Correlation between Impulsiveness, Cortical Thickness and Slant of The Forehead in Healthy Adults

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ABSTRACT

Impulsiveness is a multidimensional psychological construct with high clinical interest because it is a risk factor for several psychiatric disorders. This study was designed to investigate structural correlates of self-reported impulsiveness, measured by using the Short Scale of Impulsive Behaviour, Barratt Impulsiveness Scale and Zuckerman Sensation Seeking Scale V. As a secondary objective, and based on preliminary findings concerning the positive relationship between impulsiveness and the slant of the forehead degrees (SFD), we explore this relationship and the correlation between SFD and cortical thickness (CT) of the entire cortex. From a sample of 48 participants' structural magnetic resonance images, three self-reports measuring impulsiveness and SFD were obtained. CT of the whole cortex was obtained for each participant through Freesurfer. Correlations between impulsiveness and CT and between CT and SFD were analyzed. Correlations between impulsiveness and SFD were also analyzed. Results showed significant adjusted and corrected correlations, both negative and positive, between impulsiveness and CT. Five negative associations with fronto-temporal and occipital areas were found. Of the 15 positive correlations, eight were with the right anterior cingulate cortex and three with left superior frontal gyrus. Positive correlations between 14 impulsiveness scores and SFD were also found. In conclusion, CT in prefrontal and temporal areas influences self-reported impulsiveness in healthy adults. Furthermore, SFD could influence the CT of regions involved in impulsiveness. Finally, we suggest that a higher SFD higher self-reported impulsiveness in healthy adults.

Keywords: *Impulsiveness, Cortical Thickness, Prefrontal Cortex, Free Surfer*

Introduction

Impulsiveness can be defined as "predisposition toward rapid, unplanned reactions to internal or external stimuli without regard to the negative consequences of these reactions" (Moeller *et al*., 2001). Presently, it is regarded as a multidimensional psychological construct (Caswel *et al*., 2015) included in most explanatory models of personality (Whiteside and Lynam, 2001). Impulsiveness can be easily observed in people (Barratt, 1984) and, furthermore, it holds great clinical interest since high levels constitute a risk factor for many psychiatric disorders (Altszuler *et al*., 2016). It has been associated with the attention deficit hyperactivity disorder (Tajima-Pozo *et al*., 2015), with the borderline personality disorder (O'Neill *et al*., 2013), antisocial behaviour (Maneiro *et al*., 2017), substance abuse (Gullo *et al*.,

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2014; Marín-Mayor *et al*., 2014), bipolar disorder (Ozten *et al*., 2015) and addiction to online gambling (Du *et al*., 2016). Therefore, a key question which has yet to be clarified is to define which neurobiological factors are implicated in impulsiveness (Fineberg *et al*., 2014). The prefrontal cortex seems to be the most involved area in the inhibitory control of conduct and the one that has generated most evidence up to now (Knutson *et al*., 2015).

In healthy people, negative associations by using Voxel Based Morphometry (VBM) have been found among impulsiveness and gray matter volume (GMV) of the bilateral orbitofrontal cortex (Matsuo *et al*., 2009; Kumari *et al*., 2009), the left anterior cingulate cortex (Matsuo *et al*., 2009) and the left orbitofrontal cortex (Schilling *et al*., 2013b). In contrast, some positive associations have also been found in frontal and posterior cingulate regions (Cho *et al*., 2013; Gardini *et al*., 2009). A measurement which has generated growing scientific interest in the last decade consists of evaluating the cortical thickness (CT) by surface-based morphometry (SBM), rather than with VBM (Choi *et al*., 2008). Research through SBM has also shown some variations in the CT in prefrontal regions in more impulsive subjects. In a systematic review of CT in people diagnosed with a bipolar disorder, a significant decrease prefrontal areas were observed (Hanford *et al*., 2016). Likewise, in adult patients diagnosed with Attention Deficit Hyperactivity Disorder, lower CT was found in the dorsolateral prefrontal cortex, the orbitofrontal prefrontal cortex and the anterior cingulate cortex (Makris *et al*., 2006). Previous studies also found that healthy subjects with higher scores in self-informed impulsiveness had lower CT in the superior frontal cortex, the medial frontal cortex and the orbitofrontal prefrontal cortex (Kumari *et al*., 2009; Schilling *et al*., 2012; Schilling *et al*., 2013a). More recently, it has been found, by using SBM, that higher impulsiveness traits were associated with a thinner cortex in the left superior, middle and inferior frontal cortex (Tu *et al*., 2017).

In short, the above-mentioned data suggest that morphological variations in prefrontal regions play a fundamental role in impulsiveness, both in healthy and clinical subjects.However, impulsiveness seems not to be solely under the control of the prefrontal cortex (Braquehais *et al*., 2010), since temporal regions are also implicated (Hanford *et al*., 2016; Lyoo *et al*., 2006).

Thus, our main objective is to identify structural correlates of impulsiveness in healthy subjects by exploring the CT of the entire cortex through SBM (http://surfer.nmr.mgh.harvard.edu). As a secondary objective and based on preliminary findings concerning the positive association between impulsiveness and the slant of the forehead (Guerrero *et al*., 2016; 2018a; 2018b) we explored the relationship between the slant of the forehead degree (SFD) and the CT of the entire cortex, an aspect that is yet to be studied.

Material and Methods

Participants

Two advertisements were placed in training centers and libraries of Barcelona city (Spain) in order to recruit our sample. All the subjects were right- handed. The volunteers were screened by a short private clinic interview using Mini-International Neuropsychiatric Interview (Sheehan *et al*., 1998). Those with hyperactivity and attention deficit-related symptoms or a psychiatric background in first-degree relatives were excluded. In total, nine volunteers were excluded. The final sample consisted of 48 volunteers. (66.7% male) with an age mean of 36.2 years-old (SD = 9.9). Their academic level was elementary in 7 subjects (14.6%), intermediate in 16 subjects (33.3%) and university degree in 25 subjects (52.1%). Participants completed three self-reports and after that they went on to take a profile picture, whose method will be further detailed later. Finally, an appointment was made for magnetic resonance imaging. Each participant signed an informed consent before entering the study and agreed on the use of data for research purposes.

Impulsiveness measurements

Multiple scales of self-reported impulsivity were used to ensure a more representative contruct, three self-reports have been used which add up to 15 different scores.

The short scale of impulsive behaviour (UPPS-P) (Whiteside and Lynam, 2001). The Spanish version of the UPPS-P (Cándido *et al*., 2012) also measures five dimensions of impulsiveness: negative and positive urgency, lack of premeditation, lack of perseverance and sensation seeking. The UPPS-P contains 20 items scored by a four-point Likert-type scale, where 1 means fully agree, 2 partially agree, 3 partially disagree and 4 totally disagree; higher scores reflect more impulsiveness.

The Barratt Impulsiveness Scale (BIS-11) (Patton *et al*., 1995). The Spanish version of the BIS-11 (Oquendo *et al*., 2011) also measures impulsiveness as a personality trait. It has three sub-scales: attentional impulsiveness, motor impulsiveness, and non-planning impulsiveness. It has 30 items scored in a Likert-type scale ranging from 0 (rarely or never), 1 (occasionally), 3 (often) to 4 (always or almost always). Higher scores reflect more impulsiveness.

The Zuckerman Sensation Seeking Scale V or SSS-V (Zuckerman *et al*.1978) has been adapted to Spanish by Pérez and Torrubia (1986). It has 40 items and provides total scores as well as four 10-item factors each: thrill and adventure seeking (TAS), experience seeking (ES), disinhibition (DIS) and boredom susceptibility (BS). The choice was compulsory for one of the two alternatives, true or false.

True answers scored one point.

Measurement of the slant forehead degrees

The profile photographs were taken by a digital reflex Canon camera model EOS 1100 D EF-S 18-55. The participants remained seated on a chair previously fixed to the floor by the researcher and all volunteers were trained to adopt a natural head position (NHP). NHP is defined as an innate, physiological and reproducible position achieved when a person is in a relaxed position, sitting or standing, looking at the horizon or at an external reference point (mirror, a point on the wall, etc.) at the same eye level (Moorrees, 1994). Therefore, the edge of the photograph was regarded as the true vertical (TV) and as a reference in the measurement of the SFD. The digital photographs were printed in DIN-A4 format. The degrees of the angle of the forehead inclination were measured by a semicircular protractor (brand Staedtler 568) with a 10cm ruler. Two anthropometric points of reference were taken from the methodology created by Farkas (1994): triquion (TR) and glabella (G). The vertex of the angle was fixed on the glabella, from which two lines were drawn. Line 1 was vertically drawn, parallel to the edge of the photograph TV and was set as 0º. Line 2 was drawn from the G to the TR. The SFD was measured as the angle, in degrees, formed by the line that goes from the G to the TR (Figure 1a). Each participant was independently measured by three experts in craniofacial morphology. The agreement reached between them was high with intraclass correlation coefficient CCI = 0.99. Average of the three SFD measurements was used in the analyses. The same method has been used in previous investigations (Guerrero *et al*., 2016; Guerrero-Apolo *et al*., 2018a: Guerrero-Apolo *et al*., 2018b).

Magnetic resonance imaging acquisition

Magnetic resonance imaging scans were obtained using 1.5 T (GE BRIVO). High-resolution 3D-FSPGR images, powered in T1, were taken for each participant. The acquisition parameters were the following: TE= minimum; TI= 300 ms; Flip Angle= 20º; 130 adjacent axial sections; mould 256 x 256, 25 cm FoV; Slice Thickness = 1.2 mm; Receiver Bandwidth 15.63 Khz.

Structural MRI data preprocessing: Data was analyzed using Freesurfer 5.3.0 (http://surfer.nmr.mgh.harvard.edu). Freesurfer provides automated algorithms for the volumetric segmentation of subcortical structures and estimation of CT (Fischl and Dale, 2000). CT is calculated as the closest distance from the gray/white boundary to the gray/cerebrospinal fluid boundary at each vertex on the tessellated surface (Fischl and Dale, 2000). All the specifications about FreeSurfer parcellations, including reliability, validity and anatomic limits, are described in Desikan, *et al*. (2006). The images were visually inspected so as to detect structural artifacts and abnormalities and none of the segmentations were corrected.

Statistical analysis

To analyze the association between impulsiveness measures and CT and previous verification of linearity, partial Pearson correlation coefficient was calculated. The adjustment terms considered were academic level and age. The ICC was calculated for interobserver agreement. Data was analyzed with Stata 14. Type I error was set at the usual 0.05 level. With the aim of not hiding possible relevant associations, no correction of the Type I error was applied to results presented in the tables. Nevertheless, the false discovery rate (FDR) (Benjamini and Hochberg, 1995) was applied to know what statistics would hold some significance after correction.

Results

Table 1 shows a description of the impulsiveness measures and the SFD. Impulsiveness measures obtained with UPPS-P and Zuckerman showed the most extreme scores, with observed minimum and maximum values matching or close to the theoretically possible. Scores of BIS-11 were less extreme.

Table 1: Description of age, SFD and impulsiveness measures.

N=48	Mean	SD	Minimum	Maximum
Age	36.19	9.90	23	57
Slant of the forehead degrees (SFD)	17.73	5.49	10	34
UPPS-P Total (20-80)	41.83	10.38	24	69
UPPS-P Negative urgency (4-16)	9.79	2.81	5	16
UPPS-P Positive urgency (4-16)	9.39	2.78	4	16
UPPS-P Sensation seeking (4-16)	9.00	2.94	4	16
UPPS-P Lack of premeditation (4-16)	7.22	2.41	4	15
UPPS-P Lack of perseverance (4-16)	6.41	2.43	4	16
BIS11 Total (0-120)	44.35	15.62	21	91
BIS11 Attention impulsiveness (0-32)	13.77	4.55	6	27
BIS11 Motor impulsiveness (0-40)	14.75	6.50	3	32
BIS11 Non-planning impulsiveness (0-48)	15.83	7.04	1	34
SSS-V Total (0-40)	20.22	7.05	5	32
SSS-V Thrill and adventure seeking (0-10)	5.45	3.08	0	10
SSS-V Excitation seeking (0-10)	6.35	2.12	2	10
SSS-V Disinhibition (0-10)	4.25	2.20	0	9
SSS-V Boredom susceptibility (0-10)	4.16	2.01	1	8

Between brackets range of possible values.

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Correlations between impulsiveness measures and cortical thickness

Table 2 shows statistically significant negative adjusted correlations between impulsiveness and CT and Table 3 shows the positives ones. Figure 1b presents the significant cerebral regions. There were six negative (three in left and three in right hemisphere) and fifteen positive (six in left and nine in right hemisphere) results. Four out of the six negatives corresponded to SSS-V boredom susceptibility. From the 15 positives eight were with the caudal anterior cingulate cortex (all in the right hemisphere) and three were with superior frontal cortex (all in the left hemisphere). After FDR correction 19 of 21 significant correlations held significant.

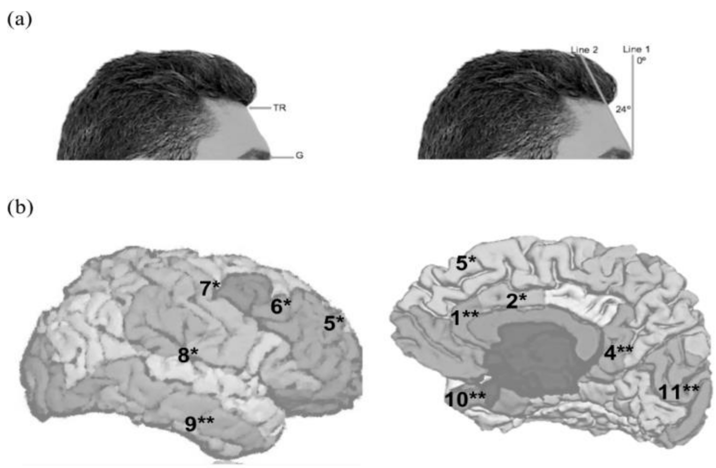


Figure 1. (a) Measurement of the angle of the forehead slant. TR: triquion; G: glabella. (b) Statistically significant correlations between impulsiveness and cortical thickness in regions based on the parcellation system of Desikan et al. (2009): 1. Rostral anterior cingulate cortex; 2. Caudal anterior cingulate cortex; 4. Isthmus cingulate cortex; 5. Superior frontal gyrus; 6. Caudal middle frontal gyrus; 7. Precentral gyrus; 8. Transverse temporal cortex; 9. Inferior temporal gyrus; 10. Bilateral temporal pole; 11. Pericalcarine cortex. *positive correlations. **negative correlations.

Table 2: Statistically significant negative correlations between cortical thickness and impulsiveness measures.

	Rostral anterior cingulate	Isthmus cingulate	Pericalcarine	Inferior temporal	Temporal pole	
UPPS-P			Right			
Lack of premeditation			-0.310			
			0.036			
SSS-V	Left					
Excitation seeking	-0.369					
	0.012*					
SSS-V		Right		Left	Left	Right
Boredom susceptibility		-0.321		-0.338	-0.400	-0.411
		0.030*		0.022*	0.006*	0.005*

In each cell: hemisphere, Pearson correlation (adjusted by academic level and age), uncorrected p value

*Significant after FDR correction.

Table 3: Statistically significant positive correlations between cortical thickness and impulsiveness measures.

	Caudal anterior cingulate	Caudal middle frontal	Precentral		Superior frontal	Transverse temporal
UPPS-P Total	Right					
	0.041					
	0.004*					
UPPS-P	Right					
Positive urgency	0.308					
	0.037					
UPPS-P	Right	Left				
Sensation seeking	0.499	0.371				
	<0.0005*	0.011*				
UPPS-P	Right					Left
Lack of premeditation	0.380					0.292
	0.009*					0.049*
UPPS-P	Right					
Lack of perseverance	0.319					
	0.031*					
BIS11 Total	Right				Left	
	0.327				0.345	
	0.026*				0.019*	
BIS11 Attention impulsiveness			Left	Right	Left	
			0.361	0.302	0.402	
			0.017*	0.041*	0.006*	
BIS11 Motor impulsiveness					Left	
					0.298	
					0.044*	
BIS11 Non-planning impulsiveness	Right					
	0.357					
	0.015*					
SSS-V Total	Right					
	0.300					
	0.043*					

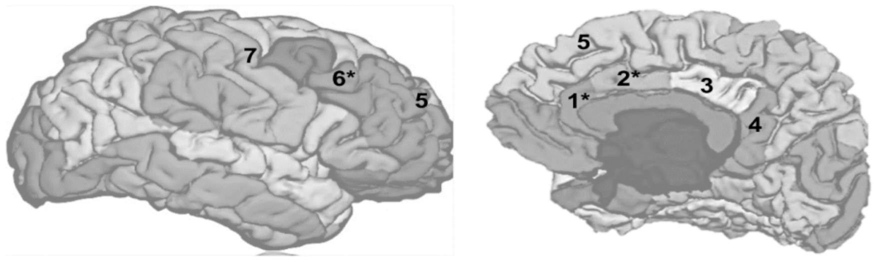
In each cell: hemisphere, Pearson correlation (adjusted by academic level and age), uncorrected p value

*Significant after FDR correction.

Correlations between slant of the forehead degree and cortical thickness

Figure 2a graphically and Figure 2b numerically present adjusted correlations between CT and SFD. Six positive associations were found statistically significant and half of them continued to be significant after FDR correction. The six correlations were very similar with values slightly above 0.30.

(a)



(b)

	r^1	Uncorrected p
Right caudal anterior cingulate cortex	.305	.035*
Right cingulate cortex	.310	.032
Right anterior cingulate cortex	.304	.035*
Right medial prefrontal cortex	.314	.030
Left caudal middle frontal gyrus	.304	.036*
Left motor cortex	.357	.013

Figure 2. (a) Statistically significant positive correlation between cortical thickness and the slant forehead degrees in regions based on the parcellation system of Desikan et al. (2009): Freesurfer gyral labels: Cingulate cortex (1. Rostral anterior cingulate cortex, 2. Caudal anterior cingulate cortex, 3. Posterior and 4. Isthmus cingulate cortex); Anterior cingulate cortex (1. Rostral anterior cingulate and 2. Caudal anterior cingulate cortex); Medial prefrontal cortex (1. Rostral anterior cingulate cortex 2. Caudal anterior cingulate cortex, and 5. Superior fronta gyrus); Motor cortex (6. Caudal middle frontal gyrus and 7. Precentral gyrus). (b) Correlation between cortical thickness and the slant forehead degrees. [1]: Pearson correlation adjusted by academic level and age. *Significant after FDR correction.

Correlations between slant of the forehead degree and impulsiveness

Table 4 presents statistically significant adjusted correlations between the impulsiveness measures obtained with the three questionnaires and SFD. Statistical significance was obtained for fourteen out of the fifteen correlations calculated. All significant correlations were positive, ranging from values r = .336 (UPPS-P Lack of perseverance) to r = .607 (UPPS-P Sensation seeking). After FDR correction none of the fourteen correlations lost statistical significance.

Table 4: Statistically significant positive correlations between impulsiveness measures and slant of the forehead degrees.

	Slant of the forehead degrees
UPPS-P Total	0.534
	<.0005*
UPPS-P Positive urgency	0.407
	.005*
UPPS-P Sensation seeking	0.607
	<.0005*
UPPS-P Lack of premeditation	0.522
	<.0005*
UPPS-P Lack of perseverance	0.336
	.023*
BIS11 Total	0.528
	<.0005*

BIS11 Attention impulsiveness	0.556
	<.0005*
BIS11 Motor impulsiveness	0.453
	.002*
BIS11 Non-planning impulsiveness	0.392
	.007*
SSS-V Total	0.585
	<.0005*
SSS-V Thrill and adventure seeking	0.395
	.007*
SSS-V Excitation seeking	0.425
	.003*
SSS-V Disinhibition	0.502
	<.0005*
SSS-V Boredom susceptibility	0.408
	.005*

In each cell: Pearson correlation (adjusted by academic level and age), uncorrected p value.
*Significant after FDR correction.

Discussion

In this exploratory study we have found some significant correlations between the self-reported impulsiveness and cortical thickness in the prefrontal and temporal regions in healthy subjects. These findings are consistent with growing evidence of the influence of frontotemporal variations on impulsiveness. Furthermore, it is the first study which finds a positive correlation between the slant of forehead degree and the cortical thickness in prefrontal regions.

We also sought to obtain a higher self-reported representativeness of impulsiveness, which accounts for the 15 analyzed scores. In the exploration of the CT and its association with the UPPS-P model, we have found significant correlations in four scores. With respect to the negative ones, only the factor lack of premeditation has correlated with the right pericalcarine cortex. There exists scant evidence of the effect of pericalcarine cortex on impulsiveness, although some negative correlations have been found between the CT and the local gyrification index (LGI) in sensation seeking and attention impulsiveness (BIS) respectively (Holmes *et al.*, 2016; Hirjak, *et al.*, 2016). Despite the fact that the UPPS-P structural correlations are hardly known, this finding backs up former studies on significant morphological variations in the right pericalcarine cortex in terms of the presence of impulsive traits. However, we must point out that lack of premeditation has not been able to stand a statistical significance correction (FDR, $p < 0.05$).

In the UPPS-P questionnaire the positive correlations found must be highlighted. In particular the total scores and factors such as positive urgency, sensation seeking, lack of premeditation and lack of perseverance have correlated with the CT in the right caudal anterior cingulate cortex and, except positive urgency, all the above-mentioned factors have stood an FDR correction. These findings are in agreement with previous studies which, by using VBM, also found positive correlations between impulsiveness factors and GMV in right superior and middle frontal cortex, medial prefrontal cortex and posterior and anterior cingulate regions (Gardini *et al*., 2009; Cho *et al*., 2013). In the standard FreeSurfer atlas (Desikan *et al*., 2006), the caudal anterior cingulate cortex is part of the anterior cingulate cortex, whose region establishes significant associations between impulsive traits and morphological variations (Gardini *et al*., 2009; Matsuo *et al*., 2009; Thomann *et al*., 2015). Furthermore, the cingulate cortex has been associated with control of impulses, novelty seeking, persistence and impulsive behaviour (Bechara, 2005; Gardini *et al*., 2009). This finding may suggest that an increase in the CT of the right caudal anterior cingulate cortex exerts an influence on impulsiveness assessed with the UPPS-P model and, consequently, one might think of a consistent neuro-anatomical correlate found for this model.

On the other hand, the sensation seeking factor has also positively correlated with the left caudal middle frontal cortex. This region seems to be involved with cognitive control (Goghari and MacDonald, 2008) and inhibition of impulsive decisions (Essex *et al*., 2012). From this perspective it's surprising that the left caudal middle frontal cortex has solely correlated with the sensation seeking factor out of the 15 scores analyzed. This seems to suggest a modest influence of the CT of the middle frontal cortex on the impulsive traits depicted in this study. Contrary to this finding, however, a negative association (Holmes *et al*., 2016) has previously been observed, which leads us to be very cautious about drawing conclusions. Furthermore, although the UPPS-P model is made up of our very different traits (Sharma *et al*. 2013) our exploration shows consistent evidence of a common neuroanatomical structure (right caudal anterior cingulate cortex) in five out of six scores of the model analyzed. Unlike some previous studies (Boes *et al*., 2009; Matsuo *et al*., 2009; Schilling *et al*., 2012; Tu *et al*., 2017) We did not find any negative associations between the CT and BIS. Our results show positive correlations (after FDR correction for all the scores) in influencing areas in the inhibitory control of impulsive conduct (superior frontal cortex and caudal anterior cingulate cortex). Which is consistent with earlier studies where the same association was found in prefrontal (Gardini *et al*., 2009; Cho *et al*., 2013; Du *et al*., 2016) and temporal (Schilling *et al*., 2012) areas. However, the heterogeneity of results of previous studies makes it difficult to draw some conclusions about the relationship between the variability in CT of prefrontal areas and BIS. Despite that our results in BIS seem to back up the evidence, independent of the CT, of the critical role of prefrontal and temporal structures. The correlation between the BIS total score with right caudal anterior cingulate cortex and left superior frontal cortex contrasts with the negative association found in left superior frontal cortex (Tu *et al*., 2017), which suggests, along with our findings, that variations in the left superior frontal cortex influence impulsiveness assessed with BIS total score. Another score, attention impulsiveness, not only correlates with the left superior frontal cortex, but also with the bilateral precentral cortex, a region which seems to be implicated in inhibitory control (Ma *et al*., 2012). This observation concerning the precentral cortex is consistent with previous studies, where positive associations with the impulsiveness in an adolescent sample were found by using VBM (Schilling *et al*., 2013b). The same association was found in the LGI in precentral and postcentral regions (Hirjak *et al*., 2016). Another factor that has correlated with the left superior frontal cortex has been motor impulsiveness. This finding is contrary to previous observations (Matsuo *et al*., 2009; Schilling *et al*., 2012). Even though our sample is comparable to previous studies, the factorial structure of the BIS-11 has been troublesome and the results derived from this self-report must be cautiously interpreted (Reid *et al*., 2013). Our findings in BIS show that variations in CT, in the left superior frontal cortex, can become an influencing structural correlation. Furthermore, the only scores that has not correlated with superior frontal cortex has been non-planning impulsiveness, an observation that is consistent with a previous study (Schilling *et al*. 2012). However, this factor has indeed correlated with the right caudal anterior cingulate cortex, where positive correlations have been found by using VBM (Cho *et al*., 2013; Gardini *et al*., 2009) as well as some variations in the LGI of frontal areas (Hirjak *et al*., 2016). This seems to indicate that regions of the cingulate cortex also exert their influence on non-planning impulsiveness.

Our latest self-report analyzed (SSS-V) showed four negative and one positive correlations, all of them in different brain regions (corrected results), which confirmed the higher number of negative correlations found in the three self-reports analyzed. With respect to the negative correlations, we have found a correlation between the ES and the CT in the left rostral anterior cingulate cortex. This finding can be expected given the influence of the cingulate cortex on impulsiveness traits (Gardini *et al*., 2009; Matsuo *et al*., 2009). What we found in the BS factor is more unexpected because of its correlation with four brain regions (right isthmus cingulate, right temporal pole, left temporal pole and left inferior temporal). This factor showed no correlations with the other three factors that make up SSS-V (Zuckerman *et al*., 1978). Together with our finding, this suggests that BS may be an independent factor where reductions in the CT of temporal and posterior regions of the cingulate cortex could be implicated in this trait. Therefore findings in right temporal pole, left temporal pole and left inferior temporal cortex support former studies on the importance of temporal regions in the manifestation of impulsive traits (Gardini *et al*., 2009; Hanford *et al*., 2016; Hirjak *et al*., 2016; Schilling *et al*., 2012; Schilling *et al*., 2013b), including general impulsiveness (Lyoo *et al*., 2006). They also support the evidence that impulsiveness is not exclusively under the control of the prefrontal cortex (Braquehais *et al*., 2010).

On the other hand, TAS is regarded as a non-impulsive way of seeking sensations (Zuckerman, 1983). Oddly enough, TAS did not correlate with any brain structures in our study. This finding can support Zuckerman's TAS and back up the idea of the uses of the factors ES and BS as an equivalent measurement for impulsiveness. Although the sensation seeking trait and impulsiveness have distinct developmental trajectories (Steinberg *et al*., 2008), they can share a common neuroanatomical structure as well as underlie the same neurobiology (Holmes *et al*., 2016). Considering the influence exerted by impulsiveness on the sensation seeking trait (Eysenck and Eysenck, 1985), it would back up the use of SSS-V as an equivalent measurement to impulsiveness.

On the other hand, SSS-V total score has only correlated with right caudal anterior cingulate cortex (corrected result), which supports the evidence shown in this study concerning the influence of this region on the impulsive traits. In this sense, it is worth highlighting that right caudal anterior cingulate cortex has correlated with eight scores, including the total score of the three self-reports analyzed.

With respect to our secondary objective, this is the first study that explores the SFD with the CT of the entire cortex. Our finding of the positive correlations between SFD and the CT in prefrontal regions (Figure 2) with self-reported impulsivity supports the growing body of scientific evidence of the influence of these regions on the self-reported impulsiveness. Based on our data it seems that SFD can influence the CT in frontal but not posterior regions of the brain. However, the complexity in discussing these findings is obvious and more studies need to be carried out in order to draw consistent conclusions. It appears that the frontal lobes influence the shape of the forehead and a higher development in of the frontal protuberance (bulky superciliaries) results in a higher slant (Balueva and Lebedinskaya, 1991). Likewise, subjects with protruding superciliar structure seem to report structure seem to report a higher obstinacy in their behaviour (Han and Park, 2014). This observation is consistent with Pujol, *et al*. (2011), where it was found that more compulsive subjects, therefore, possibly more impulsive (Voltas-Moreso *et al*., 2013) presented with a lengthening pattern in the space of the cerebral-spinal fluid of the frontal operculum which correlated positively with the frontal protuberance (superciliary arches). Together with our finding, it is necessary to point out that previous studies suggest that the structure of the face can facilitate information about the brain (Sisodiya *et al*., 2008) or that the face, the craniofacial skeleton and the central nervous system have an interconnected development (Kjaer, 1995).

Some limitations to our study must be duly considered. First, we did not control the consumption of tobacco or other substances A factor that is strongly associated with externalization or disinhibitory disorders (alcohol dependence, drug taking or behaviour disorders) is negative urgency of the model UPPS-P (Settles *et al*., 2012), where no correlation was found.

Second, the size of the sample was modest, which limits the generalization of our results. However, the number of participants is similar to comparable former previous studies (Kumari *et al*., 2009; Schilling *et al*., 2012).

Third, our study has focused on subjective impulsiveness measurements and, despite being described as an efficient method (Mathias *et al*., 2008), it would be convenient to replicate or refute our findings with objective measurements since there exists the evidence of no correlation between objective measurements and GMV in frontal areas (Tschernegg *et al*., 2015). That is why we must be cautious and limit our findings to the instruments used rather than to impulsiveness broadly speaking.

Finally, despite the existence of individual differences in the profile view of the slant of the forehead (Adams *et al*., 2013; Oh *et al*., 2016; Guerrero *et al*., 2016; Guerrero *et al*., 2018a,) an aspect that can trigger some controversy is the anthropometric measurement SFD. However, a recent study found a high level of interobserver agreement in the visual assessment of the level of the forehead slant, whose measurement obtained a high correlation with the anthropometric SFD measurement (Guerrero *et al*., 2016; Guerrero *et al*., 2018a). This backs up the validity of the anthropometric SFD measurement used in this study. Furthermore, in our SFD measurement the NHP has been taken into account, usually used in profile photographs in order to control the placement of the reference points in teleradiography (Lundstrom, *et al*., 1995).

In conclusion, our exploration supports the growing evidence of the importance of the CT variations in frontal and temporal areas in the assessment of self-reported impulsiveness among healthy subjects. If we consider that the morphology of craniofacial structures and that of the brain is interwoven in a complex fashion (DeMyer, 1975), then we can suggest a relationship between the slant of the forehead and the CT variations in frontal regions. However, this preliminary finding must be taken cautiously and we must and observe the results of future investigations. We suggest that a new line of research could be opened about the importance of SFD in the manifestation of the impulsive behavior in healthy subjects, as well as about the relationship between SFD and structural and functional aspects of the underlying brain tissue. Thus, this study examined the cortical thickness correlates of auto-report impulsiveness, demonstrating that prefrontal and temporal regions are crucial for impulsiveness in healthy adults. Likewise, the slant of the forehead is associated with the thickness of crucial cortical regions for impulsiveness traits.

Abbreviations: BIS-11: Barratt Impulsiveness Scale; BS: Boredom Susceptibility; CT: Cortical Thickness; DIS: Disinhibition; ES: Experience Seeking; G: Glabella; GMV: Gray Matter Volume; NHP: Natural Head Position; TAS: Thrill and Adventure Seeking; TR: Triquion; SBM: Surface-Based Morphometry; UPPS-P:

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Short Scale of Impulsive Behaviour; SFD: Slant of The Forehead Degree; SSS-V: Zuckerman Sensation Seeking Scale V; TV: True Vertical; VBM: Voxel Based Morphometry

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