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RESEARCH ARTICLE

Anterior insular cortex plays a critical role in interoceptive attention

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Abstract Accumulating evidence indicates that the anterior insular cortex (AIC) mediates interoceptive attention which refers to attention towards physiological signals arising from the body. However, the necessity of the AIC in this process has not been demonstrated. Using a novel task that directs attention toward breathing rhythm, we assessed the involvement of the AIC in interoceptive attention in healthy participants using functional magnetic resonance imaging and examined the necessity of the AIC in interoceptive attention in patients with AIC lesions. Results showed that interoceptive attention was associated with increased AIC activation, as well as enhanced coupling between the AIC and somatosensory areas along with reduced coupling between the AIC and visual sensory areas. In addition, AIC activation was predictive of individual differences in interoceptive accuracy. Importantly, AIC lesion patients showed disrupted interoceptive discrimination accuracy and sensitivity. These results provide compelling evidence that the AIC plays a critical role in interoceptive attention.

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Introduction

Our brain constantly [illegible] physiological signals arising from sensor inputs in our body. Although attention toward inputs from the external environment [illegible]. Interoceptive attention has been intensively [illegible] the attention [illegible] of the [illegible] conscious focus on bodily somatic and visceral signals or responses [illegible]. Interoceptive attention has been less studied due to difficulties in its measurement (*Brener and Ring, 2016*; *Ring et al., 2015*; *Craig, 2002*; *Craig, 2003*; *Craig, 2010*; *Critchley, 2005*; *Critchley, 2004*; *Farb et al., 2013a*). Previous theories suggest that subjective emotions arise from the bodily reactions and visceral experiences

(Cannon, 1987; Critchley and Harrison, 2013; Damasio, 1996; Dolan, 2002; Tranel and Damasio, 1994) in which interoceptive awareness plays a central role. Appropriate attention to bodily states and accurate perception of interoceptive information are essential in generating emotional awareness and in the maintenance of normal physiological conditions (Craig, 2002; Craig, 2003; Craig, 2010; Critchley, 2005; Wiens, 2005). The link between deficits in interoceptive attention and psychiatric symptoms may also be explained by the James-Lange theory of emotion (Cannon, 1987), the somatic marker hypothesis (Damasio, 1996; Damasio et al., 1991) or the three-dimensional model of interoception (Garfinkel and Critchley, 2013) and the more recent predictive processing model (Allen et al., 2016; Allen and Friston, 2018; Barrett and Simmons, 2015; Seth, 2013; Seth and Critchley, 2013; Seth et al., 2011).

A recent number of studies have emphasized the role of the insula in interoceptive representations (Daubenmier et al., 2013; Farb et al., 2013b; Ronchi et al., 2015). Neuroanatomical evidence, consistent with neuroimaging findings, suggests that the anterior insular cortex (AIC) is an important structure for the generation of feelings and representing interoceptive information (Craig, 2002; Craig, 2003; Craig, 2009; Critchley et al., 2004; Stephani et al., 2011). Although the AIC has been recognized as an interoceptive cortex (Craig, 2003; Critchley et al., 2004; Ernst et al., 2014; Singer et al., 2009; Terasawa et al., 2013), the region is frequently activated, and AIC activation seems ubiquitous across a wide range of tasks involving cognition, emotion and other cognitive processes in addition to interoceptive attention (Allen et al., 2013; Seeley et al., 2007; Uddin et al., 2014; Yarkoni et al., 2011). Therefore, tasks that actively and reliably engage interoceptive attention need to be employed. In addition, the correlational AIC activation found in functional neuroimaging studies alone does not provide causal evidence for its role in interoceptive attention, leaving the question of whether the AIC is critical in interoceptive attention unanswered. Studying patients with focal lesions in the AIC (Gu et al., 2012; Gu et al., 2015; Ronchi et al., 2015; Starr et al., 2009; Wang et al., 2014; Wu et al., 2019) would thus provide a unique opportunity to examine the necessity of the AIC in this fundamental process.

One challenge to the study of interoceptive attention is the vague nature of interoceptive processes. According to the classical definition of attention by James (1890) only those elements that are clearly perceived and represented by the mind are the target of attention. However, most existing tasks measuring interoceptive attention fail to meet this criterion (Ring et al., 2015). In contrast to exteroceptive attention toward external sensory inputs, precise measurements of interoceptive attention are difficult to obtain experimentally due to the imprecise perception of visceral changes such as heart rate (Brener and Ring, 2016; Paulus and Stein, 2010; Ring et al., 2015; Windmann et al., 1999). Multiple sources of bodily information contribute to bodily signals, and most of these sources of somatic changes cannot be accurately captured by introspection in normal physiological states (Ring et al., 2015). This limitation impedes accurate measurement of interoceptive attention and examination of the neural mechanisms underlying this process. To overcome this barrier, perceivable visceral changes need to be used.

Breathing is a sensation that humans can easily perceive. As an autonomous vital movement, breathing can be actively controlled in humans (Daubenmier et al., 2013; Davenport et al., 2007). The unique physiological characteristics of respiration render breath an ideal target for measuring interoceptive accuracy and sensitivity (Garfinkel et al., 2015) and for exploring the neural activity underlying interoceptive attention. Thus, we designed a breath detection task to measure interoceptive attention (attention to bodily signals), in which participants were required to indicate whether the presented breathing curve is delayed or not relative to their own breathing rhythm (breath detection task, BDT), in contrast to exteroceptive attention (attention to visual signals), in which participants were required to indicate whether the visual dot stimulus is delayed relative to the breathing curve (dot detection task, DDT). This design enabled us to examine the involvement of the AIC in interoceptive processing in healthy participants and the necessity of the AIC in this processing in patients with AIC lesions.

Based on previous evidence, Critchley (2004) hypothesized that the AIC is critical for interoceptive attention to the subjective awareness by integrating information from an individual's homeostatic state and the external environment. We first conducted functional magnetic resonance imaging (fMRI) studies with two samples to map the neural substrates underlying interoceptive attention to internal bodily signals in contrast to exteroceptive attention toward external visual signals in

[illegible]

Results

Behavioral results of the fMRI studies

[illegible]

[illegible]

Imaging results of the whole brain analysis of the first fMRI study

Main effects of interoceptive attention and feedback delay, and their interaction

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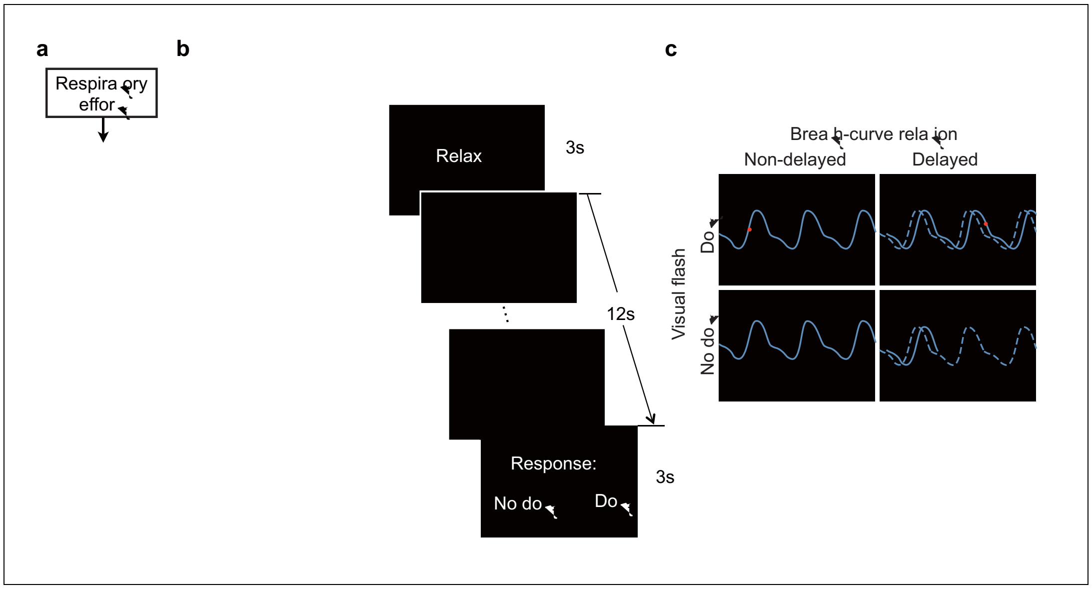

[illegible] FEF [illegible] *Figure 2a* [illegible] *Table 3*). In [illegible] ition [illegible] *Raichle et al., 2001* [illegible]

[illegible] AIC [illegible] *Figure 2b* [illegible] *Table 4*). [illegible] BD [illegible] DD [illegible] *Figure 2c* [illegible] *Table 5*). [illegible] AIC [illegible] *Figure 2d*). In [illegible] AIC [illegible] BD [illegible] DD [illegible] AIC [illegible] BD [illegible] AIC [illegible] AIC [illegible]

Table 1. t ti [illegible] s o [illegible] vior l [illegible] sults o t [illegible] l stu [illegible] s.

		First sample			Second sample		
		Df	T	Cohen's d	Df	T	Cohen's d
acc racy	intero s. 0.5	43	4.5 ***	2. 8	27	3.77***	2.59
	intero s. extero	43	−2.36*	0.35	27	– .83	0.35
d'	intero s. 0	43	3.09***	2.0	27	2.89***	2.67
	intero s. extero	43	-2.3 *	0.35	27	-2.83**	0.50
β	intero s. extero	43	−2.3 *	0.35	27	−2.83**	0.50
RT	intero s. extero	43	2.89**	0.44	27	0.6	0. 2

* p<0.05; **p<0.0 ; ***p<0.00 .

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Table 2. [illegible] rso [illegible] or [illegible] l tio [illegible] nts [illegible] n B [illegible] s [illegible] tors [illegible] n t [illegible] vior l [illegible] su [illegible] nts or t [illegible] irst t [illegible] on n [illegible] ross t [illegible] two s [illegible] s.

		Relative accuracy	Subjective difficulty	BPQ	Positive PANAS	HAMA	BDI
	Relati e acc racy	-					
st sample	S bjecti e diffic lty	−0.43** (0.38)	-				
	BPQ	0.27 (0. 7)	−0. 5 (0.29)	-			
	Positi e PA AS	0.3 (.38)	−0.04 (0. 9)	−0.006 (0. 9)	-		
	HA A	−0.006 (0. 9)	−0. 4 (0.28)	0.25 (0.69)	−0. 2 (0.25)	-	
	BD	−0.002 (0. 9)	−0.004 (0. 9)	0. 6 (0.32)	−0.06 (0.20)	0.70*** (> 00)	-
	Relati e acc racy	-					
2nd sample	S bjecti e diffic lty	-	-				
	BPQ	−0. 7 (0.33)	-	-			
	Positi e PA AS	0. 2 (0.27)	-	0.07 (0.25)	-		
	HA A	0.29 (0.69)	-	0.40 (.90)	−0.034 (0.24)	-	
	BD	0.034 (0.24)	-	0.075 (0.25)	−0.43 (2.84)	0.47* (4.96)	-
	Relati e acc racy	-					
st + 2nd samples	S bjecti e diffic lty	-	-				
	BPQ	0.06 (0. 7)	-	-			
	Positi e PA AS	0.25 (. 6)	-	0.03 (0. 5)	-		
	HA A	0. 2 (0.25)	-	0.3 * (4.9)	−0.09 (0.20)	-	
	BD	0.008 (0. 5)	-	0. 4 (0.28)	−0.20 (0.56)	0.60*** (> 00)	-

* corrected p<0.05; ** corrected p<0.0 ; *** corrected p<0.00 ; al e in brackets represents Bayes factor. BPQ, body perception q estionnaire; PA AS, positi e and negati e affecti e sched le; HA A, Hamilton anxiety scale; BD , Beck depression in entory.

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Correlation bet een interocepti e acc racy and A C acti ation

o l-wi ssion n l sis t l tionship n t int pti t s -in ti-v tion st t p o t int tion ontr st n p i ip nts int pti u p r or-m u in t BD wit pti u p r or m u in t DD ontroll s ov ri . H r int pti u w s s i wit r int tion t o t r l AIC n G ross p i ip nts *Figure 3a Table 6*. AIC tiv tion ur-in t int pti p ssin involv t n in to p siol i l s n ls n m t in il s n ls to rn l visu l input i p i in ivi u l i s in int pti t ntion *Figure 3b*

Table 3. A tiv tion n tiv tion o t in ions involv in in ptiv ntion in ption ption.

Region	L/R	BA	MNI X	Y	Z	T	Z	K
Positi e								
Cerebel m cr s			−30	−70	−24	3.02	nf.	73834
Middle occipital gyr s	R	9	32	−68	22	.99	nf.	
Cerebel m cr s			−20	−78	−48	.72	7.80	
nferior frontal gyr s	R	44	52	4	24	.24	7.63	
nferior parietal lob le	R	40	36	−48	44	. 9	7.62	
nferior parietal lob le		40	−38	−46	42	0.4	7.32	
Postcentral gyr s	R	2	46	−40	54	0.29	7.27	
S pramarginal gyr s	R	40	48	−34	42	0.00	7. 5	
S perior occipital gyr s	R	7	22	−72	46	9.99	7. 5	
Cerebel m V B			−32	−70	−52	9.78	7.06	
S perior parietal lob le (ntraparietal s lc s)	R	7	6	−78	52	9.69	7.02	
Cerebel m V	R		22	−74	−50	9.6	6.99	
Middle frontal gyr s		46	−44	50	2	9.20	6.80	
Middle frontal gyr s	R	46	42	42	24	9. 6	6.78	
S pplementary motor area	R	6	8	4	76	8.92	6.68	
nferior occipital gyr s	R	37	52	−66	− 2	8.68	6.56	
Cerebel m cr s	R		2	−76	−36	8.66	6.56	
Middle occipital gyr s (ntraparietal s lc s)	R	9	32	−76	34	8.58	6.52	
Thalam s	R		8	−20	20	8.55	6.50	
nferior temporal gyr s	R	20	56	−38	−20	8.4	6.43	
nferior frontal gyr s	R	45	44	38	2	8.3	6.38	
S perior parietal lob le (ntraparietal s lc s)		7	−20	−72	46	8.2	6.33	
S pplementary motor area		6	-2	-4	74	8.08	6.27	
nferior frontal gyr s		44	−54	2	26	8.07	6.26	
Ca date	R		6	-8	24	7.89	6. 7	
Anterior cing late cortex	R	32	2	8	44	7.78	6. 2	
Vermis			-2	−74	− 2	7.76	6. 0	
Middle frontal gyr s	R	46	50	4	40	7.75	6. 0	
Middle frontal gyr s		46	−40	34	34	7.72	6.08	
S pramarginal gyr s		40	−60	−36	28	7.47	5.95	
Middle frontal gyr s	R	6	28	2	48	7.0	5.69	
Anterior ins lar cortex	R		34	20	4	6.98	5.68	
Postcentral gyr s		2	−62	−26	36	6.87	5.62	
nferior frontal gyr s		6	−52	8	2	6.84	5.59	
S perior frontal gyr s		6	−26	4	66	6.73	5.53	
Middle occipital gyr s (ntraparietal s lc s)		7	−24	−66	36	6.66	5.49	
ing al gyr s		8	− 8	−90	− 8	6.6	5.46	
S perior parietal lob le			−24	−44	72	6.55	5.42	
Ca date			-8	22	4	6.45	5.37	
Precentral gyr s		6	−40	2	56	6.23	5.23	
S perior occipital gyr s		8	−22	−92	28	6.20	5.2	
Middle occipital gyr s		8	−24	−94	6	6.09	5. 4	

Table 3 continued on next page

Table 3 continued

Region	L/R	BA	MNI X	Y	Z	T	Z	K
iddle occipital gyr s	R	8	30	−86	6	6.09	5. 4	
F siform gyr s		37	−46	−46	−22	5.82	4.97	
Anterior ins lar cortex			−30	20	8	5.50	4.76	
C ne s		9	0	−88	34	5.22	4.57	
S perior parietal lob le		5	− 8	−60	66	5. 8	4.54	
F siform gyr s	R	37	44	−32	−20	4.96	4.39	
egati e								
Anterior cing late cortex	R	32	4	38	-4	7.47	5.95	3232
Anterior cing late cortex		32	-6	38	-4	7. 0	5.94	
S perior frontal gyr s		9	− 6	38	54	5.97	5.07	
edial s perior frontal gyr s	R	32	0	52	20	5.33	4.65	
edial s perior frontal gyr s		32	-8	50	26	5.32	4.63	
iddle frontal gyr s		8	−24	30	56	5. 2	4.50	
S perior frontal gyr s		9	−20	32	48	4.54	4.08	
Prec ne s		23	− 0	−44	40	6.45	5.37	8 9
Prec ne s	R	23	6	−60	24	4.24	3.85	
iddle temporal gyr s		2	−60	− 0	− 4	5.89	5.02	787

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t ntion (*Figure 4b*). imil r [illegible] sults [illegible] o [illegible] in [illegible] n t [illegible] t AIC [illegible] s [illegible] s t [illegible] (*Figure 4—figure supplement 1*). n t [illegible] sis o t [illegible] sults Cs o t [illegible] t [illegible] = [illegible] z = [illegible] s in [illegible] positi [illegible] in t n [illegible] us l mo [illegible] DC [illegible] mo l. D t rom o p [illegible] ip nt [illegible] lu [illegible] us [illegible] nt [illegible] tiv tion in t [illegible] ion o in [illegible] oul not [illegible] i nti [illegible]. For mo [illegible] o p rison r n- om [illegible] ts (FX B [illegible] si n mo l [illegible] tion (B [illegible] in [illegible] t t t [illegible] innin [illegible] mo l [illegible] n [illegible] pro [illegible] o [illegible] s t o [illegible] mo ul tor [illegible] ts o in [illegible] ptiv [illegible] n

Table 4. A tiv tion n [illegible] tiv tion o t [illegible] in [illegible] ions involv in [illegible] – non- [illegible] l.

Region	L/R	BA	MNI X	Y	Z	T	Z	K
Positi e								
Anterior ins lar cortex	R		30	26	-4	5.26	4.60	6 8
nferior frontal gyr s	R	45	42	22	8	4.40	3.98	
Ca date	R		8	24	4	4.29	3.90	
nferior parietal lob le		40	−38	−54	42	5.23	4.58	598
Ang lar gyr s	R	39	44	−44	30	4.99	4.4	3 7
nferior parietal lob le	R	40	56	−54	44	4. 7	3.80	
iddle frontal gyr s	R	6	34	8	46	4.78	4.26	780
iddle frontal gyr s	R	9	34	8	34	4.74	4.23	
iddle frontal gyr s	R	46	34	28	32	4.32	3.92	
egati e								
ing al gyr s		7	− 0	−78	-4	6.2	5.22	443

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Table 5. A tiv tion o in ions l to t int tion t n int ptiv t ntion n – non- l int ption –[l – non- l ption .

Region	L/R	BA	MNI X	Y	Z	T	Z	K
Positi e								
Anterior ins lar cortex	R		28	28	0	5.52	4.77	5 6
nferior frontal gyr s	R	47	40	26	– 0	4.66	4. 7	
iddle frontal gyr s	R	9	40	4	40	5.36	4.67	2330
S pplementary motor area	R	8	4	22	54	5. 9	4.55	
Anterior cing late cortex	R	32	6	36	38	5. 2	4.5	
S perior frontal gyr s	R	8	6	30	44	4.7	4.2	
nferior frontal gyr s	R	45	46	22	6	4.50	4.05	
iddle frontal gyr s	R	6	34	4	52	4.27	3.88	
S pplementary motor area		6	– 2	8	52	3.64	3.38	
Anterior cing late cortex	R	32	0	30	28	3.49	3.25	
S pramarginal gyr s	R	40	54	–46	26	4.9	4.35	748
iddle temporal gyr s	R	2	66	–32	– 0	4.70	4.20	
nferior parietal lob le	R	9	60	–48	42	4.56	4. 0	
S perior temporal gyr s	R	42	58	–40	6	4.49	4.04	

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ptiv t ntion (BD n DD rtin on t on tion rom t AIC to t oCG n rom t AIC to (*Figure 4c* n *Figure 4—figure supplement 2*). B in t t int r- ptiv n ptiv t ntion throu mo ul tin t top- own on tivit rom t AIC to t two nso s.

p r orm p r r in usin B si n mo l r in (B A) onsi rs t int poolin in orm tion ross ll mo ls in sion (*Stephan et al., 2010*). For B A (*Figure 4d*) t mo ul tor t o int ptiv t ntion (BD) s s ni nt on t on tion rom t AIC to t oCG (= . Bon rro or p). mo ul tor t o ptiv t ntion (DD) on t on tion rom t AIC to t s s ni nt witout or tion (= p=). B A sults onsist nt wit t win- nin mo l mo omp rison n t sults: t mo ul tor t rom t AIC to t oCG s riv n int ptiv t ntion (BD) s t mo ul tor t rom t AIC to t s riv n ptiv t ntion (DD). In ition t B A sults t import o t intrinsi on tion rom t AIC to t oCG in t t- wor (= Bon rro or p=).

Region-of-interest (ROI) analysis results of the second fMRI study

int tion n t ntion l us (int ptiv l in BD n ptiv l in DD) n (wit n witout l) s s ni nt in t t n t AICs t: (= p= ; t: (= . p= ; *Figure 5a*) on irm t int tion t in t l AIC n in l s o t irst s mp . m in t o t ntion l us (BD vs. DD) s s ni nt in t t AIC wit tiv tion urin t BD t n ur- in t DD (= . p=) t not s ni nt in t t AIC (p=). m in t o t s not s ni nt in it r t or t AIC t: F t: F . In ition simil r to t sults o t irst s mp oun s ni or l tion n t int tion t o t t n t AICs n l tiv int ptiv u t: rson r = p= on -t i t: rson r = p= on -t i *Figure 5b*). In ition p t rn o t spir tor volu un r BD n DD (*Figure 5—figure supplement 1*). spi t i in t spir tor volu n int ptiv n ptiv on itions (BD n DD s s ni nt (= . p this i out or t

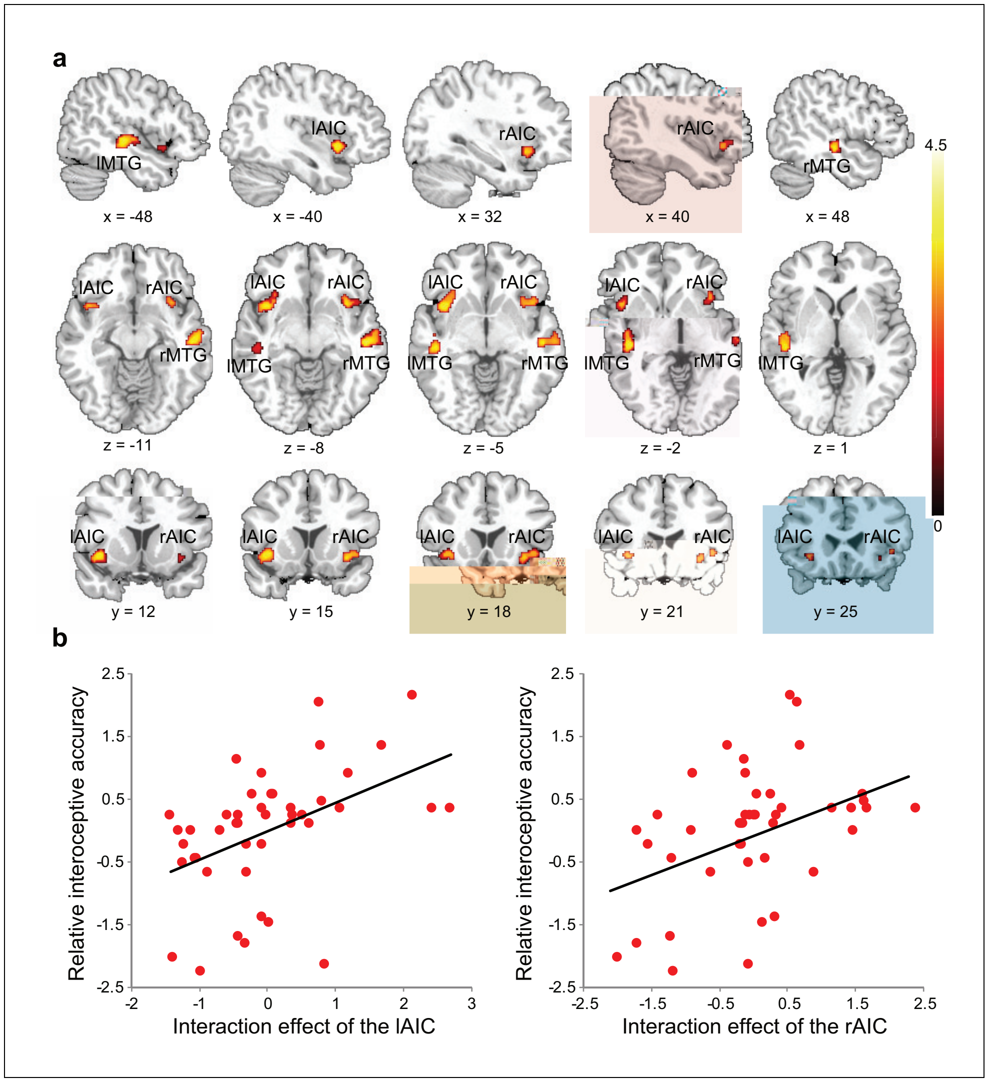

Figure 3. Relationship bet een brain acti ation and beha ioral performance across participants. (**a**) This as re ealed in a regression analysis of contrast images for the interaction bet een interocepti e attention deployment (BDT s. DDT) and breath c r e feedback condition (delayed s. no-delayed), ith performance acc racy on interocepti e and exterocepti e tasks as regressor-of-interest and co ariate, respecti ely. A C, anterior ins lar cortex; TG, middle temporal gyr s. (**b**) Correlational patterns bet een the interaction effect of bilateral A C acti ation and relati e interocepti e acc racy. Data ere normalized as z-scores.

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The follo ing so rce data is a ailable for fig re 3:

Source data 1. CSV file containing data for ***Figure 3b***.

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int tion t F . sults urt r illustr t t int tion t in t AIC is not su t to t on oun in o t in ort i n t nt t o t s.

in n l sis o t on l s mpl s ni nt o rl p t n t tiv tions wit out n wit p siolo i or tion or t in n t int tion ts ***Figure 5—figure supplement 2***. urt o n p siolo i l noi im AIC tiv tion o p rin t ontr st ps wit out n wit p siolo i or tion t n t l p rmissiv t s ol p on or . i n in n ls o t AIC t n t n l s wit n wit out p siolo i or tions w s onl vi nt or t m in t o int pti vs. pti t ntion BD vs. DD t not or t int tion ontr st on irmin t t t interaction effect of the AIC was not significantly improved by the physiological noise (see *Figure 5—figure supplement 3*). Although the results from the above comparison imply that the AIC was selectively engaged in interoceptive processing.

Lesion study results: the necessity of the AIC in interoceptive attention

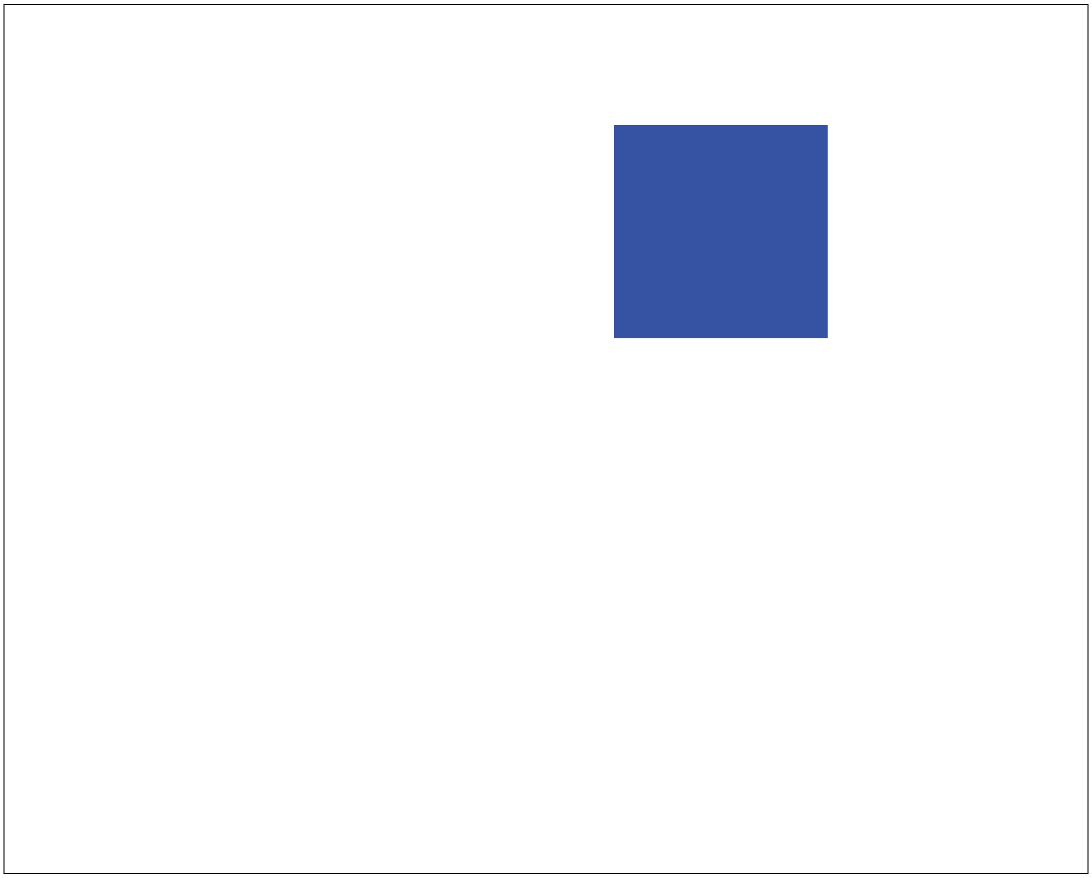
Figure 6 shows the insular lesion overlap for the AIC patient group. The region with the most overlap was similar to the AIC reported in the literature (*Kurth et al., 2010*; *Naidich et al., 2004*). We found a significant interaction effect between group (AIC, BDC and NC) and task (BD and DD) in performance accuracy (F [illegible] = [illegible], p = [illegible]) and discrimination sensitivity (d') (F [illegible] = [illegible], p = [illegible]). Simple comparisons were conducted between groups over tasks. For the BD task, patients with AIC lesions had significantly lower performance accuracy (t [illegible] = −[illegible], p [illegible], BF = [illegible] compared with NC; t [illegible] = −[illegible], p = [illegible], BF = [illegible] compared with BDC) (*Figure 7a*) and discrimination sensitivity (d') compared with the NCs and BDCs groups (t [illegible] = −[illegible], p [illegible], BF = [illegible] compared with NC; t [illegible] = −[illegible], p = [illegible], BF = [illegible] compared with BDC) (*Figure 7b*), indicating diminished interoceptive attention. However, there was no significant difference in accuracy between the NC and BDC groups (t [illegible] = [illegible], p = [illegible]; d': t [illegible] = [illegible], p = [illegible]). For the DD task, the patients with AIC lesions did not show significant abnormalities in performance accuracy (AIC vs. NC: t [illegible] = [illegible], p = [illegible], BF = [illegible]; AIC vs. BDC: t [illegible] = −[illegible], p = [illegible], BF = [illegible]) and in d' (AIC vs. NC: t [illegible] = [illegible], p = [illegible], BF = [illegible]; AIC vs. BDC: t [illegible] = −[illegible], p = [illegible], BF = [illegible]) compared with the NC and BDC groups. There was no significant interaction effect on β (F [illegible], p = [illegible]) (*Figure 7d–f*). A summary of the statistical results of the lesion study is provided in *Table 8*. Our results demonstrate significant impairment in discrimination ability when attending to bodily signals but not to external visual input in patients with AIC lesions.

Discussion

Using fMRI, we showed that the AIC is involved in interoceptive attention towards respiration with the functional connectivity between the AIC and the somatosensory cortex and visual areas modulated by interoceptive and exteroceptive attention, respectively. To [illegible] on the necessity of the AIC in supporting interoceptive attention by showing reduced behavioral performance on the interoceptive tasks in patients with focal AIC lesions. Thus, this study demonstrates that the AIC plays a critical role in interoceptive attention.

The necessity of the AIC in interoceptive attention

Previous functional neuroimaging studies have shown that the insula is active during autonomic arousal and emotional functions (*Craig, 2002*; *Craig, 2003*; *Critchley et al., 2004*) and emphasize the central role of the insula in interoceptive processes. The engagement of interoceptive processes depends on the integration of ascending bodily signals with higher-order contextual information attributed to [illegible]. [illegible] attribute



[illegible] signals. Most importantly, participants' performance during the interoceptive task was significantly correlated with the activation of the AIC, further demonstrating the involvement of the AIC in interoceptive attention.

Anatomically, the insula receives thalamo-insular projections of the interoceptive pathways (Craig, 2002). The AIC [illegible] subjective feelings (Craig, 2003; Craig, 2009; Flynn, 1999) and is critical for instantaneous representation of the state of the body (Allen et al., 2016; Allen and Friston, 2018; Cao et al., 2014; Gu et al., 2015). During the [illegible]BD, this is [illegible] then in [illegible] to [illegible] signals ([illegible]). [illegible] ment [illegible] the [illegible] to [illegible] ernal visual [illegible] ([illegible]). The [illegible] ury). The present results provide additional support to previous findings that the activation of the

Table 7. Positive ... activation ... AIC ... [illegible]

Region	L/R	BA	MNI X	Y	Z	T	Z	K
Positi e								
nferior frontal operc l m	R	44	52	8	26	7.49	5.96	5895
Precentral gyr s	R	6	58	0	36	6.7	5.52	
ns la cortex	R		38	0	4	6.35	5.30	
P tamen	R		20	8	0	6.33	5.29	
Rolandic operc l m	R	48	48	4	0	6.0	5.09	
Ca date	R		8	0	4	5.86	5.00	
nferior frontal gyr s	R	45	42	36	0	4.35	3.94	
Postcentral gyr s	R	43	58	– 6	32	6.95	6.55	2078
S pramarginal gyr s	R	2	66	–22	34	6.04	5.	
S perior temporal gyr s	R	42	62	–32	20	5.28	4.6	
Precentral gyr s		6	–58	0	30	6.89	5.63	55
P tamen			–20	0	2	6.04	5.	
S pplementary motor area		6	-8	-4	64	5.90	5.02	
Ca date			-8	6	2	5.4	4.70	
Triangle nferior fronal gyr s		48	–38	32	24	5.2	4.56	
S perior temporal gyr s		44	–48	–42	24	5. 9	4.55	
ns la cortex			–36	-2	8	5. 9	4.55	
S pplementary motor area	R	6	4	4	64	5. 9	4.55	
S pramarginal gyr s		2	–56	–28	40	5. 3	4.50	
S perior frontal gyr s		6	–24	-2	58	4.73	4.22	
Postcentral gyr s		3	–56	–20	34	4.53	4.07	
Middle frontal gyr s		6	–28	-8	52	4.48	4.04	
Middle temporal gyr s	R	37	48	–60	8	5.44	4.72	569
Cerebel m V b			– 6	–74	–48	4.95	4.38	427
Cerebel m V			–24	–66	–52	4.75	4.24	
egati e								
C ne s		7	– 0	–96	6	7.30	5.85	5904
C ne s	R	8	4	–90	28	6.80	5.40	
ing al gyr s	R	8	4	–62	-2	6.05	5.	
ing al gyr s		8	– 8	–74	-8	5.26	4.60	
Calcarine		8	0	–76	8	5.	4.49	
F siform gyr s		8	–24	–80	– 6	4.95	4.38	
Calcarine	R	7	20	–54	6	4.72	4.22	
Cerebel m Cr s			–38	–78	– 8	4.37	3.95	
Middle occipital gyr s		8	– 6	–86	-4	4.22	3.84	

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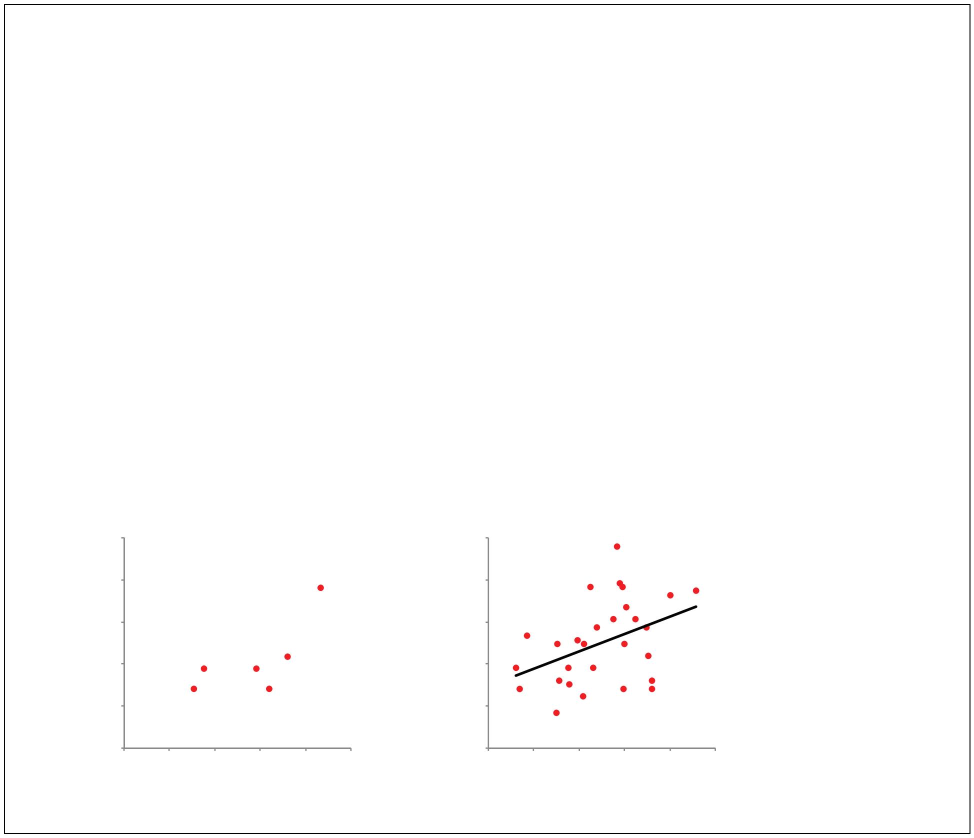
r t AIC is ... to ... in ... nsi ... t ... ti ... o ... il s n ls o ... t (*Critchley et al., 2004*). Consist nt wit t notion t t t AIC ontri ... s to ... ur ... ption o ... il st t s (*Bechara and Naqvi, 2004*) t insul wor s s ... ony ... il in or tion into int rn l ... li ... s or int ini ... ost sis n to ... i ... t ... nt tions o ... r l st t s t t lin to t ... nt tions o t ... rn l worl (*Farb et al., 2013a*).

ur in i ... o ... l ro o t AIC in int ... pti ... t ntion its wit ... nt p ... ti ... o - i ... ount o t ... in (*Bastos et al., 2012*; *Friston and Kiebel, 2009*; *Rao and Ballard, 1999*)



ever, suggests that the brain actively tries to predict possible future states and to minimize the discrepancy between actual and predicted states. In the context of interoceptive and emotional predictive coding (*Allen and Friston, 2018; Gu et al., 2013*), previous studies hypothesize that interoceptive predictions are computed within a network of brain regions with the AIC as the key node (*Allen et al., 2016; Barrett and Simmons, 2015; Seth, 2013*). Empirical evidence that directly supports this computational role of the insula is still rare. A previous study using [illegible] per- form and DCM [illegible] demonstrated that the AIC is the only region among a network of [illegible] brain regions that shows [illegible] in connectivity with the somatosensory cortex (*Allen et al., 2016*). Our finding is consistent with this previous study and extends the

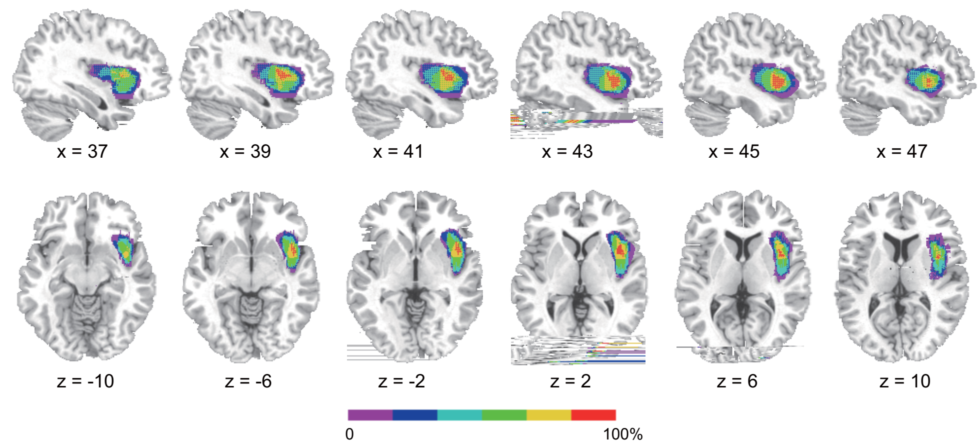


Figure 6. Reconstr ction of anterior ins lar cortex lesions of six patients. Red color indicates 00% o erlap. eft lesions ere flipped to the right side to map the lesion o erlap.

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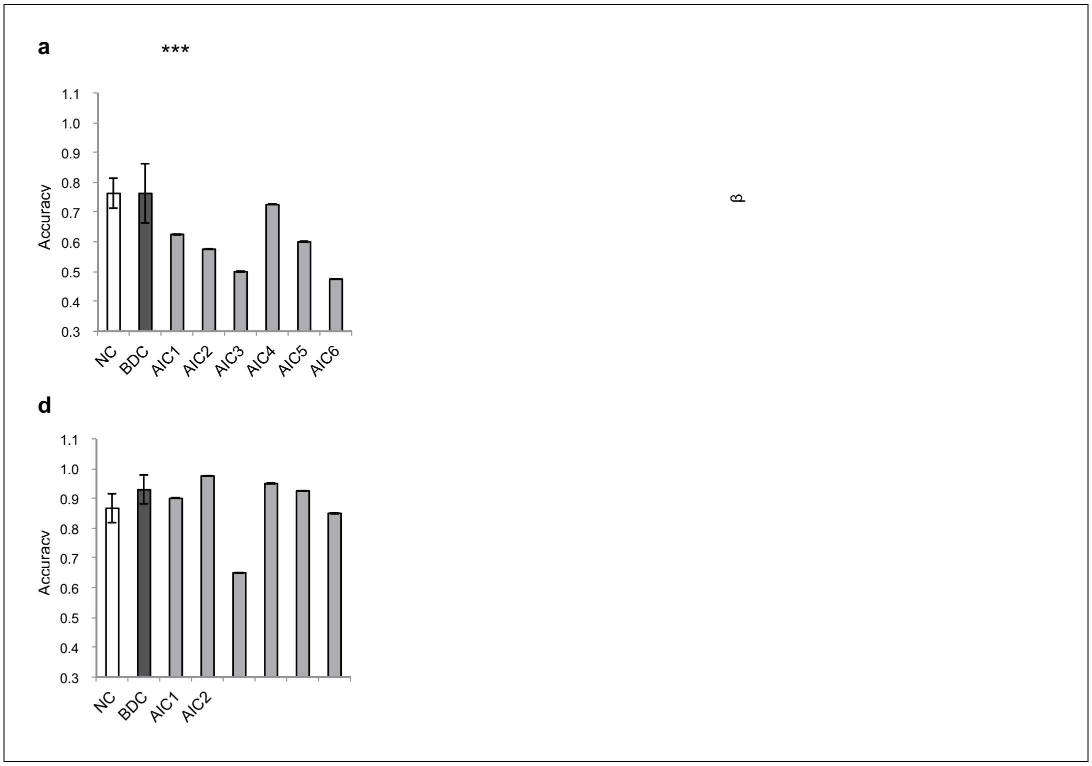
ro o t AIC in pr i ti o i to t i l in ption usi t l n sion ppr s.

ro o t AIC in in ptiv ntion i nti t l stu s s nt t t ro p ti nts wit l to t insul . l ti to non-insul r sion p ti nts n lt ontrols AIC sions to i it in u n nsitivit o in ptiv ntion. in i s provi us l vi monstr ti t i l ro o t AIC in in ptiv ntion. ition ll t insul ort onsi s li nsor ion t t p i ip s in t intuiti p ssi o ompl situ tions (*Augustine, 1996*; *Butti and Hof, 2010*; *Menon and Uddin, 2010*) in r ti t s n i is ro motor n so to nsor inputs wit ntion s s ms vi intrin on tivit to i nti n spon to s i nt sti uli (*Menon and Uddin, 2010*; *Uddin, 2015*). AIC in p i ul r is no t t i niti p ss s in lu i tto u ontrol o ntion (*Corbetta et al., 2002*; *Corbetta et al., 2008*; *Wu et al., 2015*) n on ious tion o s n ls risi ro t utono i rvous s s m (*Craig, 2002*; *Critchley, 2004*). o t vior l i it o in ptiv ntion in p ti nts wit AIC sions is to t isruption in t in r tion o t so i n r l inputs wit t t pr n t tion o t pr nt in rn l st . t s i o rt in t p o s n l . Con qu ntl it s to ilu in is rimin ti w t r t ispl spir tor ury is i nt ro in rn l st s.

ost pr vious sion stu s in i in ptiv i its wit AIC sions (*Critchley and Garfinkel, 2017*; *García-Cordero et al., 2016*; *Ibañez et al., 2010*; *Ronchi et al., 2015*; *Starr et al., 2009*; *Terasawa et al., 2015*; *Wang et al., 2014*) supporti t lusion t t in ptiv u s on wi l istri t wor wit t insul ort s no (*Craig, 2002*; *Critchley and Harrison, 2013*). How r t pr rv tions o in ptiv p ssi (*Khalsa et al., 2009*) n l- w ss ross l ts r o sts (*Philippi et al., 2012*) w u nt in on p ti nt wit r l insul r s. stu s mostl on su tiv port usi on li w ss (*Khalsa et al., 2009*) t t o ns t ot r in stu s s t inst n su i l stu s or p us t tus solit s t p r i l us poste n pot l mus (*Damasio et al., 2013*) ront l n mpor l ions or p l sup rior mpor rus n mpor l po (*García-Cordero et al., 2016*; *Shany-Ur et al., 2014*). In t ur nt stu t BD in ptiv ntion t t qui s t in r tion o in ptiv w ss n u . ur min tion o in ptiv ntion in p ti nts wit l AIC sions s t t sions o t AIC w i- wit i it in r orm in i ti t t t AIC i l in supporti t ision o in ptiv p ssi .



Mechanisms of the AIC in relation to interoceptive attention

Interoceptive attention is the mechanism that coordinates the processing of bodily signals and higher level representation of that information. The AIC reportedly encodes and represents bodily information (...). This region also then transmits this information to other neural systems for higher computations in conscious perception and decision-making (*Bechara and Naqvi, 2004; Flynn, 1999*).

AIC2

Gu and FitzGerald, 2014). The AIC is a key node of the salience network that integrates information from multiple sources, including affective, cognitive, and visceral signals, for subjective awareness (Craig, 2009; Gu et al., 2012; Gu et al., 2015; Kleckner et al., 2017; Seeley et al., 2007) and responds to the switch between networks that supports internal oriented processing and cognitive control (Menon, 2011; Menon and Uddin, 2010; Sridharan et al., 2008). Supporting this argument, we showed that the AIC is intrinsically connected to the somatosensory and the poCG and that this connection is positively modulated by interoceptive attention relative to exteroceptive attention.

On the other hand, areas such as the dmPFC, the ACC, the FEF and IFG of the so-called cognitive control network (CCN) (Fan, 2014; Wu et al., 2018) were also involved in the interoceptive process. This is supported by the results of the enhanced connection and connectivity between the AIC and these regions. Both somatosensory areas and the network that include the AIC and the ACC are possible pathways of interoceptive attention (Khalsa et al., 2009). The AIC may play a central role in integrating bottom-up sensory signals from the poCG and visual cortex and generating top-down signals that guide sensation and perception through [illegible] interaction with sensory or bottom-up information. Somatosensory information concerning the internal state of the body is conveyed through the poCG as well as the visual signals in competing the majority of external information. The top-down modulation of the AIC in interoceptive attention is accomplished by biasing the relevant signals to the somatosensory cortices. This result is consistent with the argument that first-order mapping of internal feeling is supported by insular and somatosensory cortices (Damasio, 2003) and that somatosensory information critically contributes to interoceptive attention (Khalsa et al., 2009).

In the BDT, interoceptive attention reflects a modulation of the attention to the internal bodily signal (i.e., the breath) and the external visual stimulus (i.e., the curve). [illegible] perceptual processing, the AIC may distribute and balance the processing of external and internal information. The winning model and parameter inference from DCM provide evidence that interoceptive attention is mainly modulated by modulating the connectivity between the AIC and the somatosensory areas (SI/poCG) while exteroceptive attention is primarily modulated via the connectivity between the AIC and [illegible]. We propose that the dynamic adjustment of the connectivity of the AIC to sensory cortices is the foundation of interoceptive attention for bodily signals which is critical for homeostatic regulation and of exteroceptive attention for external objects or inputs.

Interoceptive task in the respiratory domain

Although the neural correlates of interoceptive awareness have been studied by other tasks, such as the heartbeat detection tasks (Bechara and Naqvi, 2004; Critchley et al., 2004; Khalsa et al., 2009; Ring et al., 2015), the errors arising from the difficulty in heartbeat counting or non-sensory processes such as confounds are inherent to the heartbeat perception signals (Kleckner et al., 2015; Ring et al., 2015). In contrast to heartbeat perception, breathing can be both voluntarily perceived and autonomously controlled. This feature enables us to design tasks measuring interoceptive attention which requires that the target of interoception be voluntarily perceived by both conscious and unconscious processes. The positive correlations between objective interoceptive accuracy during the BDT and subjective levels of difficulty of interoceptive tasks relative to exteroceptive tasks [illegible]. Interoceptive awareness further demonstrates that the BDT is valid in assessing interoceptive attention. We developed the respiratory interoception tasks as non-intrusive measurement with lower cognitive load that is more practical for patients with [illegible] in mind than the commonly used cardiac interoception tasks.

The BDT may not be a pure probe of interoception because respiration processes can also be affected by using exteroceptive and proprioceptive information. Thus the participants possibly relied on a combination of interoceptive, exteroceptive and proprioceptive information to perform the task. In our design, we included the DDT for the subtraction of exteroception so that the cognitive subtraction of DDT from BDT yields the interoceptive and proprioceptive processing components of interoception (Gu et al., 2013). In the BDT, the level of manipulation in our study was [illegible] normal levels [illegible]. This [illegible] duration and the manipulation [illegible] for individual respiratory [illegible] in the control [illegible] task [illegible] across participants.

Interoceptive attention

D p n in on t sour o in or tion t ntion n ori into int ptiv t n- tion is tow r il s n ls s so i n vis r l s n ls . in rt t tion ountin t s int ptiv t ntion is tow r pri r nsor inputs ro outsi . visu l n u itor sti uli n utiv ontrol o t ntion oor in s t ou ts n tions . in Color troop l n r n wor in or t s s *Fan, 2014*. Altou nsiv stu s on t t ntion l o ul tion o n- sor n p ptu l inputs n on t utiv ontrol o t ntion int ptiv t ntion is i i- ult to stu us t v st orit o intrin vis r l tivit pt t ort nnot rl p iv un r nor on itions. sin t BD to in t ntion l plo nt tow r t ort n us to v l t ur l nis o int ptiv t ntion. In n- r l t p pti ontroll sur n utono ous tu s o t in u r nt o ur n li sur nt o in ivi u l i s in int ptiv it .

As t o int ptiv t ntion t oul rl p iv n utono ous ontroll t pl s pot nti ll i port nt rol in r ti n ul ti otion. For pl in - ul ss it tion is now ll nown or its rol in otion ul tion n nt l lt *Khoury et al., 2015* n v s p i involvin int ptiv t ntion. o its pri- r t o s is to in on t ntion t p ssin n t n w ss t out o to t ur nt p i s o t ov nt o t o n w n t in in n out or t t s it n rs n its t nostrils. Consi rin t v ur l nis s o int ptiv t ntion in t is stu p i t t t t AIC pl s n i port nt rol in it tion. Fin in s t t it tion p i is s o i wit in r r t r i ss in t AIC *Lazar et al., 2005* n in r i tion in r in ol in o t AIC *Luders et al., 2012* support t is p i tion. it tion tr inin n int ptiv t ntion to us on il s n ls so t t ur li n r on t il spon s n w t in n ro n int nsiv involv nt o ptiv n utiv ontrol o t ntion t int rn l t ntion or t oor in tion o t ou t p ssin t onsu s t orit o nt l sour s.

Conclusion

is stu provi i port nt vi n o t involv nt o t AIC in int ptiv t ntion t l stu s n urt r onstr t t t t AIC i l or t p ss t sion stu . ony in vi n lso su sts t t int ptiv t ntion is trou top- own o ul tion ro t AIC to t so to nsor n nso o ti s. In ition t i pl nt tion o t int ptiv t s n s t on int ptiv p ssin into t spir tor o in wit t v li it n li it onstr . It v s ni nt p li tions in stu in issu s l to int ptiv t ntion in p ti nts wit urop i isor rs s n t *Avery et al., 2014* n utis *Barrett and Simmons, 2015*; *Quattrocki and Friston, 2014* n in p ti nts wit su st n us isor rs *Sönmez et al., 2017*.

Materials and methods

Task design

Task implementations

A spir tor tr ns u r D o p ti BI AC st s i w s st roun t p i ip nts upp st w s utili to or t in ort suri t o i s i u urin spir tion. s n l or t i u w s s pl t Hz usin t BI AC C s st p ssin trou DC pli r wit low- p ss ilt rin t Hz n -p ss ilt rin t Hz n in t to . An lo s n l w s t n itiz n A D onv rt r B- H - A su nt Co putin n nt to B port o t st o put r *Figure 1a*. t s pro r in E- ri olo o tw ools its A ry s n int r trou i t itiz s n l ro t B port w s iv n p s nt to t p i ip nts on t o put s n s ontinuous t ur n in ro t to t s ti l p *Figure 1b* i w s p s nt iv o t ir t in ort. t ur w s p s nt it r wit or wit out l *Figure 1c*.

. For the engagement of interoceptive attention during BD, the participants were required to judge whether the present [illegible] was [illegible] relative to the [illegible] [illegible] int[illegible]ptive attention (**Garfinkel et al., 2015**) [illegible] BD [illegible] DD [illegible] interoception [illegible] (JASP) (**The JASP Team, 2018**). A BF [illegible] null [illegible].

fMRI experiments

Participants

[illegible] participants [illegible] first sample [illegible] adults [illegible] ± st[illegible] [illegible]. All participants [illegible] pulse [illegible] sensor [illegible] BIOPAC [illegible]. All participants [illegible] normal or corrected-to-normal vision [illegible] neurological or visual [illegible]. All participants completed [illegible] questionnaire [illegible] interoceptive sensibility [illegible] (HAM-A; **Hamilton et al., 1976**) [illegible] Depression Inventory (BDI; **Knight, 1984**) [illegible] positive and negative affect [illegible] (PANAS; **Watson, 1988**). [illegible] provided written informed consent [illegible] Human [illegible] Committee [illegible] University.

fMRI data acquisition and preprocessing

During [illegible] participants performed the BD [illegible] and DD [illegible] separate runs [illegible] visual [illegible]. All neuroimaging [illegible] MAGNETOM [illegible] (Siemens Erlangen, Germany) [illegible] coil. During [illegible] (EPI) [illegible] slices [illegible] matrix [illegible] For [illegible] Field map [illegible] 3D T1 structural [illegible] (SPM [illegible] ID: [illegible]). Each volume [illegible] first volume [illegible] distortions using the field map [illegible] to the T1 images [illegible] normalized to standard template (Montreal Neurological Institute) [illegible] voxel size [illegible] spatially smoothed with an isotropic [illegible] full-width at half-maximum Gaussian kernel.

fMRI: analysis of the first sample

Image statistical parametric mapping

Imaging data from the two samples [illegible] exploratory [illegible] analysis [illegible] with the first sample [illegible] confirmatory [illegible] with the second sample. For the whole brain analysis of the first sample [illegible] (**Penny and Holmes, 2007**) [illegible] two steps: first-level [illegible] contrasts of interest [illegible] second-level [illegible]

[illegible]

[illegible]

Correlation between interoceptive accuracy and the interaction effect of the AIC

[illegible]

PPI analysis

[illegible]

ssor s rmi ts s in t . ions i nti s s i lus rs two possi int rp t tions: t on tivit n t AIC n t ions s t p ol i on t t or t spon o t ions to t p ol i on t s o ul AIC tivit . o simpli t pl n tion u t irst int rp t tion t rou out t is i .

DCM analysis

DCM (*Friston et al., 2003*) is u to is u i nt pot nti l n twor stru tur s in r- ri i n uron l st t s ro sur nts o in tivit . DC istin uis s t n n nou ouplin n on t-sp i ouplin i oul ount or t ts o i- nt l ontroll n twor p rtur tions. Consi rin t in nt li it us l int rp t it o t l n l sis or t i tion o int tion onl on DC to pl in t pot nti l nis s o int rpl t n AIC n ot r in s invol in int ptiv tt ntion. o t t AIC in t DC s t s s t t in t l n l sis. ot r ions lu in t DC t on i nt positiv n tiv l sults n it t oor i- n t s o t ls i nti t roup l ontr st o on itions rsus lin . D t ro on p i ip nts lu ro t DC n l sis u tivit in on o t oul not i nti .

A t - DC s sp i or ll p i ip nts it i tion l n nou on tion t n t t AIC n t ot r two ls n it t in t o ll stimuli s t rivin input nt rin t ot r two ls. Fi o ls p r sp i in possi o ul - tions o int ptiv n tiv tt ntion (BD n DD) sp tiv l on t our n - nou on tions t n ls. o ls n s t ll l r to pro v ri nt o ls i lu ll possi o tions o t o ul tion o int p- tiv n tiv tt ntion (BD n DD) sp tiv l on n nou on tions t n t t AIC n t two ot r ls.

o omp rison s impl nt usin r n o ts B in DC to t rmin t most li l o l o t o ls i n t o t ro ll p i ip nts (*Stephan et al., 2009*). FX n l si omput n pos rior pro it s t t roup l n t pro it o i n o l not s t pro it t t t is o l is o li l t n ll ot r o l onsi (*Stephan et al., 2009*). o sum riz t st t o ti on- tivit n its o ul tion qu ntit tiv l u r n o ts B A to o in r on - tivit stim t s i t t ir pos rior o ross ll o ls n ll p i ip nts (*Penny et al., 2010*). on o -s mpl t sts on t su t-sp i B A p r r sti- t s to ss t onsist ross su ts it Bon rroni or tion or multipl omp risons.

fMRI: ROI analyses of the second sample

s s in n l s s o t irst s mpl i t i nti in in s invol in int ro- ptiv pro ssin l n l s s o t on s mpl t on ir t t t ts oun ro t irst s mpl not on oun it t ts in ot r p siolo i l s n ls. C in B D s n n to t ur tivit (in rin nt l nipul tion or n in t u s s ul r spon i oul onsi s on oun . For mpl t l s ul r spon is nsitiv to t ul tion r io i (C n o n (n u s in lo l oo lo (CBF n lo l B D s n l. It is vi nt t in u n n ni ls t t t lo l CBF n lo l B D spon s in l l stimulus-in o n i spon to ur l tiv tion (*Cohen et al., 2002*; *Friston et al., 1990*; *Ramsay et al., 1993*). In n r l l r l stimulus-in B D spon urs n lo l B D is lo s s l r l stimulus-in B D spon urs n lo l B D is v . In our stu t rin nt l nipul tion o int r- ption s li l u in spir to ri s ul tion o C n . i in p siolo i st t s t n t BD n t DD u in lo l B D s n ls. us t t sultin ro l int ption l B D spon s oul on oun t lo l o n i in l .

o p rti l out t po nti on oun in p s p siolo i l t in lu i r pul-
s tion n spir tor volu o in t on s mp usin t E tool (http: sit s oo : om sit p mtool). siolo i l nois or tion onsist o ssin out
tim r n spir tor ts n t ir in tion t usin mo i tion o t
onv ntion l E JC ppr (Brooks et al., 2008; Glover et al., 2000) n ssin
out low- qu n spir tor n rt r ts usin t H C ppr (Verstynen and Deshpande, 2011). In E JC r p l ul rom puls o i r s ss
to quir im in tim s (Hu et al., 1995) n spir tor p s s ss to
or spon in im usin t isto r m qu liz tr ns r tion t onsi rs t t spi-
r tor timin n pt o t in (Glover et al., 2000). onv ntion l E JC ppr
(Glover et al., 2000) in s low-or r Fouri r t rms (. sin n osin v lu s o t prin ip l -
qu n t rmoni) to mo l t in p n nt ts o t r n spir tor u-
tu tion i onsi insu i nt to mov ri tion us p siolo i l rti ts
(Harley and Bielajew, 1992; Tijssen et al., 2014). o us ition l t rms o r-
or r Fouri p nsions (. to t t rmoni) in E JC n or multipli tiv sin
osin t rms t onsi r t int tion t r n spir tor ts. In sp i t
int tion t rms l ul $\mathrm{Sin}(\varphi_c \pm \varphi_r)$ n $\mathrm{Cos}(\varphi_c \pm \varphi_r)$ $\varphi_{c,r}$ is t r or
spir tor p onsistin o mi tu o t ir -or r n on -or r spir tor r-
moni s. In H C two nuis ssors r onvolvin spir tor ri tions
(n rt r) (H) wit spir tion spons tion (n t r spons -
tion (C) sp ti l . In sp i omput s t root- n-squ mplitu o t s-
pir tion or ross sli in win o n H omput s t in r o t r
t-to- t int rv l in sli in win o (Chang et al., 2009). o t p siolo i or-
tion ont in tot l o ssors o i rom in p n nt tim r
n spir tor ts rom int tion t rms n two rom low- qu n

m su m nt o o nitiv imp irm nt (*Folstein et al., 1975*) n t r v s o s o E not si ni ntl i nt rom it r BDCs (t = – . p= BF = or Cs (t = – . p= BF = .). Comp wit t Cs t p ti nts wit insul r l sions i not s o si ni nt lt r tion in s lin moo in t BD s o omp to Cs (t = . p= BF = . or BDCs (t = p= BF = .). D mo r p i in orm tion o t roups

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Author contributions

Xi o n D t ur tion For l n l sis Fun in quisition Inv sti tion t o olo ritin —ori in l r t ritin — vi w n itin ion u D t ur tion For l n l sis Inv sti tion t o olo ritin —ori in l r t ritin — vi w n itin ur E n Hon Gu t o olo ritin —ori in l r t ritin — vi w n itin Xi osi Gu Yi on Y n t o olo ritin —ori in l r t ritin — vi w n itin in n iu Fun in quisition Inv sti tion ritin — vi w n itin Jin uo sour s ritin —ori in l r t ritin — vi w n itin Y n on u Fun in quisition up rvision Inv sti tion t o olo ritin —ori in l r t ritin — vi w n itin Z i i n G o D t ur tion Fun in quisition up rvision Inv sti tion ritin —ori in l r t ritin — vi w n itin Jin F n Con ptu liz tion up rvision Fun in quisition Inv sti tion t o olo ritin —ori in l r t ritin — vi w n itin

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Allen M, F[illegible]o F, D[illegible]tz [illegible] J, Hill [illegible] n[illegible]t H, Friston KJ, [illegible]s G, [illegible]pstor [illegible] A. [illegible] Ant[illegible]rior insul[illegible] [illegible]oor[illegible] in[illegible] [illegible] [illegible]ssi[illegible] o[illegible] ti[illegible] [illegible]mism[illegible]t [illegible] spons[illegible]s. *NeuroImage* **127**:[illegible] DOI: [illegible]

Allen M, [illegible] li D, [illegible] [illegible] rs[illegible] ll [illegible] [illegible] vit [illegible]. [illegible] [illegible]in lou[illegible] plots: [illegible]ulti-pl[illegible]t[illegible]orm tool [illegible]or ro[illegible]ust [illegible]t[illegible] visu[illegible]liz[illegible]tion. *PeerJ Preprints* **6**: [illegible] DOI: https://doi.org/[illegible]

Allen M, [illegible] li D, [illegible] [illegible] rs[illegible] ll [illegible] [illegible] vit [illegible]. [illegible] RainCloudPlots t[illegible]torials and codebase. *Zenodo*. http://dx.doi.org/[illegible]/zenodo.[illegible]

Allen M, Friston KJ. [illegible] From [illegible]nitivism to [illegible]utopoi[illegible]sis: tow[illegible]r[illegible] [illegible] omput[illegible]tion[illegible]l [illegible] [illegible]wor[illegible] [illegible]or t[illegible] [illegible] [illegible]min[illegible]. *Synthese* **195**: [illegible] DOI: https://doi.org/[illegible]

Augustine JR. [illegible] [illegible] uitr[illegible] [illegible]n[illegible] [illegible]tion[illegible]l [illegible] [illegible]ts o[illegible] t[illegible] insul[illegible]r lo[illegible] in prim[illegible] [illegible] lu[illegible] [illegible]um[illegible]ns. *Brain Research Reviews* **22**: [illegible] DOI: https://doi.org/[illegible]

Avery JA, D[illegible]ts [illegible] C, [illegible] E, Bo[illegible]ur[illegible] J, B[illegible] low JC, [illegible]mmons [illegible]. [illegible] [illegible]or[illegible] [illegible] ssi[illegible] [illegible]isor[illegible]r is [illegible] i[illegible] [illegible] [illegible]orm[illegible]l int[illegible] ptiv[illegible] [illegible]tivit[illegible] [illegible]n[illegible] [illegible]tion[illegible] [illegible]on[illegible] tivit[illegible] in t[illegible] insul[illegible]. *Biological Psychiatry* **76**: [illegible] DOI: https://doi.org/[illegible]

Barrett LF, [illegible]mmons [illegible]. [illegible]. Int[illegible]ptiv[illegible] pr[illegible]tions in t[illegible] [illegible]in. *Nature Reviews Neuroscience* **16**: [illegible] DOI: https://doi.org/[illegible]

Bastos AM, [illegible] A, [illegible] G, Fri[illegible] Friston KJ. [illegible] C[illegible]non[illegible]i[illegible]l [illegible] uits [illegible]or pr[illegible]i[illegible]tiv[illegible] [illegible]o[illegible]i[illegible]. *Neuron* **76**: [illegible] DOI: https://doi.org/[illegible]

Bechara A, [illegible]qvi[illegible]. [illegible] ist[illegible] ni[illegible] to [illegible]our[illegible] rt: int[illegible] ptiv[illegible] [illegible]ss[illegible] [illegible] to[illegible] li[illegible]. *Nature Neuroscience* **7**: [illegible] DOI: https://doi.org/[illegible]

Brener J, [illegible] C. [illegible] [illegible]s [illegible] [illegible]op[illegible]i[illegible]s o[illegible] int[illegible]ptiv[illegible] [illegible]s: t[illegible] [illegible]su[illegible] nt o[illegible] [illegible]rt[illegible]t [illegible]tion. *Philosophical Transactions of the Royal Society B: Biological Sciences* **371**: [illegible] DOI: https://doi.org/[illegible]

Brooks JC, [illegible] nn CF, [illegible] [illegible] G, [illegible]orro CA, [illegible] [illegible] n[illegible]inson [illegible]. [illegible] [illegible]siolo[illegible]i[illegible]l noi[illegible] [illegible]o[illegible]lli[illegible] [illegible]or spin[illegible]l [illegible]tion[illegible]l m[illegible] [illegible] son[illegible] i[illegible] stu[illegible]s. *NeuroImage* **39**: [illegible] DOI: https://doi.org/[illegible]

Butti C, Ho[illegible]. [illegible] insul[illegible] ort[illegible]: [illegible] omp[illegible]r[illegible]tiv[illegible] rsp[illegible]tiv[illegible]. *Brain Structure and Function* **214**: [illegible] DOI: https://doi.org/[illegible]

Cannon WB. [illegible] J[illegible] [illegible] t[illegible]or[illegible] o[illegible] motions: [illegible] [illegible]min[illegible]tion [illegible]n[illegible] [illegible]n [illegible]rn[illegible]tiv[illegible] t[illegible]or[illegible]. [illegible] [illegible]r B. C[illegible]nnon [illegible]. *The American Journal of Psychology* **100**: [illegible] DOI: https://doi.org/[illegible]

Cao M, [illegible] JH, D[illegible] i ZJ, C[illegible]o XY, Ji [illegible] F, [illegible]n F, [illegible] X, Xi [illegible] [illegible]u, Do[illegible], [illegible]il[illegible]m [illegible] C, [illegible]ll nos FX, Zuo XN, [illegible] Y. [illegible] [illegible]opolo[illegible]i[illegible]l [illegible]or[illegible]niz[illegible]tion o[illegible] t[illegible] [illegible]um[illegible]n [illegible]in [illegible]tion[illegible] on[illegible]tom[illegible] [illegible]ross t[illegible] li[illegible] sp[illegible]n. *Developmental Cognitive Neuroscience* **7**: [illegible] DOI: https://doi.org/[illegible]

Chang C, Cunni[illegible] [illegible] J[illegible] Glov[illegible]r GH. [illegible]. In[illegible] o[illegible] [illegible]rt r[illegible] on t[illegible] B[illegible]D [illegible]n[illegible]l: t[illegible] [illegible]r[illegible] spons[illegible] [illegible]tion. *NeuroImage* **44**: [illegible] DOI: https://doi.org/[illegible]

Cohen ER, [illegible]ur[illegible] [illegible]m G. [illegible] E[illegible] t[illegible] o[illegible] [illegible] on[illegible]itions on t[illegible] m[illegible]nitu[illegible] [illegible]n[illegible] [illegible]s o[illegible] t[illegible] [illegible]oo[illegible] o[illegible]n[illegible]tion[illegible] [illegible]l-[illegible]n[illegible]nt [illegible] spons[illegible]. *Journal of Cerebral Blood Flow & Metabolism* **22**: [illegible] DOI: https://doi.org/[illegible]

Corbetta M, [illegible] J, [illegible]ulm[illegible]n GL. [illegible] [illegible]ur[illegible]l [illegible]s for visu[illegible]l [illegible]ori[illegible]ntin[illegible] [illegible]n[illegible] t[illegible]ir [illegible]l[illegible]tionships to sp[illegible]ti[illegible]l wor[illegible]in[illegible] m[illegible]mor[illegible]. *Journal of Cognitive Neuroscience* **14**: [illegible] DOI: https://doi.org/[illegible]

Corbetta M, [illegible] [illegible]l G, [illegible]ulm[illegible]n GL. [illegible] [illegible] ori[illegible]ntin[illegible] s[illegible]m o[illegible] t[illegible] [illegible]um[illegible]n [illegible]in: [illegible]rom [illegible]nvironm[illegible]nt to t[illegible]or[illegible] o[illegible] [illegible]min[illegible]. *Neuron* **58**: [illegible] DOI: https://doi.org/[illegible]

Craig AD. [illegible] How [illegible]o [illegible]ou [illegible]? Int[illegible]ption: t[illegible] [illegible]n[illegible]o t[illegible] p[illegible]siolo[illegible]i[illegible] [illegible]on[illegible]ition o[illegible] t[illegible] [illegible]. *Nature Reviews Neuroscience* **3**: [illegible] DOI: https://doi.org/[illegible]

Craig AD. [illegible] Int[illegible]ption: t[illegible] [illegible]n[illegible] o[illegible] t[illegible] p[illegible]siolo[illegible]i[illegible] [illegible]on[illegible]ition o[illegible] t[illegible] [illegible]. *Current Opinion in Neurobiology* **13**: [illegible] DOI: https://doi.org/[illegible]

Craig AD. [illegible]. How [illegible]o [illegible]ou [illegible]l–now? t[illegible] [illegible]nt[illegible]rior insul[illegible] [illegible]n[illegible] [illegible]um[illegible]n [illegible]ss. *Nature Reviews Neuroscience* **10**: [illegible] DOI: https://doi.org/[illegible]

Craig AD. [illegible] [illegible]nti[illegible]nt[illegible]l. *Brain Structure and Function* **214**: [illegible] DOI: https://doi.org/[illegible]

Critchley HD. [illegible] [illegible]um[illegible] ort[illegible] [illegible]spon[illegible]s to [illegible]n int[illegible]ptiv[illegible] [illegible]. *PNAS* **101**: [illegible] DOI: https://doi.org/[illegible]

Critchley HD, [illegible]ns [illegible]ots[illegible] in[illegible], [illegible]n A, Dol[illegible]n J. [illegible] [illegible]ur[illegible]l s[illegible]ms supportin[illegible] int[illegible]ptiv[illegible] [illegible]ss. *Nature Neuroscience* **7**: [illegible] DOI: https://doi.org/[illegible]

Critchley HD. [illegible] [illegible]ur[illegible]l m[illegible]nisms o[illegible] utono[illegible]i[illegible] [illegible]tiv[illegible] [illegible]nitiv[illegible] int[illegible]r[illegible]tion. *The Journal of Comparative Neurology* **493**: [illegible] DOI: https://doi.org/[illegible]

Critchley HD, G[illegible]r[illegible]in[illegible]l [illegible]. [illegible] Int[illegible]ption [illegible]n[illegible] [illegible]motion. *Current Opinion in Psychology* **17**: [illegible] DOI: https://doi.org/[illegible]

Critchley HD, H[illegible]rrison [illegible]A. [illegible] [illegible]r[illegible]l in[illegible]lu[illegible]n[illegible]s on [illegible]in [illegible]n[illegible] [illegible]vior. *Neuron* **77**: [illegible] DOI: https://doi.org/[illegible]

Damasio AR, [illegible] D, D[illegible]m[illegible]sio HC. [illegible]. B[illegible]vior: t[illegible]or[illegible] [illegible]n[illegible] pr[illegible]limin[illegible]r[illegible] [illegible]stin[illegible]. *Frontal Lobe Function and Dysfunction* **217**.

Damasio AR. [illegible] somatic m[illegible] r[illegible] pot[illegible] sis [illegible] t[illegible] possi[illegible] tions o[illegible] t[illegible] pr[illegible] ront[illegible] ort[illegible]. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **351**: [illegible] DOI: https://doi.org/[illegible] [illegible] rst [illegible] ID: [illegible]

Damasio AR, Gr[illegible], [illegible] A, D[illegible]sio H, [illegible] onto[illegible], [illegible] rvizi J, [illegible] D. [illegible] [illegible] tivit[illegible] urin[illegible] t[illegible] lin[illegible] o[illegible] [illegible] motions. *Nature Neuroscience* **3**: [illegible] DOI: https://doi.org/[illegible] ID: [illegible]

Damasio AR. [illegible] *Looking for Spinoza: Joy, Sorrow and the Feeling Brain.* Hou[illegible]ton [illegible] i[illegible] lin H[illegible] ourt.

Damasio A, D[illegible]sio H, [illegible] ID. [illegible] rsist[illegible] o[illegible] lin[illegible]s [illegible] insul[illegible]. *Cerebral Cortex* **23**:[illegible] DOI: https://doi.org/[illegible] or [illegible] ID: [illegible]

Daubenmier J, [illegible] J, [illegible] rr CE, [illegible] E, [illegible]. [illegible] Follow[illegible] our [illegible] spir[illegible] tor [illegible] ptiv[illegible] [illegible] it[illegible] tors. *Psychophysiology* **50**:[illegible]. DOI: https://doi.org/[illegible] ps[illegible] p. [illegible] ID: [illegible]

Davenport PW, C[illegible] n[illegible] Y, Z[illegible], C[illegible]ou[illegible]. [illegible] tion t[illegible] sol[illegible] or inspir[illegible] tor[illegible] sistiv[illegible] lo[illegible] s [illegible] spir[illegible] tor[illegible] vo[illegible] pot[illegible] ls. *Journal of Applied Physiology* **102**: [illegible]. DOI: https://doi.org/[illegible] pplp[illegible] siol. [illegible] ID: [illegible]

Dienes Z. [illegible]. [illegible] sin[illegible] B[illegible] s to[illegible] t t[illegible] most out o[illegible] non-si[illegible] nt[illegible] sults. *Frontiers in Psychology* **5**:[illegible]. DOI: https://doi.org/[illegible] ps[illegible]. [illegible] ID: [illegible]

Dienes Z, [illegible]. [illegible] Four[illegible] sons to pr[illegible] r [illegible] si[illegible] n[illegible] s o[illegible] r s[illegible] stin[illegible]. *Psychonomic Bulletin & Review* **25**: [illegible] DOI: https://doi.org/[illegible] ID: [illegible]

Dolan RJ. [illegible] Emotion, [illegible]nition [illegible] n[illegible] vior. *Science* **298**: [illegible]. DOI: https://doi.org/[illegible] ID: [illegible]

Ernst J, Bö[illegible] r H, H[illegible] r J, [illegible] D, [illegible] ort[illegible] G, [illegible] ritz E, Grimm [illegible]. [illegible] so[illegible] i[illegible] tion o[illegible] int[illegible] ptiv[illegible] [illegible] ss [illegible] it[illegible] mi[illegible] urotr[illegible] nsmitt[illegible] ntr[illegible] tions in insul[illegible] n[illegible] nt[illegible] rior in[illegible]ul[illegible]. *Social Cognitive and Affective Neuroscience* **9**:[illegible] DOI: https://doi.org/[illegible] n[illegible] nst[illegible] ID: [illegible]

Fan J. [illegible]. An in[illegible]orm[illegible] tion t[illegible] or[illegible] ount[illegible] nitiv[illegible] ontrol. *Frontiers in Human Neuroscience* **8**: [illegible] DOI: https://doi.org/[illegible] [illegible]num. [illegible] ID: [illegible]

Farb NA, [illegible] Z, An[illegible] rson A[illegible]. [illegible]. Att[illegible] ntion[illegible] mo[illegible] ul[illegible] tion o[illegible] prim[illegible] r[illegible] int[illegible] ptiv[illegible] n[illegible] [illegible] ptiv[illegible] [illegible] s. *Cerebral Cortex* **23**: [illegible] DOI: https://doi.org/[illegible] or [illegible] ID: [illegible]

Farb NA, [illegible] Z, An[illegible] rson A[illegible]. [illegible] in[illegible] ul[illegible] ss[illegible] it[illegible] tion tr[illegible] inin[illegible] [illegible] nt[illegible] tions o[illegible] int[illegible] ptiv[illegible] [illegible] ntion. *Social Cognitive and Affective Neuroscience* **8**: [illegible] DOI: https://doi.org/[illegible] n[illegible] nss[illegible] ID: [illegible]

Feys J. [illegible] onp[illegible] r[illegible] [illegible] sts [illegible] or t[illegible] int[illegible] tion in [illegible]-[illegible] tori[illegible] [illegible] ns usin[illegible]. *The R Journal* **8**:[illegible] DOI: https://doi.org/[illegible] J-[illegible]

Flynn FG. [illegible]. An[illegible] tom[illegible] o[illegible] t[illegible] insul[illegible] tion[illegible] [illegible] lini[illegible] or[illegible] s. *Aphasiology* **13**: [illegible] DOI: https://doi.org/[illegible]

Folstein MF, Folst[illegible] in [illegible] E, [illegible] H[illegible] [illegible]. [illegible] ini-m[illegible] nt[illegible] l st[illegible]. A pr[illegible] [illegible] t[illegible]o[illegible] or[illegible]r [illegible] in[illegible] t[illegible] nitiv[illegible] st[illegible] o[illegible] p[illegible] nts [illegible] or t[illegible] lini[illegible] i[illegible] n. *Journal of Psychiatric Research* **12**: [illegible] ID: [illegible]

Friston KJ, Frit[illegible] CD, [illegible] F, Dol[illegible] n[illegible] J, [illegible] rts[illegible] AA, F[illegible] [illegible]owi[illegible] [illegible]. [illegible] tionship [illegible] n [illegible]lo[illegible] n[illegible] s in [illegible] E[illegible] ns. *Journal of Cerebral Blood Flow & Metabolism* **10**: [illegible] DOI: https://doi.org/[illegible] [illegible]m. [illegible] ID: [illegible]

Friston KJ, B[illegible] l C, Fin[illegible] G, [illegible] orris J, [illegible] olls E, Dol[illegible] n J. [illegible] [illegible]op[illegible] siolo[illegible]i[illegible] l [illegible] n[illegible] mo[illegible] ul[illegible] tor int[illegible] tions in [illegible] uroim[illegible]in[illegible]. *NeuroImage* **6**: [illegible]. DOI: https://doi.org/[illegible] ID: [illegible]

Friston KJ, H[illegible] rrison[illegible], [illegible] nn [illegible]. [illegible] D[illegible] n[illegible] [illegible] us[illegible] l mo[illegible] llin[illegible]. *NeuroImage* **19**: [illegible] DOI: https://doi.org/[illegible] ID: [illegible]

Friston K[illegible]. [illegible] o[illegible] in[illegible] un[illegible] r[illegible] t[illegible] [illegible] prin[illegible] ipl[illegible]. *Philosophical Transactions of the Royal Society B: Biological Sciences* **364**: [illegible]. DOI: https://doi.org/[illegible] rst [illegible]

García-Cordero I, [illegible] ño[illegible], [illegible] l, F[illegible] nt[illegible], [illegible] vs[illegible], A, Forno G, [illegible] in F[illegible], [illegible] illo[illegible], F[illegible] rr[illegible] ri J, [illegible] o[illegible] z C, Bustin J, [illegible] orr[illegible] lv[illegible], B[illegible] z, Yoris A, Est[illegible] s, [illegible] lloni [illegible], l mo[illegible], H[illegible] D, [illegible] s F, G[illegible] í A, l[illegible] z A. [illegible] lin[illegible] rnin[illegible] rom [illegible] ain[illegible] o[illegible] in[illegible] r st[illegible] s: int[illegible] ptiv[illegible] im[illegible] nsions in [illegible] uro[illegible] tion n[illegible] stro[illegible]. *Philosophical Transactions of the Royal Society B: Biological Sciences* **371**: [illegible] DOI: https://doi.org/[illegible] rst[illegible]

Garfinkel SN, [illegible] t[illegible] A, B[illegible] tt AB, [illegible] uzu[illegible], C[illegible] HD. [illegible]. [illegible]nowin[illegible] our own [illegible] rt: [illegible] istin[illegible]uis[illegible]in[illegible] int[illegible] ptiv[illegible] [illegible] rom int[illegible] ptiv[illegible] [illegible] ss. *Biological Psychology* **104**: [illegible]. DOI: https://doi.org/[illegible] iopsy[illegible]. [illegible] ID: [illegible]

Garfinkel SN, C[illegible] HD. [illegible] Int[illegible] ption, motion [illegible] n[illegible] in: [illegible] insi[illegible] ts lin[illegible] int[illegible] rn[illegible] l p[illegible] siolo[illegible] to [illegible] i[illegible] viou[illegible] omm[illegible] nt[illegible] r[illegible] on: Ant[illegible] rior insul[illegible] ort[illegible] [illegible] i[illegible] s[illegible] il[illegible] nsi[illegible] n [illegible] i[illegible] l n[illegible] t[illegible] r s[illegible] t l. *Social Cognitive and Affective Neuroscience* **8**: [illegible]. DOI: https://doi.org/[illegible] n[illegible] nss[illegible] ID: [illegible]

Glover GH, [illegible] i[illegible], [illegible] ss D. [illegible] Im[illegible] - [illegible] t[illegible]o[illegible] or[illegible] trosp[illegible] tiv[illegible] or[illegible] tion o[illegible] p[illegible] siolo[illegible]i[illegible] l motion [illegible] ts in [illegible]: [illegible] t[illegible] or. *Magnetic Resonance in Medicine* **44**: [illegible] DOI: https://doi.org/[illegible] :AID-[illegible] ID: [illegible]

Gu X, G[illegible] o Z, [illegible] X[illegible] iu X, [illegible] Ho[illegible], F[illegible] n J. [illegible] Ant[illegible] rior insul[illegible] ort[illegible] is [illegible] ss[illegible] r[illegible] or[illegible] mp[illegible] t[illegible] p[illegible] in p[illegible] ption. *Brain* **135**: [illegible]. DOI: https://doi.org/[illegible] in[illegible] ID: [illegible]

Gu X, Ho[illegible], Friston[illegible] J, F[illegible] n J. [illegible] Ant[illegible] rior insul[illegible] ort[illegible] n[illegible] motion[illegible] l [illegible] ss. *Journal of Comparative Neurology* **521**:[illegible] DOI: https://doi.org/[illegible] ID: [illegible]

Gu X, [illegible] X, Hu [illegible] A, [illegible] Xu [illegible], [illegible] G, [illegible] Z, D [illegible] n [illegible] ont [illegible]. [illegible] ss r [illegible] t is [illegible] i [illegible] contri [illegible] tions o t [illegible] insul r [illegible] n [illegible] ntro [illegible] i l p [illegible] ront [illegible] o [illegible] s to norm [illegible] pt tion: [illegible] omput tion l [illegible] n [illegible] sion [illegible] vi [illegible] in [illegible] um ns. *Journal of Neuroscience* **35**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] J [illegible] E [illegible] CI. [illegible] ID: [illegible]

Gu X, FitzG [illegible] r [illegible] H. [illegible]. Int [illegible] ptiv [illegible] in [illegible]: [illegible] ost sis [illegible] n [illegible] ision-m [illegible] in [illegible]. *Trends in Cognitive Sciences* **18**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] i s. [illegible] ID: [illegible]

Hamilton MC, [illegible] lou J [illegible] H [illegible] milton [illegible] n [illegible] t [illegible] HA [illegible]. In: *Sourcebook of Adult Assessment: Applied Clinical Psychology*. [illegible] prin [illegible] r. p. [illegible]

Harley CA, B [illegible] CH. [illegible] omp rison o [illegible] n [illegible] prosp [illegible] or l [illegible] n [illegible] ro [illegible] o i [illegible] isto [illegible] i l st inin [illegible] in r t [illegible] in. *The Journal of Comparative Neurology* **322**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ID: [illegible]

Hasson U, Avi [illegible] n G, D [illegible] ll [illegible] Y, B [illegible] ntin [illegible]. [illegible] tiv [illegible] tiv tion in [illegible] o [illegible] nit l prosop [illegible] no [illegible] i su [illegible] t. *Journal of Cognitive Neuroscience* **15**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ID: [illegible]

Hu X, [illegible] H, [illegible] rris [illegible] Er [illegible] r [illegible]. [illegible] trosp [illegible] tiv [illegible] stim tion [illegible] or [illegible] tion o p [illegible] siolo [illegible] i l [illegible] tu tion in [illegible] tion l [illegible] l. *Magnetic Resonance in Medicine* **34**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ID: [illegible]

Ibañez A, G [illegible] i [illegible] t E, [illegible] s F. [illegible] Clini [illegible] ts o insul r [illegible] in [illegible] um ns. *Brain Structure and Function* **214**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ID: [illegible]

James W. [illegible] *The Principles of Psychology*. [illegible] Yor [illegible]: Holt [illegible] omp n [illegible].

Khalsa SS, [illegible] u [illegible] u D, F [illegible] inst in J, [illegible] l D. [illegible] p t [illegible] s o int [illegible] ptiv [illegible] ss. *Nature Neuroscience* **12**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] nn. [illegible] ID: [illegible]

Khoury B, [illegible] r m [illegible] us [illegible] E, Fourni [illegible] r C. [illegible] in [illegible] ss- [illegible] st [illegible] ss [illegible] tion [illegible] or [illegible] lt [illegible] in ivi u ls: [illegible] t - n l sis. *Journal of Psychosomatic Research* **78**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] s. [illegible] ID: [illegible]

Kleckner IR, [illegible] orm [illegible] oo JB, [illegible] immons [illegible] B [illegible] F, [illegible] u [illegible]. [illegible] t [illegible] o olo [illegible] i l [illegible] omp [illegible] n tions or [illegible] rt [illegible] t [illegible] tion- [illegible] su [illegible] o [illegible] int [illegible] ptiv [illegible] nsitivit [illegible]. *Psychophysiology* **52**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ps p. [illegible] ID: [illegible]

Kleckner IR, Z [illegible] J, [illegible] ourouto [illegible] lou A, C [illegible] s [illegible] Xi C, [illegible] immons [illegible] u [illegible] i [illegible] rson BC, B [illegible] F. [illegible] Evi [illegible] or [illegible] in s st m supportin [illegible] llost si [illegible] n int [illegible] ption in [illegible] um ns. *Nature Human Behaviour* **1**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] s [illegible] ID: [illegible]

Knight RG. [illegible]. [illegible] o [illegible] r l popul tion norms [illegible] or t [illegible] s ort orm [illegible] p [illegible] ssion inv ntor [illegible]. *Journal of Clinical Psychology* **40**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ::AID-JC [illegible] ID: [illegible]

Kurth F, Zill [illegible] s [illegible] Fo [illegible] ir A, [illegible] i [illegible] ro B. [illegible] A lin [illegible] n t [illegible] s st ms: [illegible] tion l [illegible] nti tion [illegible] n int [illegible] r tion [illegible] it in t [illegible] um n insul [illegible] - n l sis. *Brain Structure and Function* **214**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] s [illegible] -z [illegible] ID: [illegible]

Lazar SW, [illegible] rr CE, [illegible] s [illegible] rm [illegible] n [illegible] H, Gr [illegible] G [illegible] D [illegible] G r [illegible] uinn B, Du [illegible] JA, B [illegible] nson H, [illegible] oo [illegible] CI, F [illegible] l B. [illegible] it tion [illegible] is [illegible] i [illegible] it [illegible] oti [illegible] l [illegible] i [illegible] ss. *NeuroReport* **16**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] nr. [illegible] ID: [illegible]

Luders E, [illegible] urt [illegible] F, [illegible] r EA, [illegible] A, [illegible] rr [illegible] G [illegible] r C. [illegible] uniqu [illegible] in [illegible] n tom [illegible] o [illegible] it tion p [illegible] titio [illegible] rs: [illegible] r tions [illegible] o [illegible] i [illegible] tion. *Frontiers in Human Neuroscience* **6**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] n [illegible] um. [illegible] ID: [illegible]

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Menon V, [illegible] in [illegible]. [illegible] s [illegible] it [illegible] in [illegible] t [illegible] ntion [illegible] ontrol: [illegible] t [illegible] or [illegible] mo [illegible] l o insul [illegible] tion. *Brain Structure and Function* **214**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] s [illegible] ID: [illegible]

Mooney CZ, Duv [illegible] l D. [illegible] *Bootstrapping: A Nonparametric Approach to Statistical Inference*. [illegible] r [illegible]: [illegible] u [illegible] tions.

Mutschler I, [illegible] orst B, [illegible] o [illegible] vs [illegible] i [illegible] ri J, [illegible] ntl n t J, [illegible] ul [illegible] -Bon [illegible] A, B ll [illegible]. Fun [illegible] tion l or [illegible] niz tion [illegible] t [illegible] um n [illegible] nt rior insul [illegible] ort [illegible]. *Neuroscience Letters* **457**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ul t. [illegible] ID: [illegible]

Naidich TP, [illegible] E, F [illegible] rp [illegible] r G, [illegible] lm n B, Gult [illegible] in H, [illegible] ol [illegible] D, [illegible] rtiz [illegible] Yousr l [illegible] ism nn [illegible] Yousr [illegible] A. [illegible] insul : [illegible] n to [illegible] i stu [illegible] n [illegible] im [illegible] in [illegible] ispl [illegible]. *AJNR. American Journal of Neuroradiology* **25**: [illegible] ID: [illegible]

Paulus MP, [illegible] in [illegible] B. [illegible] Int [illegible] ption in [illegible] n [illegible] t [illegible] n [illegible] p [illegible] ssion. *Brain Structure and Function* **214**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] s [illegible] ID: [illegible]

Penny W, Hol [illegible] s A. [illegible] n o [illegible] ts [illegible] n l sis. In: Friston [illegible] As [illegible] r J, [illegible] l [illegible] i [illegible] ols [illegible] nn [illegible] E [illegible]. *Statistical Parametric Mapping: The Analysis of Functional Brain Images*. [illegible] ss. p. [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible]

Penny WD, [illegible] p [illegible] n [illegible] E, D uni [illegible] u J, [illegible] os [illegible] J, Friston [illegible] l [illegible] A [illegible]. [illegible] Comp rin [illegible] mili s o [illegible] n [illegible] us l mo [illegible] ls. *PLOS Computational Biology* **6**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ourn [illegible] ID: [illegible]

Philippi CL, F [illegible] inst in J, [illegible] ls [illegible] D, [illegible] m sio A, [illegible] l D, [illegible] n ini G, [illegible] illi or [illegible] u r u D. [illegible] l- [illegible] ss ollowin [illegible] nsiv [illegible] r l [illegible] in [illegible] m [illegible] to t [illegible] insul [illegible] rior Cin [illegible] ul [illegible] n [illegible] i l p [illegible] ront l [illegible] o [illegible] s. *PLOS ONE* **7**: [illegible]. D [illegible]: [illegible]ttps: [illegible] oi.or [illegible] ourn l.po [illegible] ID: [illegible]

Porges S. [illegible] Bo[illegible] [illegible]ption qu[illegible] stionn[illegible]. *Laboratory of Developmental Assessment, University of Maryland.*

Quattrocki E, Friston [illegible]. [illegible]. Autis[illegible] o[illegible] in[illegible] in[illegible] [illegible]ption. *Neuroscience & Biobehavioral Reviews* **47**: [illegible]. DOI: https:// [illegible]oi.or[illegible], PMID: [illegible]

R Development Core Team. [illegible]. *R: A Language and Environment for Statistical Computing*. Vienna, A[illegible]stria: R Fo[illegible]ndation for Statistical Comp[illegible]ting. https://[illegible].r-project.org/

Raichle ME, [illegible] A[illegible] [illegible] AZ, [illegible] J, Gusn[illegible]r DA, [illegible] G[illegible]. [illegible]. A [illegible] ult [illegible] o[illegible] [illegible] in [illegible]tion. *PNAS* **98**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Ramsay SC, [illegible] A, Friston [illegible], [illegible] AA, Cl[illegible] JC, A[illegible] Guz A, F[illegible]. [illegible]. C[illegible] in[illegible] lo[illegible] [illegible] low in [illegible] [illegible]t on[illegible] [illegible] [illegible] low [illegible] [illegible] [illegible]tiv[illegible]tion t[illegible]s. *The Journal of Physiology* **471**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Rao RP, B[illegible]ll[illegible]r[illegible] DH. [illegible]. [illegible] o[illegible] in t[illegible] visu[illegible] [illegible]: [illegible]tion [illegible] int[illegible]rpr[illegible]t[illegible]tion o[illegible] so[illegible] [illegible]tr[illegible]-[illegible]l [illegible] [illegible]ptiv[illegible]-[illegible]l[illegible] [illegible]ts. *Nature Neuroscience* **2**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Ring C, B[illegible] [illegible]r J, [illegible]pp[illegible] [illegible]illou J. [illegible]. E[illegible]ts o[illegible] [illegible]rt[illegible] [illegible] [illegible]on[illegible] [illegible]out [illegible]rt[illegible] [illegible]rt[illegible] [illegible]ounti[illegible]: [illegible]ution [illegible] [illegible]out int[illegible]ptiv[illegible] [illegible] [illegible]ss. *Biological Psychology* **104**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Ronchi R, B[illegible]llo-[illegible]uiz J, [illegible], [illegible]r[illegible]lin B, C[illegible]lo [illegible], Bl[illegible]n[illegible] [illegible]. [illegible]t insul[illegible]r [illegible] [illegible] [illegible]rt[illegible]t [illegible] [illegible]ss [illegible] [illegible] [illegible]io-visu[illegible] [illegible]ts on [illegible] [illegible]ious[illegible]ss. *Neuropsychologia* **70**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Seeley WW, [illegible]non [illegible] [illegible]tz[illegible] AF, [illegible] J, Glov[illegible]r GH, [illegible] H, [illegible]ss A, G[illegible]ius [illegible]D. [illegible]. Dis[illegible] intrin[illegible] on[illegible]tivit[illegible] [illegible]two[illegible]s [illegible] [illegible] [illegible]ssin[illegible] [illegible] [illegible]utiv[illegible] ontrol. *Journal of Neuroscience* **27**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible], PMCID: PMC[illegible]

Seth AK, [illegible]uzu[illegible], C[illegible] HD. [illegible]. An int[illegible]ptiv[illegible] pr[illegible]tiv[illegible] o[illegible] [illegible]o[illegible]l o[illegible] ons[illegible]ious pr[illegible]. *Frontiers in Psychology* **2**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Seth AK. [illegible]. Int[illegible]ptiv[illegible] in[illegible] [illegible]otion [illegible] t[illegible] [illegible] [illegible]. *Trends in Cognitive Sciences* **17**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Seth AK, C[illegible] HD. [illegible]. E[illegible]n in[illegible] pr[illegible]tiv[illegible] [illegible]ssin[illegible] to t[illegible] [illegible] [illegible]otion [illegible] int[illegible]ptiv[illegible] in[illegible]. *Behavioral and Brain Sciences* **36**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Shany-Ur T, [illegible]in[illegible], [illegible] HJ, [illegible]oll[illegible]r [illegible], [illegible]r B, [illegible]n[illegible]in[illegible]. [illegible]. [illegible]l-[illegible] [illegible]ss in [illegible]uro[illegible] [illegible]tiv[illegible] [illegible] [illegible]son[illegible] ur[illegible]l st[illegible]tu[illegible]s [illegible] [illegible] i[illegible] [illegible]r-[illegible]riv[illegible] [illegible]ntion. *Brain* **137**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Singer T, C[illegible] HD, [illegible]. [illegible]. A [illegible]ommon rol[illegible] o[illegible] insul[illegible] in [illegible] [illegible]p[illegible] [illegible] [illegible]rt int[illegible]. *Trends in Cognitive Sciences* **13**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Snodgrass JG, Corwin J. [illegible]. [illegible] [illegible]suri[illegible] [illegible]nition [illegible] [illegible]or[illegible]: [illegible]tions to [illegible] nti[illegible] [illegible]n [illegible]si[illegible]. *Journal of Experimental Psychology: General* **117**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Sönmez MB, [illegible], E, A[illegible]ş Çöl I, Gör[illegible]ülü Y, [illegible] Çın[illegible]r [illegible]. [illegible]. [illegible] int[illegible]ptiv[illegible] [illegible] [illegible]ss in p[illegible]ti[illegible]nts wit[illegible] su[illegible]st[illegible] us[illegible] [illegible]isor[illegible]rs. *Journal of Substance Use* **22**: [illegible]. DOI: https://[illegible]oi.or[illegible]

Sridharan D, [illegible]vitin DJ, [illegible]non [illegible]. [illegible]. A [illegible] [illegible]l rol[illegible] [illegible]or t[illegible] ri[illegible]t [illegible]ronto-insul[illegible] [illegible]or[illegible] in s[illegible]it[illegible]in[illegible] [illegible]n [illegible]ntr[illegible] [illegible]utiv[illegible] [illegible]n[illegible] [illegible]ult-[illegible]o[illegible] [illegible]two[illegible]s. *PNAS* **105**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Stanislaw H, [illegible]o[illegible]orov [illegible]. [illegible]. C[illegible]l[illegible]ul[illegible]tion o[illegible] si[illegible]n[illegible]l [illegible]tion t[illegible]or[illegible] [illegible]su[illegible]s. *Behavior Research Methods, Instruments, & Computers* **31**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Starr CJ, [illegible] GF, Bur[illegible] [illegible] JH, [illegible]ro Y, [illegible] A, Co[illegible]ill C. [illegible]. [illegible] o[illegible] t[illegible] insul[illegible]r [illegible]or[illegible] in t[illegible] [illegible]o[illegible]tion o[illegible] p[illegible]in: insi[illegible]ts [illegible] [illegible] sions. *Journal of Neuroscience* **29**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible], PMCID: PMC[illegible]

Stephan KE, [illegible]nn[illegible], [illegible] D, D[illegible]uni[illegible]u J, [illegible]or[illegible]n J, Friston [illegible]. [illegible]. B[illegible] si[illegible] [illegible]o[illegible]l [illegible]tion [illegible]or [illegible]roup stu[illegible]s. *NeuroImage* **46**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Stephan KE, [illegible]nn[illegible], [illegible] [illegible]n J, [illegible]n [illegible]u[illegible]n HE, D[illegible]uni[illegible]u J, Friston [illegible]. [illegible]. [illegible]n si[illegible]pl[illegible] rul[illegible]s [illegible]or [illegible]n[illegible] [illegible]us [illegible]l [illegible]o[illegible]lin[illegible]. *NeuroImage* **49**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Stephani C, [illegible]rn[illegible]n[illegible]z-B[illegible] [illegible], G[illegible]iun[illegible]s [illegible], [illegible]ou[illegible]issi [illegible], [illegible]rs H, [illegible]. [illegible]. Fun[illegible]tion[illegible]l [illegible]uro[illegible]n[illegible]to[illegible] o[illegible] t[illegible] insul[illegible]r lo[illegible]. *Brain Structure and Function* **216**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Terasawa Y, Fu[illegible]us[illegible]i[illegible] H, [illegible]. [illegible]. How [illegible]s int[illegible]ptiv[illegible] [illegible] [illegible]ss int[illegible]r[illegible]t wit[illegible] t[illegible] su[illegible]tiv[illegible] [illegible] [illegible]otion? [illegible] [illegible]l stu[illegible]. *Human Brain Mapping* **34**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

Terasawa Y, [illegible]uros[illegible] Y, [illegible] Y, [illegible]or[illegible] Y, [illegible]. [illegible]. Att[illegible]nu[illegible] [illegible]nsitivit[illegible] to t[illegible] [illegible]otions o[illegible] ot[illegible]rs [illegible] insul[illegible]r [illegible]sion. *Frontiers in Psychology* **6**: [illegible]. DOI: https://[illegible]oi.or[illegible], PMID: [illegible]

The JASP Team. [illegible]. JASP. 0.9.

Tijssen RH, Jenkinson M, Brooks JC, Jezzard P, Miller KL. [illegible]. Optimizing RetroICor and RetroKCor corrections for multi-shot 3D FMRI acquisitions. *NeuroImage* **84**:[illegible]–[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Tranel D, Damasio H. [illegible]. *Somatic Markers and the Guidance of Behaviour: Theory and Preliminary Testing.* New York: Oxford University Press.

Tzourio-Mazoyer N, Landeau B, Papathanassiou D, Crivello F, Etard O, Delcroix N, Mazoyer B, Joliot M. [illegible]. Automated anatomical labeling of activations in SPM using a macroscopic anatomical parcellation of the MNI MRI single-subject brain. *NeuroImage* **15**:[illegible]–[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Uddin LQ, Kinnison J, Pessoa L, Anderson ML. [illegible]. Beyond the tripartite cognition-emotion-interoception model of the human insular cortex. *Journal of Cognitive Neuroscience* **26**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Uddin LQ. [illegible]. Salience processing and insular cortical function and dysfunction. *Nature Reviews Neuroscience* **16**:[illegible]–[illegible]. DOI: https://doi.org/[illegible]nrn[illegible], PMID: [illegible]

Verstynen TD, Deshpande V. [illegible]. Using pulse oximetry to account for high and low frequency physiological artifacts in the BOLD signal. *NeuroImage* **55**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Wang X, Gu X, Fan J, Wu S, Zhao F, Hof PR, Liu J, Gao Z. [illegible]. Recovery of empathetic function following resection of insular gliomas. *Journal of Neuro-Oncology* **117**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Watson D. [illegible]. Intraindividual and interindividual analyses of positive and negative affect: their relation to health complaints, perceived stress, and daily activities. *Journal of Personality and Social Psychology* **54**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Wiens S. [illegible]. Interoception in emotional experience. *Current Opinion in Neurology* **18**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Windmann S, Schonecke OW, Fröhlig G, Maldener G. [illegible]. Dissociating beliefs about heart rates and actual heart rates in patients with cardiac pacemakers. *Psychophysiology* **36**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Wu Q, Chang CF, Xi S, Huang IW, Liu Z, Juan CH, Wu Y, Fan J. [illegible]. A critical role of temporoparietal junction in the integration of top-down and bottom-up attentional control. *Human Brain Mapping* **36**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Wu T, Dufford AJ, Egan LJ, [illegible] A, Chen C, Yuan C, Chen C, Fan J. [illegible]. [illegible] the cognitive control network in the brain. *Cerebral Cortex* **16**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Wu T, Wang X, Wu Q, Spagna A, Yang J, Yuan C, Wu Y, Gao Z, Hof PR, Fan J. [illegible]. Anterior insular cortex is a bottleneck of cognitive control. *NeuroImage*. DOI: https://doi.org/[illegible], PMID: [illegible]

Xuan B, Mackie MA, Spagna A, Wu T, Tian Y, Hof PR, Fan J. [illegible]. The activation of interactive attentional networks. *NeuroImage* **129**:[illegible]. DOI: https://doi.org/[illegible], PMID: [illegible]

Yarkoni T, Poldrack RA, Nichols TE, Van Essen DC, Wager TD. [illegible]. Large-scale automated synthesis of human functional neuroimaging data. *Nature Methods* **8**:[illegible]. DOI: https://doi.org/[illegible]nmeth[illegible], PMID: [illegible]