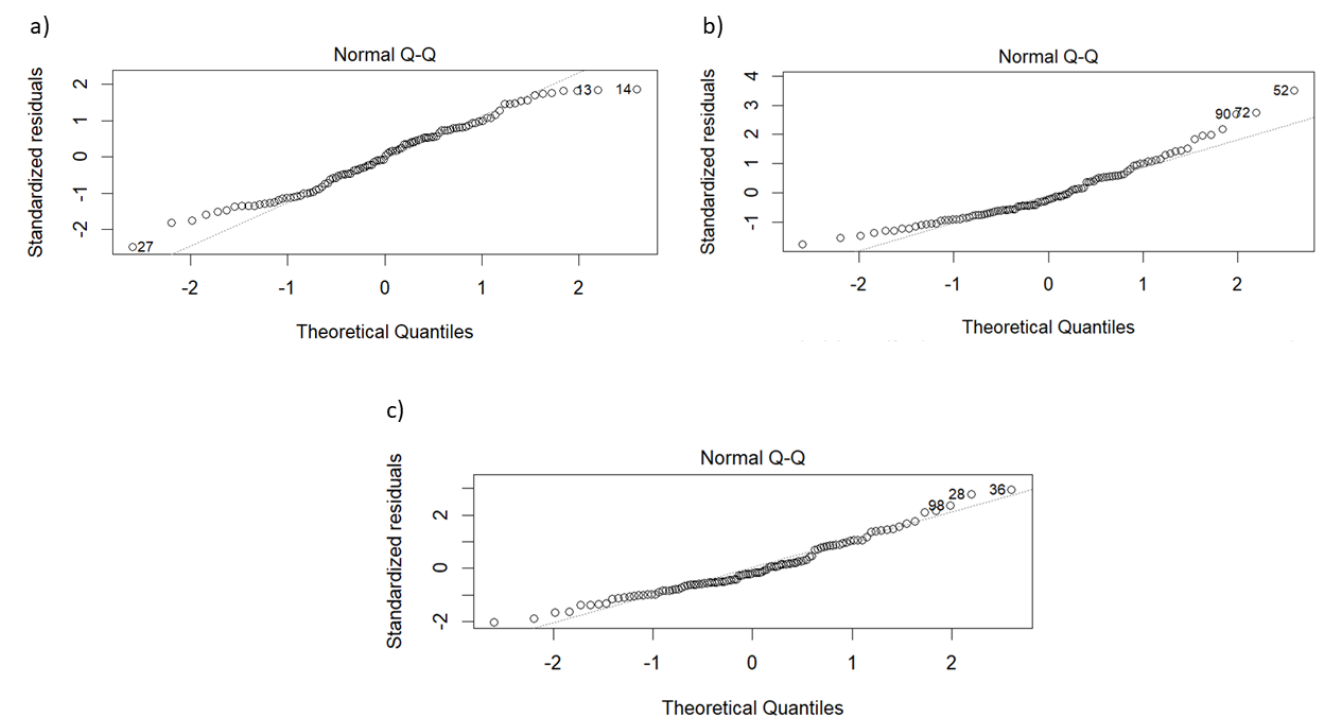
Table S10: Post hoc test (emmeans function) results of the LMM regarding Affiliative behaviors & Social Proximity, including fixed factor interaction between Max Duration and N° Events, based on pairwise comparison of means. Results are averaged over the levels of Sex and Age Category with Tukey contrast for comparing a family of 9 estimates (adjusted p-values with Bonferroni method)

Interaction Max duration : N° events		estimate	SE	df	t ratio	p value
short + one	medium + one	0.0102	0.0144	99.2	0.7060	0.9986
short + one	long + one	-0.0691	0.0145	99.2	-4.7630	0.0002***
short + one	short + two	-0.0598	0.0145	99.2	-4.1200	0.0025**
short + one	medium + two	-0.0496	0.0204	99.2	-2.4280	0.2806
short + one	long + two	-0.1289	0.0204	99.2	-6.3320	<.0001***
short + one	short + three or more	-0.0754	0.0145	99.2	-5.1970	<.0001***
short + one	medium + three or more	-0.0653	0.0204	99.2	-3.1930	0.0471*
short + one	long + three or more	-0.1446	0.0204	99.2	-7.1000	<.0001***
medium + one	long + one	-0.0793	0.0145	99.2	-5.4630	<.0001***
medium + one	short + two	-0.0700	0.0204	99.2	-3.4220	0.0244*
medium + one	medium + two	-0.0598	0.0145	99.2	-4.1200	0.0025**
medium + one	long + two	-0.1391	0.0204	99.2	-6.8310	<.0001***
medium + one	short + three or more	-0.0856	0.0204	99.2	-4.1870	0.0019**
medium + one	medium + three or more	-0.0754	0.0145	99.2	-5.1970	<.0001***
medium + one	long + three or more	-0.1547	0.0204	99.2	-7.5990	<.0001***
long + one	short + two	0.0093	0.0207	99.2	0.4510	1.0000
long + one	medium + two	0.0195	0.0207	99.2	0.9420	0.9899

long + one	long + two	-0.0598	0.0145	99.2	-4.1200	0.0025**
long + one	short + three or more	-0.0063	0.0207	99.2	-0.3050	1.0000
long + one	medium + three or more	0.0039	0.0207	99.2	0.1860	1.0000
long + one	long + three or more	-0.0754	0.0145	99.2	-5.1970	<.0001***
short + two	medium + two	0.0102	0.0144	99.2	0.7060	0.9986
short + two	long + two	-0.0691	0.0145	99.2	-4.7630	0.0002***
short + two	short + three or more	-0.0156	0.0144	99.2	-1.0860	0.9750
short + two	medium + three or more	-0.0055	0.0204	99.2	-0.2690	1.0000
short + two	long + three or more	-0.0848	0.0204	99.2	-4.1460	0.0022**
medium + two	long + two	-0.0793	0.0145	99.2	-5.4630	<.0001***
medium + two	short + three or more	-0.0258	0.0204	99.2	-1.2670	0.9386
medium + two	medium + three or more	-0.0156	0.0144	99.2	-1.0860	0.9750
medium + two	long + three or more	-0.0949	0.0204	99.2	-4.6430	0.0004***
long + two	short + three or more	0.0535	0.0204	99.2	2.6170	0.1931
long + two	medium + three or more	0.0637	0.0204	99.2	3.1140	0.0585
long + two	long + three or more	-0.0156	0.0144	99.2	-1.0860	0.9750
short + three or more	medium + three or more	0.0102	0.0144	99.2	0.7060	0.9986
short + three or more	long + three or more	-0.0691	0.0145	99.2	-4.7630	0.0002***
medium + three or more	long + three or more	-0.0793	0.0145	99.2	-5.4630	<.0001***

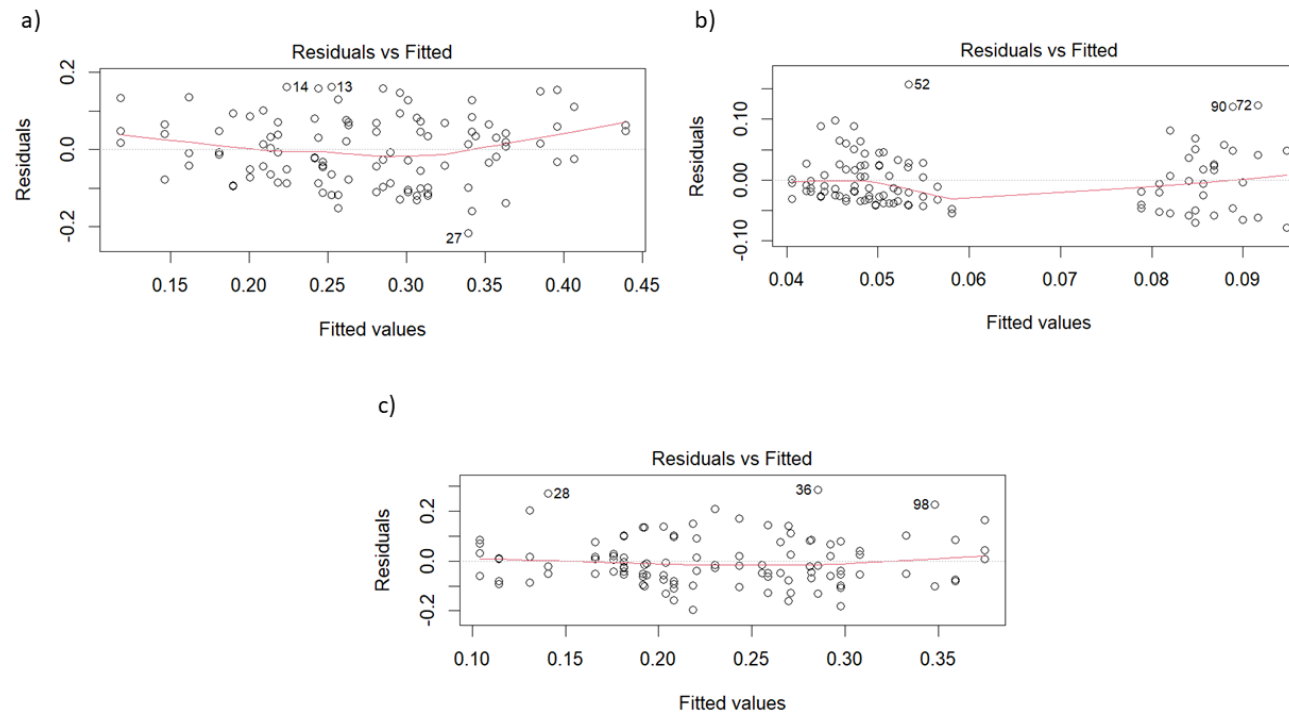
Signif. codes: p <0.05 ' * ' / p<0.01 ' ** ' p<0.001 ' *** ' ,

Figure S1. Plot of the residual normality distribution.



Representation of the residual normality distribution in model: a) inactivity, b) abnormal and self-directed behaviour and c) affiliative and social proximity.

Figure S2. Plot of the residual vs. fitted values.



Representation of the residual vs. fitted values in model: a) inactivity, b) abnormal and self-directed behaviour and c) affiliative and social proximity.