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Strong vs Weak Teams and Brand Love: Neural Correlates of Decision Making in Football Fans

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Strong vs Weak Teams and Brand Love: Neural Correlates of Decision Making in Football Fans

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Esta tese é dedicada aos meus pais e à minha namorada,

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Abstract

Football is responsible for individuals aggregation based on mutual interests and common empathetic understanding. The outcomes of such experiences can be so rewarding that ingroup members are strongly driven to perform a variety of personal efforts. This mechanism can be fairly comparable to consumer's behaviours in the means the individuals are willing to sacrifice their own resources to get the object of desire. The aim of the present work was to assess whether the relationship between a strong or weak brand and the respective consumers, represented by football teams and the correspondent supporters, can generate different brain activity patterns during a monetary sacrifice test.

Subjects were separated in 3 different groups based on team preference and based on the score of fanaticism, as revealed by the Football Supporter Fanaticism Scale (FSFS). Therefore in the "Control" group (n=20) we have both *Futebol Clube do Porto* (FCP) and *Associação Académica de Coimbra* (AAC) fans who achieved the lowest scores in the fanaticism scale (FSFS), a "FCP" group (n= 18) containing the highest scored Porto fans and finally "AAC" (n=18) referring to Académica supporters with higher score in the FSFS scale. In the performed test, volunteers were asked how much they were willing to pay to watch live a specific match while fMRI scanned. The list of questions included not only matches involving subject's team playing in different competitions and/or against different opponents, but also neutral matches. The answers were recorded and grouped in 3 intervals according to their value.

Results showed that situations of higher sacrifice evoked a higher recruitment of prefrontal, orbitofrontal and parietal regions. When facing the hardest dilemmas, the weak team fans demonstrated a more emotional-based neural response due to the greater involvement of insula, while those belonging to a strong team tend to downregulate the neural response on cognitive control areas. The categorization of

Fanatic is associated to impulsive decisions that did not seem to require much deliberation based on the reduced activity of areas related to conflict monitoring.

Keywords: fMRI, Decision Making, Neuroeconomics, Brand Love, Football.

Resumo

O Futebol é responsável pela agregação de indivíduos com base no seu interesse mútuo e compreensão empática comum. Os resultados de tais experiências podem ser tal ordem recompensantes que os membros do grupo são fortemente compelidos a fazer uma variedade de esforços. Este mecanismo pode ser justamente comparável aos comportamentos de um consumidor, na medida em que estão dispostos a sacrificar recursos próprios para obter o objeto de desejo. O objetivo do presente trabalho foi avaliar se a relação entre uma marca forte ou fraca e o respetivo consumidor, representados por equipas de futebol e os correspondentes adeptos, podem gerar diferentes padrões de atividade cerebral durante um teste de sacrifício monetário.

Os sujeitos foram separados em 3 grupos diferentes com base na preferência clubística e na pontuação de fanatismo, revelada pela Football Supporter Fanaticism Scale (FSFS). Desta forma, no grupo "Control" (n=20) havia tanto adeptos do *Futebol Clube do Porto* como da *Associação Académica de Coimbra* que obtiveram os resultados mais baixos na escala de fanatismo (FSFS), o grupo "FCP" (n=18) contendo os adeptos com maior pontuação do Porto e finalmente o grupo "AAC" (n=18) referente aos adeptos da Académica com maior pontuação na escala FSFS. Na tarefa executada, os voluntários foram questionados sobre o quanto estariam dispostos a pagar para assistir ao vivo a jogos de futebol específicos, enquanto submetidos a fMRI. A lista das perguntas incluía não só jogos envolvendo o clube preferido do sujeito em diferentes competições e/ou contra diferentes adversários, mas também jogos neutros. As respostas foram registadas e agrupadas em 3 intervalos de acordo com o seu valor.

Os resultados mostraram que situações de maior sacrifício recrutam regiões cerebrais prefrontais, orbitofrontais e parietais. Perante situações de dilemas complicados, os fãs da equipa fraca demonstraram uma resposta neuronal mais

emocional tendo em conta o maior envolvimento da insula, enquanto aqueles que pertencem a uma equipa forte tendem a ter resposta diminuída em áreas de controlo cognitivo. A classificação de fanático está associada a decisões impulsivas que não envolveram muita deliberação, o que se pode traduzir na atividade reduzida em áreas relacionados com a monitorização de conflito.

Palavras-chave: fMRI, Tomada de Decisão, Neuroeconomia, Amor por Marcas, Futebol.

Symbols & Abbreviations

Symbols

$\vec{\mu}$	Magnetic Moment
B_0	Static External Magnetic Field
$\vec{M}_0$	Net Magnetization
γ	Gyromagnetic Ratio
ω_0	Larmor Frequency
ω_H	Larmor Frequency of Hydrogen
ω_{RF}	Larmor Frequency of Radiofrequency Pulse
$\vec{M}_Z$	Longitudinal Component of Net Magnetization
$\vec{M}_T$	Transverse Component of Net Magnetization

Abbreviations

AAC	Associação Académica de Coimbra
AC-PC	Anterior Commissure – Posterior Commissure
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
BA	Brodmann Area
BOLD	Blood-oxygen-dependent Level
deOxyHB	Deoxyhemoglobin
EFTF	Escala de Fanatismo de Torcedores de Futebol
EPI	Echo Planar Imaging
FCP	Futebol Clube do Porto
FDR	False Discovery Rate
FIFA	Fédération Internationale de Football Association
fMRI	functional Magnetic Resonance Imaging
FOV	Field of View
FSFS	Football Supporter Fanaticism Scale
GLM	General Linear Model
GRE	Gradient-echo
GLM	General Linear Model
HDR	Hemodynamic Response
IV	Independent Variable
L	Left
LPFP	Liga Portuguesa de Futebol Profissional
mm	millimetres
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
Ms	Milliseconds
OFC	Orbitofrontal Cortex
OxyHB	Oxyhemoglobin
PET	Positron Emission Tomography
RF	Radiofrequency
RFX	Random Fixed Effects

R	Right
SSIS	Sport Spectator Identification Scale
TE	Echo Time
TR	Repetition Time
UEFA	Union of European Football Associations
US	United States

Contents

Chapter 1

Introduction

1.1 Motivation and State of the Art

Football, more than any other sport, is an object of interest for millions of people spread all over the world. Every day, we are confronted with manifestations of this love that goes from coffee conversations, media coverage or the bustle in day match. All this atmosphere brings people closer, who identify with each other based on the mutual interest. Affiliative groups formation is a natural consequence of this spirit. The resulting social aggregation effect, which can be seen as ingroup love, is not exclusive of football and it has being studied under other contexts. These studies have shown that individuals act with partiality to benefit ingroup members, whether they are race related [1, 2], political affiliation related [3], and even related to sports team favoritism [4, 5]. The interest and involvement in football or any other sport can be expressed by many ways and at different levels. The term "fanaticism" used in this thesis refers exclusively to the intensity of being fan and not to any kind of negative meaning related to mental disorders or to hooliganism phenomena.

Besides the social component, football is no longer a simple sport's event where people get together to watch the match. Nowadays, it became a business moving millions, where sometimes sporting success is put behind the financial success. Concerning specifically football, FIFA reports revenues of over 2 billion U.S. dollars in 2014 (FIFA 2015). In the English premier league, the total amount spent in transfers of football players was numbering in the hundreds of million pounds sterling (BBC Sport

2015). This is only possible thanks to all devotion of the fans who abdicate part of their time and money in favour of the club, truly becoming consumers. And as it happens with any consumer, the temptation to acquire the target of desire is modulated by both extrinsic and intrinsic factors. The passion and ingroup acceptance felt by individuals in those environments has the potential to precipitate actions in the hope of getting more and more of these affiliative sensations. This happens even if it costs substantial amounts of money. We can consider this link between football fans and theirs teams as recognized phenomenon. Even though, the neurobehavioural correlates of this phenomenon is not explored yet. In fact, a more general approach to the study of the individual attachment to a team, using imaging tools, is recent [6]. The aim of the present thesis is to study the dilemma of personal (financial) sacrifice versus team related affiliative activities and to understand the neural correlates of decision making in this context.

Decision making is often studied under social dilemmas. The aim of those studies is to understand the neuronal correlates of the competition and cooperation in social interactions [7]. The tools for these kind of studies are cooperative games, as the prisoner's dilemma [8-10], and often economic games, as the ultimatum game [11, 12]. The decision making process starts with the assessment of the context, i.e. the extrinsic incentives are evaluated. The formation of the reward value, given by the context, involves the ventromedial prefrontal cortex, ventral striatum and the caudate nucleus [7]. This content is processed in another network, which is thought to involve the prefrontal cortex, the orbitofrontal cortex [13] and the anterior cingulate cortex [7]. This cognitive control system processes the willingness on cooperation and the final decision direction. Of course, as the mentioned studies are related to social dilemmas, other areas related to social cognition are often recruited. Areas often reported to be involved on mentalizing and on the process of trust signals are the dorsomedial prefrontal cortex, amygdala and temporo-parietal junction [7, 14, 15].

However, this unique human behaviour has been shown that it does not rule itself by predictive models of outcome maximization, even less material or monetary outcomes [16-18]. This means that the decision on cooperation is not strictly based on self-interest and other motives are known to influence the behaviours in social

interactions. Specifically in the context of the present study, football motivates the individuals to sacrifice their own resources, without expecting any monetary or material return. This does not mean that they do not feel somehow rewarded, at least from the point of view of the personal economic status. In fact, [6] data shows that reward regions are recruited while the participants are seeing positive videos of their preferred team comparing to the visualization of neutral or negative clips. Interestingly, the signal in some of those areas showed to be correlated to the scores of fanaticism.

Little is known about the brain processes under the willing to sacrifice own resources. Dawes and colleagues studied monetary sacrifice to favour the equality in a group. They focused the analysis in the ventromedial prefrontal cortex and the insular cortex. The first was found to be associated to the decision making, while the activity in the insular cortex showed to be correlated to egalitarian behaviour [19]. Harbaugh et al. found that voluntary giving elicited activity in reward related areas, namely caudate nucleus, right nucleus accumbens and insula [20]. Moll and colleagues also found that the reward system is engaged during giving in the same way as when receiving money. They also found that medial orbitofrontal cortex, subgenual cingulate and lateral orbitofrontal cortices mediate the decisions [12]. Monetary based decision has been widely used as a valuable tool in studies evaluating the decision making, because money is a quantifiably unit which considered a good for any person and is one of the most frequent object of deliberation in daily contexts [21].

However, the nature of human behaviour under these studies is related to altruistic behaviour. Pure altruism should not be the motive for football fans will to sacrifice money, although that behaviour can share similar hedonic consequences. Hedonic motives can act also in economic decision making. Decision making on consumer is known to be driven by the prices as well as the product preference. A study using cars as triggers of rewarding mechanisms showed that product preference in this case involves the ventral striatum, medial prefrontal and anterior cingulate cortices [21]. Medial prefrontal cortex activations were also related to the consumer preference when viewing pictures of the preferred versus non-preferred drink [22], and when tasting preferred versus non-preferred drinks [23]. A study using logos of strong (well-known) and weak (lesser known) brands of car manufactures showed that

while strong brands activate positive emotional processing and associate with self-identification and reward areas, weaker brands had increased levels of activation in areas of working memory and negative response. Furthermore this effect was independent of the product [24].

Consequently it is not surprising the increasing attention that clubs pay to promote their image for the respective fans. To be seen as strong or weak brand can have a huge impact at revenues in terms of merchandise, stadium attendance and even on other products related to the club. Naturally, the motivation to find out which neural mechanisms dictate the way humans perceive brands with different appealing degrees came before the alteration of paradigm in football clubs. Brands in general, showed a huge interest in this area with the hope to find in neuroscientific approaches to increase their incomes.

In order to make a parallelism between football and brand context, we used subjects belonging to two different teams with specific characteristics. Therefore the choice for FCP and AAC subjects was not naïve. Among tens of national and international achievements, FCP won 27 national championships, being the last one in the period 2012/2013, while AAC writes its most relevant history by the conquest of two Portuguese national cups and two championships of the second division. At the time of the participants' recruitment and fMRI acquisitions, FCP was one of the top three teams of the Portuguese First League, while AAC was one at the bottom of the classification rank. Regarding that timing (the 2014/2015 championship), FCP ended it in the 2nd place, while AAC got the 15th place. In that season FCP won both matches against AAC. UEFA puts FCP in the 16th place in the teams ranking, while AAC is ranked at 126th place in the same season (UEFA, 2016). Regarding the associative members of each team, FCP and AAC were thought to have 110,000 and 11,000 members, respectively. Considering the stadium assistance, FCP stood around 30,000 spectators per home match, while AAC had an average of 4,666 spectators (LPFP, 2015). Considering these drivers [25-27], henceforward, we will consider FCP as the Strong brand and AAC as the Weak brand.

1.2 Magnetic Resonance Imaging

1.2.1 Magnetic Resonance Principles

By taking advantage of the nuclear magnetic resonance effect in certain elements, MRI combines stationary magnetic fields and radiofrequency pulses in order to rearrange the intrinsic movement of nuclear particles. This medical imaging technique allows structural differentiation based on atomic constitution of different tissues and can be used in both diagnosis and research areas [28].

Magnetic moment is an exclusive physical property of atoms that have an odd number of neutrons or protons caused by their magnetic dipole behaviour. Like any other magnetic dipole, it interacts with external magnetic fields which in this case is produced by the Magnetic Resonance Scanner. Since more than 2/3 of human body is constituted by water, hydrogen is the preferred element for this technique. Having only 1 proton, hydrogen is part of many molecules that goes from water to macromolecules such as proteins and lipids [28].

The intrinsic movement of protons previously mentioned is called spin. Essentially, it is described as a gyroscopic motion around the particle's own axis. For being a characteristic of electric charged particles, spins create themselves magnetic fields that can interact with external magnetic fields [28, 29]. Normally, proton spins act like small magnetic dipoles, with a magnetic moment $\vec{\mu}$ associated with the same magnitude but randomly orientated in space. In the presence of a static external magnetic field B_0, spins tend to orientate towards the B_0 direction. While most of spins end up pointing in the same way (parallel orientation) of the external field, some of them positioning on the opposite way (anti-parallel orientation). In the end, there is always an imbalance favoring the parallel orientation. For this reason, the sum of every spin moment called net magnetization $\vec{M}_0$ it's always aligned parallel to B_0 [28, 30].

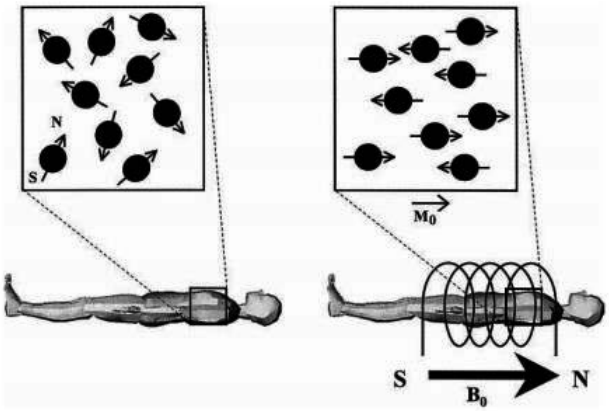

Figure 1: Randomly orientated spins on a natural environment (left), align on the presence of an external magnetic field according to its direction (right). Adapted from [31].

Precession that spins describe around the axis defined by B_0 can occur at different rates. Each element from periodic table has a specific precession frequency ω_0 associated called Larmor Frequency [29]. This value depends on the magnitude of the applied magnetic field B_0 and on gyromagnetic ratio γ following:

$$\omega_0 = \gamma B_0 \qquad 1$$

After applying the static magnetic field responsible for the precession alignment of protons spins, a radiofrequency (RF) pulse is emitted. If this wave has the same frequency as the Larmor frequency of hydrogen protons ($\omega_{RF} = \omega_H$) it will disturb the equilibrium state of net magnetization by transferring energy to the system. Extra-energized spins increase their precession angle relatively to magnetic field B_0 in such way that net magnetization can be separated into two different components: one the longitudinal $\vec{M}_Z$ and the other transverse $\vec{M}_T$, parallel and perpendicular to B_0, respectively. At this point the system reaches the resonance state [28, 29, 31].

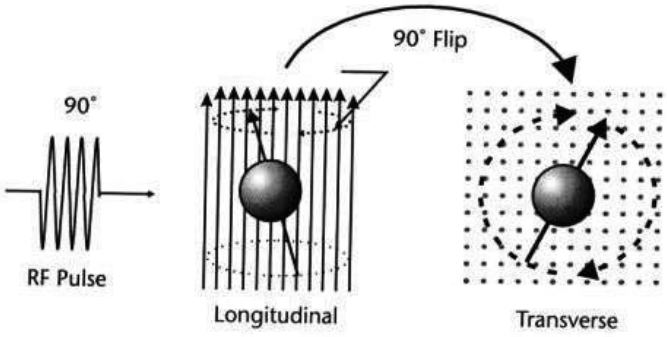

Figure 2: The excitation of a magnetic nucleus by the application of a pulse of RF energy. Longitudinal (middle) and Transverse (right) magnetization components. Adapted from [32].

After some time RF signal is turned off, this makes spins recover their initial condition of equilibrium in a process known as relaxation. The excess of energy responsible for the resonance state is transferred to the rest of system, returning net magnetization $\vec{M}_0$ back to external field's direction. While $\vec{M}_T$ decreases back to 0 (transverse relaxation), $\vec{M}_Z$ resumes its initial intensity (longitudinal relaxation) at different rate [28, 30]. Both relaxation processes produces a measurable RF signal that can be detected by coils presented in the magnetic resonance scanner. The measured signal reflects the atomic constitution of the targeted area and, after some computational treatment, provides the anatomical profile of the different structures [30].

1.2.2 Functional Magnetic Resonance Imaging

Early applications of nuclear magnetic resonance phenome in medical imaging refer to anatomical assessments as alternative to other methods involving ionic radiations such as X-Rays. However, structural studies are limited in that they cannot reveal short-term physiological changes associated with the active functioning of the brain. Functional neuroimaging studies can help overcome this limitation both by identifying the different parts of the brain where particular mental processes occur and

by characterizing the patterns of brain activation to mental function. Functional neuroimaging did not begin with fMRI, until the past decade the most commonly used functional neuroimaging technique was positron emission tomography (PET), which relies on the injection of radioactive tracers to measure changes in the brain, such as blood flow or glucose metabolism. Unlike PET method, fMRI is an imaging technique that does not require any radioactive contrast [33].

Functional magnetic resonance imaging takes advantage of brain hemodynamic alterations produced by human mental processes [34]. These imaging methods are able to detect neuronal activity through changes in regional blood perfusion, volume or even blood oxygenation [35]. Neural activations request greater energetic demands that can only be ensured by increased blood flow. One of many molecules present in blood is hemoglobin, which between several functions it is responsible for carrying oxygen to all cells. Depending whether oxygen is attached or not, hemoglobin can assume two forms oxyhemoglobin (OxyHb) or deoxyhemoglobin (deOxyHb) respectively. While oxygenated, hemoglobin behaves as diamagnetic substance, on the other hand deoxygenated hemoglobin is paramagnetic, changing the local magnetic susceptibility, which leads to the creation of magnetic field distortions in the presence of high intensity magnetic fields [36].

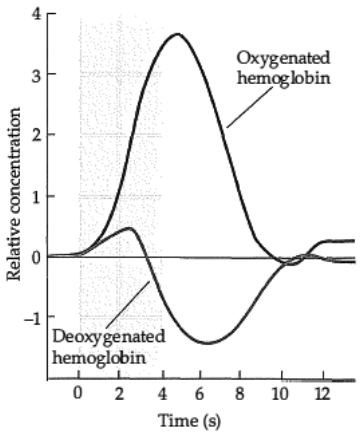

Figure 3: Changes in oxygenated and deoxygenated hemoglobin following neuronal stimulation. Adapted from [37].

Since the state of blood oxygenation is the key parameter being employed in this method, it is referred as using blood oxygen level dependent (BOLD) contrast, where the generated functional images derive from the correspondent BOLD-signals in each brain region [34]. Areas with higher ratio of OxyHB/deOxyHB will be brighter due to the reduced distortions provoked by its presence, while brain locations with low concentration of oxygenated hemoglobin will lead to weaker MR signal, thus appearing dark [38]. Thanks to the specificities of blood dynamics, this method provides an image spatial resolution that is of the order of a few millimeters, with a temporal resolution of a few seconds [35].

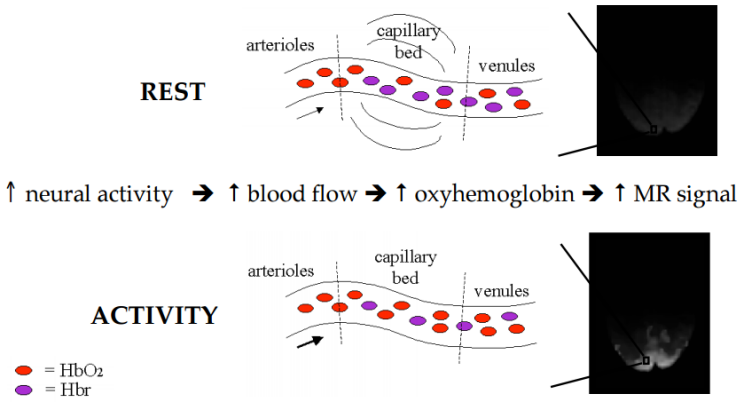

Figure 4: Schematic representation of BOLD effect in blood veins. Adapted from [39].

The change in the MR signal triggered by neuronal activity is known as the hemodynamic response (HDR). Its shape may varies between brain regions, but the hemodynamic response function in general follows the curve represented in **figure 5**.

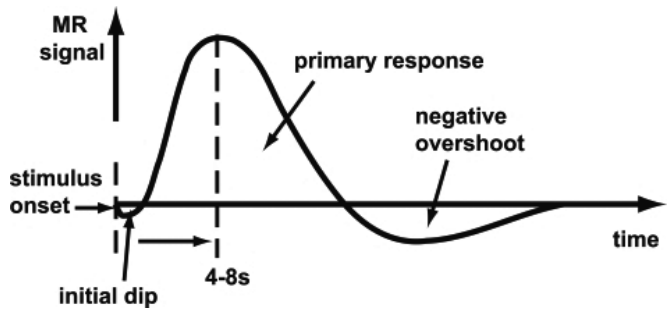

Figure 5: Standard hemodynamic response. Adapted from [40].

If one looks closely to the HDR curve, it will notice that the first observable hemodynamic change only takes place about 2 seconds after the stimulus. Before that, a small decrease in the MR signal can be found, which is called the initial dip, explained by a transient increase in deoxyhemoglobin concentration that accompanies the initial stimulus processing in brain. Maximum value is reached 3 seconds later and if the neuronal activity is extended in time, the peak may be similarly extended into a plateau, typically maintained at a slightly lower amplitude than the peak. After neuronal activity has ceased, BOLD signal decreases in amplitude to a below-baseline level and remains diminished for an extended interval. This effect, known as poststimulus undershoot, has been attributed to both biophysical and metabolic effects [37, 40].

To conclude, BOLD fMRI is a great tool to localize and quantify cerebral activity while performing a certain task. This technique can be used not only for mapping brain functional structure but also to investigate brain pathologies before their physical manifestation [37].

Chapter 2

Methods

2.1 Subjects

From the initial sixty one subjects recruited, only 58 completed the scanning session. Besides that, two out of 58 were excluded of this part of the study, due to technical problems with the joystick during the task. In the functional analysis 56 subjects were included (54 males and two females, aged from 21 to 60 years, mean age 34.4±10.7 years). Fifty five out of 56 proved to be right-handed by using the right hand to select the answers. All the subjects had normal or corrected to normal vision. An informed consent was signed by all the participants and the study was approved by the Ethics Committee of the Faculty of Medicine of the University of Coimbra, in accordance with the Declaration of Helsinki.

2.2 Football Teams as Brands

The subjects' pool is constituted by affiliated members of "Super Dragões" (an organized group of *Futebol Clube do Porto* supporters), affiliated members of "Mancha Negra" (an organized group of *Associação Académica de Coimbra* supporters) and regular people who acknowledge a greater or lesser emotional bond with one of these two teams (as assessed by two fandom scales). Both clubs competed in Portuguese First League of football at the time of the study. Porto presents itself as a top league contender, having a fan base of several million and an average stadium assistance of

near 30 thousands spectators. Académica in its regional expression only possesses a few thousands of supporters and an average stadium assistance around 4.5 thousands. We used these drivers to select these two teams to focus in the study. We sought for subjects who see their team the same way that a consumer sees major brand due to its success and prominence. In the same way, those supporting a smaller club represent consumers from alternative brands. By doing so, we expect to explore if there are any differences on cognitive mechanisms underlying the decision-making process based on the subject's type of team.

2.3 Data Acquisition

Structural and functional MRI scans were acquired in a 3T Magnetom Trio Tim MRI scanner (Siemens, Erlangen, Germany), using a 12-channel birdcage head coil. A T1-weighted MPRAGE anatomical volume was measured with repetition time (TR) of 2530 ms, echo time (TE) of 3.42 ms, resolution 1 mm^2, flip angle of 7°, matrix size 256×256, field of view of 256×256 and a slice thickness of 1 mm.

Considering the areas of interest in the present study, we were aware of the susceptibility artefact. To correct it, we acquired gradient field maps (GRE) before each EPI-BOLD sequence to map the distortions. Phase and magnitude field maps were acquired with the same orientation and the same field of view, TR of 3000 ms, TE of 30 ms, echo spacing 0.5 ms, phase resolution 100%, phase encoding direction from anterior to posterior, echo time difference of 2.46 ms and bandwidth in the phase direction of 31.25 Hz.

Functional data was obtained using Echo Planar Imaging (EPI) sequences acquired with slice thickness of 3 mm and voxel size 16 mm^2, 36 slices acquired parallel to the AC-PC line, TR 3000 ms, TE 30 ms, flip angle of 90°, matrix size 256×256 and FOV of 256×256. The task was displayed through an LCD monitor (NordicNeuroLab, Bergen, Norway) with a frequency rate of 60 Hz, dimensions of 698.40 x 392.85 mm,

placed ~156 cm away from the participants' head. The subject could actively select the response using an MR-compatible joystick (Hybridmojo, San Mateo CA, USA).

2.4 Data Analysis

Preprocessing - In order to reduce artefact and noise-related signal components, a series of operations is typically performed on raw functional datasets prior to statistical analysis. Additionally other transformations concerning spatial projection of both anatomical/functional parts must be implemented to align and merge all information from different subjects. All procedures are described ahead and were performed on *Brainvoyager QX 2.8.2* (Brain Innovation, Maastricht, The Netherlands) using the wide set of options offered by the software.

Slice scan time correction - The acquisition of a functional volume (e.g. whole brain) is not performed in a single shot, but with a series of successively measured 2D slices across time. This sequential coverage causes an acquisition time imprecision between voxels from different slices, leading to suboptimal statistical analysis. In this study, for instance, the temporal resolution (TR) for each volume is 3000ms, which means that the data of the last slice is measured nearly 3 seconds later than the data of the first slice. To overcome this problem, the time series of individual slices are "shifted" in time to match a reference time point (as when the reference slice was scanned). This approach changes the data in a way as if the whole volume would have been measured at the same moment in time. Another advantage is to allow us to use the same predictors after transforming the slice-based representation of the functional data to a 3D representation of the data in an arbitrary space (Talairach space). To be able to perform a slice re-arrangement it is necessary to know in which order each one of them was acquired, in our case the acquisition followed an ascending interleaved by 2 standard scanning order, as illustrated in **Figure 6**. Then slice time courses are resampled to match a reference time point - a specific slice for

each volume. Since this temporal shift causes a dislocation of the BOLD time course it could lead to the absence of data in some required time points. By doing a temporal interpolation, more precisely cubic spline interpolation, the non-measured time points can be estimated using measured data points "in the neighborhood" (measured in close proximity).

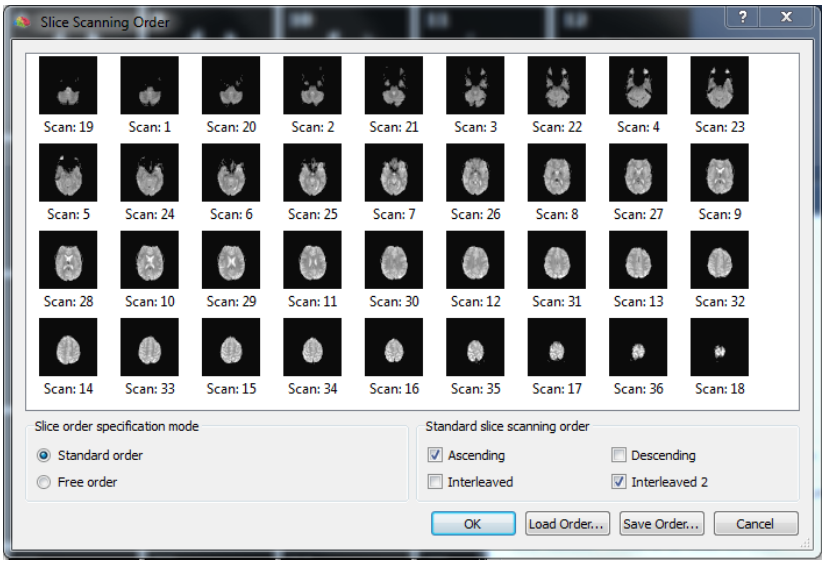

Figure 6: Slice scanning order of acquisition. Screenshot from *Brainvoyager QX*.

3D Motion Correction - Head movements during the acquisition can strongly compromise the quality of the fMRI data. Depending on the magnitude of these artefacts data sets can be either rejected or corrected for further more precise statistical analysis. For both detection and correction it is required to select a functional volume as reference for all other volumes, as long as they are aligned and from the same scanning session. From the chosen volume, 6 parameters (3 translational and 3 rotational) are estimated to describe the position of the rigid body. Any displacement in another volume can be translated by an alteration in these parameters that are also used to calculate the necessary transformations to realign with the reference volume. This process (detection and correction) includes a spatial

interpolation similar to the one performed on the slice scan time correction, which doesn't mean it has to be the same method for both parts. For instance, a trilinear interpolation was used for motion detection while motion correction was achieved combining trilinear and sinc function based methods for interpolation in the three axis.

Spatial smoothing - fMRI data inherently show spatial correlation due to functional similarities of adjacent brain regions and the blurring of the vascular system. It also helps to minimize between-subjects variability that usually occurs in group studies. The standard procedure to surpass this effect is to apply a spatial smoothing. This can be attained by convolving the fMRI signal with a Gaussian function of a specific width called Gaussian Kernel and it is described by a normal distribution curve. The size of the Gaussian Kernel defines the width of the curve, which determines in turn how much the data is smoothed, we used a 3D space domain 8 mm kernel which suits the data set dimension. As with the spatial smoothing data points are averaged with their neighbors, the final result is that sharp edges of the images are blurred and spatial correlation within the data is more pronounced, similar to the effect of a low pass filter removing the signal high frequencies while enhancing low frequencies. **Figure 7** shows the effect of different kernels on the same image [41].

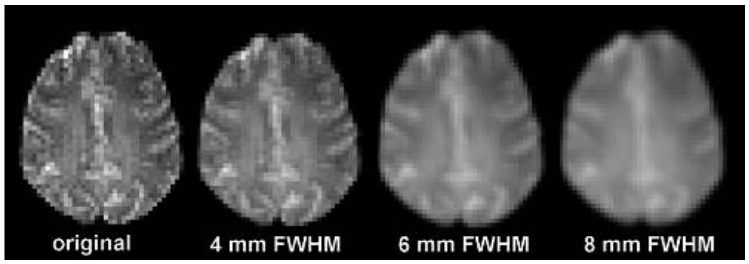

Figure 7: Effects of an increasing widths of Gaussian kernel, a low pass filtering on a generic brain image. Adapted from [41].

Temporal Filtering - Physiological noise and physical (scanner-related) noise can cause the occurrence of low-frequency drifts in voxel time courses of fMRI data. The presence of this signals reduce the quality of statistical data analysis and prevent event-averaging because time courses no longer can be described as stationary courses, for this reason temporal filtering is fundamental in any preprocessing procedure. The elimination of low frequencies is obtained by applying a high-pass filter in each voxel's time course which eliminates frequencies below a defined threshold and lets high frequencies pass (containing stimulus-related activity). There are several filters that can be used. We used a GLM approach with a design matrix containing a Fourier basis set with a cut-off value 2 cycles per run (number of sine/cosine pairs defining the degree of filtering performed).

Coregistration - Statistical analysis between subjects can only be performed if anatomical and functional data are correctly align which doesn't happen naturally since the two acquisitions are not performed at the same time. Coregistration is computed in two stages: an initial alignment bringing the functional and anatomical datasets in close proximity from a potentially very different starting point and a second fine-tuning alignment correcting small differences. This process was automatically executed and manually verified, with all structures normalized according to Talairach atlas.

2.5 Statistics and General Linear Model

The information provided by the fMRI data stems from the comparison of BOLD signal values on the same brain location in response to different scenarios induced by the task performed. Therefore it is primordial to define a method capable of quantifying this variation based on strong statistical inference. One way to assess whether the response values are different in the main condition and in the control condition would be to subtract the mean value of the "rest" condition from the mean value of the stimulus condition. However this approach fails when it comes to compare

two conditions with the same mean value despite having different time courses, as demonstrated in **figure 8**.

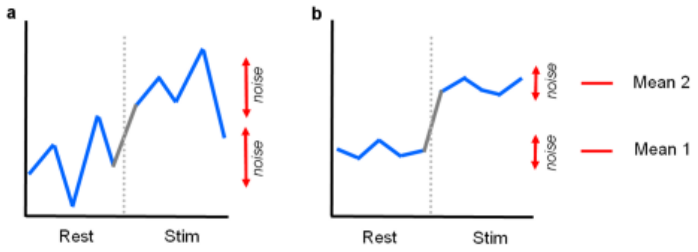

Figure 8: Two different time courses with the same mean signal value but different amounts of noise (signal *a* shows more noise than *b)*. Adapted from [42].

It becomes evident that statistical analysis must take into consideration the amount of variability of the measured data points. By incorporating the variability of measurements (caused by noise or other sources), statistical data analysis allows to estimate the uncertainty of effects like mean differences in data samples. Classic t statistics can be used in order to incorporate variability of measurements when comparing two mean values from a condition 1 and condition 2. T-test is an indicator of how likely an observed mean difference is a true effect or just the result of noise fluctuations. Since it is calculated by dividing the mean difference between mean stimulus value $\bar{X}_2$ and mean rest value $\bar{X}_1$ by the standard error of the mean difference $\hat{\sigma}_{X_2-X_1}$ (representing the expected variability), as described in **equation 2.1**, one can easily perceive that higher *t* values correspond to voxels where mean differences are explained by neural activations in response to stimuli.

$$t = \frac{\bar{X}_2 - \bar{X}_1}{\hat{\sigma}_{X_2-X_1}} \qquad 2.1$$

In association with *t* value there is an error probability *p* used in the hypothesis to test whether the observed data is inconsistent with the null hypothesis, so the null hypothesis can be rejected. This significance level test is attained based on the t value and the number of measured data points *N* using the incomplete beta function $I_x\ (a,b)$ according to **equation 2.2**. The result does not prove that the tested hypothesis is true, rather it indicates the maximum rate of type I errors (false positives) that could occur. In this type of studies, the reference threshold defined is 0.05, meaning that there is a 5% chance that a given effect appears to be present when it actually is not present. If the computed error probability falls below this standard value ($p<0.05$), the alternative hypothesis is accepted stating that the observed mean difference exists in the population from which the data points were measured.

$$p = I_{\frac{N-2}{N-2+t^2}}\left(\frac{N-2}{2}, \frac{1}{2}\right) \qquad 2.2$$

Given the gradual profile of fMRI responses, sometimes the mean comparison method may not be the ideal approach to compare BOLD signals between different conditions. This could be more problematic when temporal resolution is not low enough due to the slow signal change from one condition to the next to one, which prevents the easy assignment of time points to the correspondent conditions. This problem can be overcome using a predicted gradual time course as the reference function in the correlation analysis. With this method at each voxel the time course of the reference function is compared with the time course of the measured data by calculation of a correlation coefficient *r*, indicating how strong the covariation is, **equation 4** where *t* represents the time points which have associated the corresponding values from the reference (X_t) and data (Y_t) time courses.

$$r = \frac{\sum_{t=1}^{N}(X_t - \bar{X})(Y_t - \bar{Y})}{\sqrt{\sum_{t=1}^{N}(X_t - \bar{X})^2 \sum_{t=1}^{N}(Y_t - \bar{Y})^2}} \qquad 2.3$$

With an interval of values ranging from -1 to 1, the correlation absolute value indicates how closely the two time courses behave. So for a correlation result near 0 there is no correlation and we can assume that one time course cannot be used to predict the corresponding value in the other time course. On the other hand the signal of correlation denotes what kind of correlation exists between the two curves, for a positive correlation ($r>0$) they go up and down in the same way while for a negative correlation ($r<0$) they run on opposite directions.

Since the correlation test works based on the null hypothesis rejection/acceptance similarly to t-test, an error probability must be defined to determine if the correlation detect is caused by noise fluctuations or not. Once again, the reference value accepted by scientific community as a strong indicator for a true effect is $p<0.05$.

Despite being widely used, correlation and t-test are limited to the comparison of two conditions. To extend these approaches to multiple conditions, the General Linear Model (GLM) is required allowing the implementation of advanced statistical models containing many variables fitting to the time course of each voxel separately. The versatility of this method relies on the possibility to implement parametric statistical tests using both types of variables such as variance or covariance analysis to tell how well the overall model explains the time course. This multiple regression analysis-like model operates with a single dependent variable whose behavior is predicted or explained by the linear combination of several independent functions. The equations below represent the GLM system of equations of a single voxel with n data points:

$$y_1 = b_0 + b_1 X_{11} + \ \ldots\ \ldots\ \ldots + b_p X_{1p} + e_1$$

$$y_2 = b_0 + b_1 X_{21} + \ \ldots\ \ldots\ \ldots + b_p X_{2p} + e_2$$

. . . .

. . . .

. . . .

$$y_n = b_0 + b_1 X_{n1} + \ \ldots \ \ldots \ \ldots + b_p X_{np} + e_n$$

The dependent variable represented on the left side of the equation, y, corresponds to the measured BOLD time course of a voxel. Each data point index is associated with correspondent time point following the chronological order of acquisition. On the right side of the equation, it is described the reference functions corresponding to the time courses of the expected fMRI responses for different conditions of the experimental design. These functions contain beta weights represented by the letter *b*. Beta weights quantify the potential contribution of the associated predictor time course *X*, for each different condition. There is also a residual value represented by *e*. Note that the first beta value (b_0) has a unitary time course associated and after estimation operates as the signal level of baseline condition. Another reason to include de unitary predictor in the design matrix is the role as modulator for the other predictors in response to small condition-related fluctuations relative to the baseline signal level.

The computational processing starts with data *y* and design matrix *X* as inputs. The GLM fitting process is the estimation of the best beta values that explain the given data. Even for the best approximation from the predicted values to the measured values *y* there is always an error associated *e*. Therefore the efficiency of the prediction is measured by the minimization of the sum of squared error values.

The procedure described before is performed independently for each voxel by using the same design that results in different beta values according to the voxel's measured time course. After computing the whole brain, the statistical tests results are color mapped in a 3D set. For visualization purposes, this maps are superimposed to the anatomical information.

2.6 RFX–GLM, Population Level

To be able to extrapolate to the population, i.e. to valid the results to the population level, the analysis must be able to capture the variability of observed effects across subjects. To do so, Random-Effects analysis (RFX) can be performed, assuming the set of subjects to be a representative sample of population. By finding significant group effects through this analysis, the results can be generalized to the population from which the subjects have been drawn.

Since this method generates big data sets, it is divided in two steps also called levels, so the processing becomes a lot easier and less time consuming. In the first level, condition effects (beta values) are estimated separately for each subject. Then the generated beta values enter as input on the second level analysis and their variability is analyzed across subjects. This second step can performed by two methods. In this work, the ANCOVA approach (variance analysis) was selected since allows the inclusion of multiple within subjects factors and a between subjects factor for group analysis. ANOVA approach can be extended to ANCOVA by incorporate additional external variables as explained further up.

All RFX-GLM statistical maps were corrected for multiple comparisons using false discovery rate (FDR), with a fixed q value lower than 0.01.

2.7 Task Design

The experiment has a boxcar design as described in **figure 9**. It is separated into three different stages: 1) the fixation interval corresponding to a jittered baseline condition where a black screen is shown, lasting 9 to 21 seconds; 2) the stimulus condition during which the question is exhibited for 6 seconds, and finally 3) the response phase, having 12 seconds to do so. This sequence was repeated 16 times, one for each question, followed by a final block of fixation condition.

In the task, participants were asked how much they were willing to pay to watch live each one of the 16 matches presented during the question condition. Before the MRI session, the participants were instructed that the hypothetic purchase would occur through the "black market", next to the stadium, so it was established that not watching the game wasn't an option and there would be no negotiation about the price. With this instruction, we assure that the value introduced in the response phase represents the value of that match for that participant. The set of games included not only subject's favourite team against different kinds of opponents for different competitions, but also neutral matches between teams with no emotional connection to the subject. The sequence of questions was randomized for each participant in order to avoid some bias, related to scanner-related low-frequency drifts or some kind of fatigue that could affect that participant in the last answers of the task. Another concern relates to the subject's ability to predict when and what will happen between non-baseline blocks, by varying the duration of the baseline condition randomly, we ensure the maintenance of the attention level across the experiment. This is called stochastic of "jittered" inter-stimulus intervals.

The scanning session included another 2 tasks besides the one described in this study. One to evaluate the cognitive response towards the visualization of positive and negative videos of goals involving subject's favourite team or his rival, and the other where the participant faces a decision-making dilemma having to choose between his or his partner's desires. They are all part of a major research project that seeks to understand the neural correlates of human behaviour in football related scenarios.

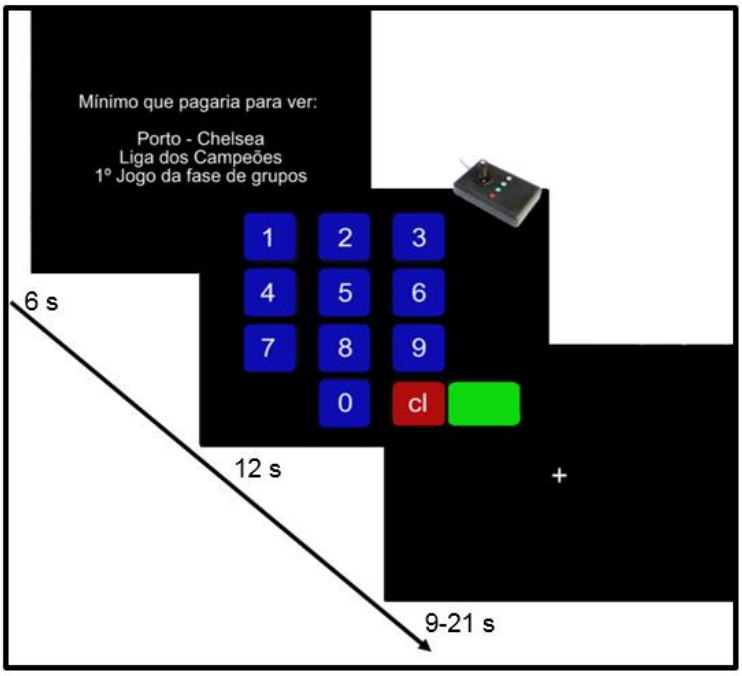

Figure 9: Experimental Design composed by three blocks: stimulus condition lasting 6 seconds, response phase lasting 12 seconds and a variable fixation interval of 9 to 21 seconds. All this blocks are sequentially repeated for the sixteen different questions of the task.

2.8 Statistical Tests

First of all, it should be noted that the task block during which the stimulus condition was displayed, stands formally as the period associated to the decision-making process and, therefore, the main focus of every test performed. This assumption could seem highly arguable when considering the existence of a block designated to value insertion, where could be expected to include the deliberation process that precedes answer selection. Despite this intuitive conception, preliminary tests comparing stimulus block against response block activations showed a greater involvement of cognitive areas in the first event, while motor areas assumed the main role in the latter one. At the light of these results, we may assume that the duration of stimulus block is long enough to allow not only stimulus perception but to also its processing towards a cognitive decision.

Back on Task Design section, the experimental assignment was described as a sequence of three distinct block events repeated over time. While "fixation" has no connection with the main stimuli presented in the study, the other two conditions (dilemma exposure and answer selection) aim to evoke brain regions associated with the decision making process. Each pair dilemma/answer was then classified accordantly to the monetary values introduced by the subject. Classification in "*high*", "*medium*" and "*low*" values was done individually to each participant. In this way, we assure that classification is tailored to the subject, allowing the comparison between levels of monetary sacrifice. The criterion here was to find a significant set of close values that allow the clustering of the answers in "*high*", "*medium*" and "*low*" values. This selection does not rely on the individual value of each response, but on the dispersion of all values of the subject. Furthermore the number of responses fitting "Higher" group tend to be naturally smaller, since only few questions pointed to bigger monetary outcomes. With this classification, we aim to create a design where the questions with higher values in the answers correspond to bigger monetary sacrifices.

The previous grouping method constitute the main focus of the first statistical analysis in this study. By comparing conditions of different levels of sacrifice, we seek to unveil if there are any cognitive differences associated to the decision process when facing situations requiring multiple levels of economical efforts. This comparison was accomplished by performing t-tests, where answers coherent with the contrasts from all subjects were included, using two different contrasts *high* vs *low* and *high* + *medium* vs *low* conditions.

Another goal of this study is to find out if the subject's preference club is somehow characterized by different patterns of activation during the dilemma. In other words, does the brain of someone affiliated to a strong club works the same way as one of someone from a weak club towards a football-related monetary sacrifice? Answering to such question requires the examination of the influence of 2 independent categorical variables task conditions and subject's group. The most suitable test on *Brainvoyager QX* with this architecture is the Two-Factor ANOVA represented by the screenshot of **figure 10**. The set of different conditions is shared by all subjects regardless the group to which they belong, for that reason this variable is classified as a

within-subjects factor. On the contrary, the second variable can only assume one value for each subject and that's why it's called between-subjects factor. Subjects can be assigned to one of 3 groups, designated as levels on the software dialog, according their result on test measuring football fanaticism (FSFS scale): those who achieved higher FSFS scores and identified as *Futebol Clube do Porto* fans fit into 'FCP' group (n=18), *Associação Académica de Coimbra* fans with the highest FSFS form 'AAC' group (n=18), the remaining subjects with the lowest score regardless club preference serve as 'Control' group (n=20). Statistical maps result from the comparison of groups and the comparison of conditions.

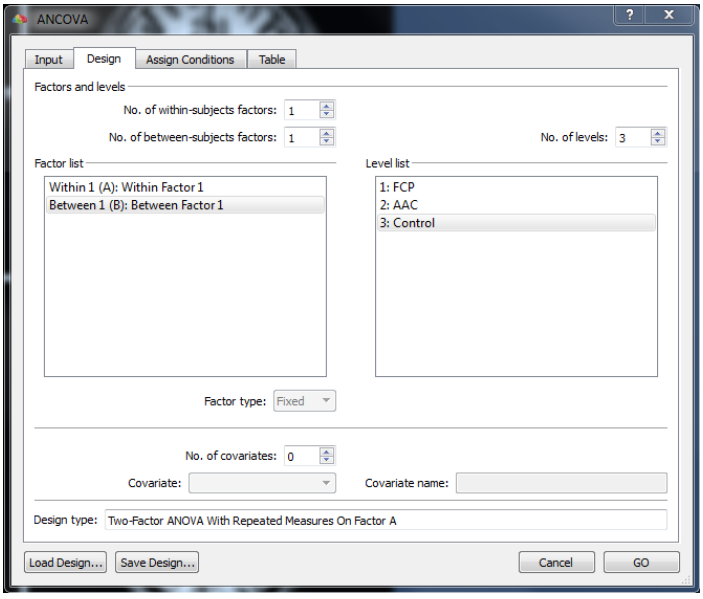

Figure 10: Two-Factor ANOVA design model used for group analysis. One within-subjects factor with 3 levels (*high*, *medium* and *low*), one between-subjects factor with 3 levels (*FCP*, *AAC* and *Control*). Screenshot from *Brainvoyager QX*.

Similar Two-Factor ANOVA test was performed to assess the main effect between *FCP* and *AAC* groups. In a main effect analysis all three levels of between-subjects factor, in this case the monetary sacrifice levels, are contrasted between groups. Since this test aims to evaluate the differences of the overall brain response

between subjects from a strong (FCP) and weak team (AAC), within-subjects factor can only assume 2 levels.

The psychological test was also used to divide the pool of participants in two levels of fanaticism. The subjects were separated in 2 groups – Fanatics and Non Fanatics according to their FSFS score surpassing or not a defined threshold. From the initial pool, 36 subjects had got a fanaticism score high enough to be classified to the 'Fanatics' group, the remaining 20 stood to 'Non Fanatic' group. Based on this separation, subjects' fanatic condition was evaluated by comparing main effect between Fanatics and Non Fanatics subjects. The statistical test to implement such approach is very similar to that used in main effect of group analysis, however instead of having 3 levels for between-subjects factor, 2 levels are enough to separate regular fans from the fanatics. Furthermore, the same principle was assessed considering only subjects from the same club. Fanatics and regular fans brain response were compared to main effect for both strong (FCP) and weak (AAC) teams. Due to the occurrence of multiple comparisons problem associated with the GLM approach, the contrasts between *fanatics and non fanatics* required the implementation of false discovery rate (FDR) method. By doing so, we reduce the probability of finding activated voxels where actually there is no true effect. We used q=0.01 or q=0.02 depending on the contrast to eliminate the falsely claimed active voxels.

The final set of results uses the concept of the monetary responses as indicator of the sacrifice made by someone when facing the dilemma. We defined a continuous scale of sacrifice, in which each subject has a score quantifying the monetary effort during the task. More information about this scale will be provided on the next section. The initial idea was to include all subjects on the same test despite club preference. However, due to the fact that the set of questions presented during the task wasn't the same for participants from both clubs, they couldn't be included in same test. For instance, Porto role of games included matches in international competitions, while Académica only counted domestic matches. Considering the fact that football matches in international competitions have an average price far superior than matches in Portugal, wouldn't be fair compare monetary sacrifices from subjects facing such unequal challenges. In the end, subjects' pool used to test fanatic condition

within clubs was the same that was used to compare *fanatics* and *non fanatics* separately by clubs. The two correlation tests were performed to test if there is a relation between the degree of fanaticism (FSFS individual score) and the BOLD signal. This kind of analysis can be implemented using a simple correlation between beta values (contrasts) and covariate values, no factors need to be added (**figure 11**). The resulting maps containing r-values were corrected for multiple comparisons using cluster threshold levels with a fixed p-value of 0.005 and voxel extent, which estimation was based on Monte Carlo simulations (1000 iterations). Significant clusters include at least 87 contiguous voxels.

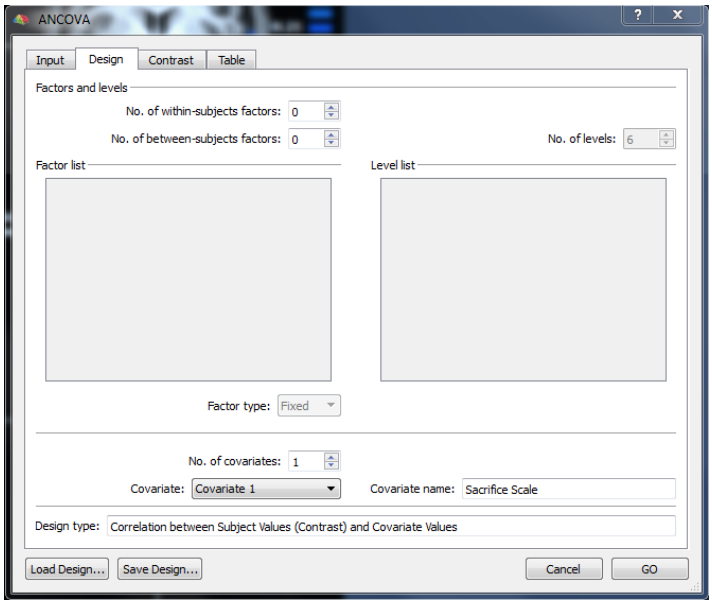

Figure 11: Statistical model design used for correlations between FSFS scores and fMRI data. No factors associated. One covariate implemented. Screenshot from *Brainvoyager QX*.

Considering the amount of voxels of a full brain inspected in every test, a mask is typically used to restrict the computational iteration to those areas that really matter. The mask was obtained by averaging all functional files, excluding bone and scalp. Eyes and cerebellum were manually extracted from the mask, using the anatomical files information (the final mask contained 87% of the initial voxels).

2.9 Behavioural Data

Many of the performed statistical analysis were only possible due the implementation of behavioral tests. Created by official entities or only in this study context, all this tests lead to continuous scales where the subjects' scores can assume any value within a range of the test instead of a much more limited discrete scale.

The first two assessments were completed before the MRI session. One to assess the identification to a team and another to assess the fanaticism for football. The use of the word fanaticism stands as a synonym of intensity of being fan, leaving out its negative connotation or any relation to hooliganism or other dysfunctional behaviors which use sports as motto.

Sport Spectator Identification Scale (SSIS) (Wann & Branscombe 1993) – Portuguese version (Theodorakis et al. 2010) – is a self-report scale assessing the identification, or psychological connection, to a team. This seven-item Likert scale has strong reliability and validity.

Escala de Fanatismo em Torcedores de Futebol (Wachelke et al. 2008), or in English Football Supporter Fanaticism Scale (FSFS), is a self-report scale assessing the fanaticism for football. The eleven-item Likert scale was translated from Portuguese of Brazil to Portuguese of Portugal by two experienced psychologists and joined by a third element.

The third assessment relies on the behavioural data recorded during the fMRI acquisition. Its formulation relies on the concept that being willing to pay higher amounts of money to watch a certain game is associated with a bigger sense of sacrifice in football-related purposes. However, such test could be hard to implement to a task with multiples dilemmas associated, each one taking to different levels of sacrifice. By calculating a mean value for all the answers to each subject we expect to have a measure to differentiate subjects who were able to make a bigger sacrifice.

Chapter 3

Results

In this section, results regarding random effects analysis are presented. For each contrast test, statistical maps are shown and clusters of activated brain regions are described in detail on tables. Only clusters lying mostly on the border of the brain cortex were excluded from the results due to being considered the result of artefacts during preprocessing.

3.1 Levels of Sacrifice

In inferential statistics, one intends to explain a variable - said dependent - based on the influence of another variable or other variables, said independent, in a way that can be generalized to the population, starting off with a sample.

For the whole pool of participants, the contrast *high + medium vs low* sacrifice was performed. Positive clusters were found in the right middle frontal gyrus, right superior frontal gyrus, medial frontal gyrus bilaterally, left superior parietal lobule and left precuneus. The same contrast evidenced a negative cluster in the lateral lingual gyrus bilaterally (See **figures 12.1-12.7**). Results are detailed in the **table 1**.

Table 1: ***high + medium vs low sacrifice*****.** Regions were identified from a RFX analysis ($-2.92>t_{55}>2.92$, $p<0.005$ corrected, minimum cluster threshold: 2160). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space. BA Brodmann Area.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Middle Frontal Gyrus – Prefrontal Cortex BA 9	R	35	40	39	4.325181	0.000065
Lingual Gyrus BA 19	R and L	8	-68	-6	-4.166112	0.000110
Superior Frontal Gyrus BA 6	R	26	4	54	4.612316	0.000024
Medial Frontal Gyrus - Prefrontal Cortex BA 9 and 10	R and L	-1	55	12	4.849761	0.000011
Superior Parietal Lobule BA 7	L	-10	-71	55	4.849761	0.000159
Superior Parietal Lobule BA 5	L	-31	-35	57	3.902877	0.000262
Precuneus BA 7	L	-45	-63	33	5.515383	0.000001

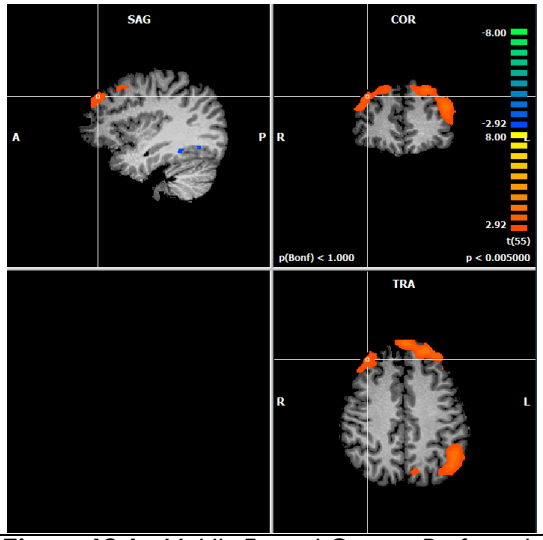

Figure 12.1 - Middle Frontal Gyrus – Prefrontal Cortex

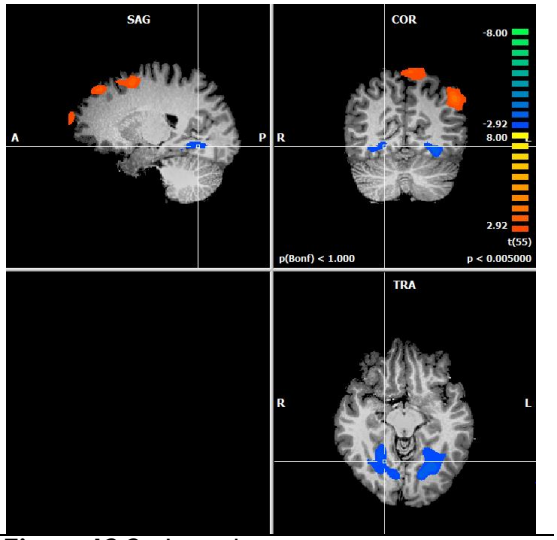

Figure 12.2 - Lingual gyrus

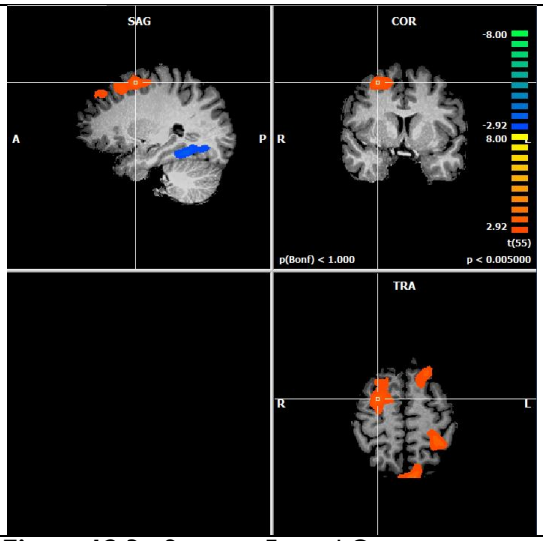

Figure 12.3 - Superior Frontal Gyrus

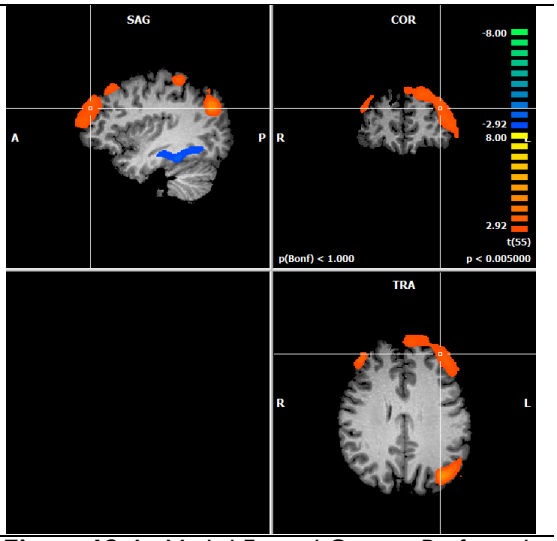

Figure 12.4 - Medial Frontal Gyrus – Prefrontal Cortex

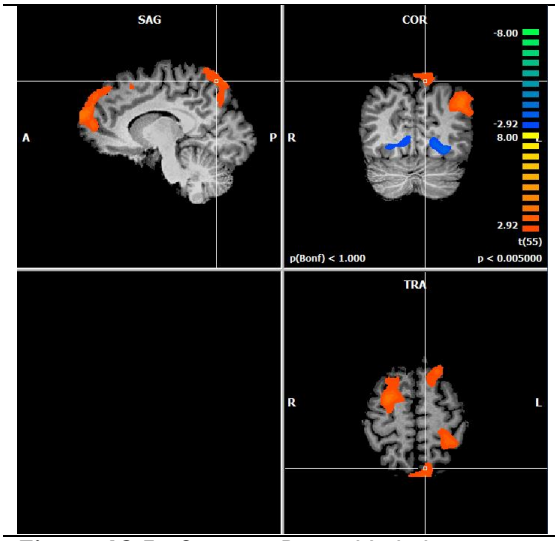

Figure 12.5 - Superior Parietal Lobule

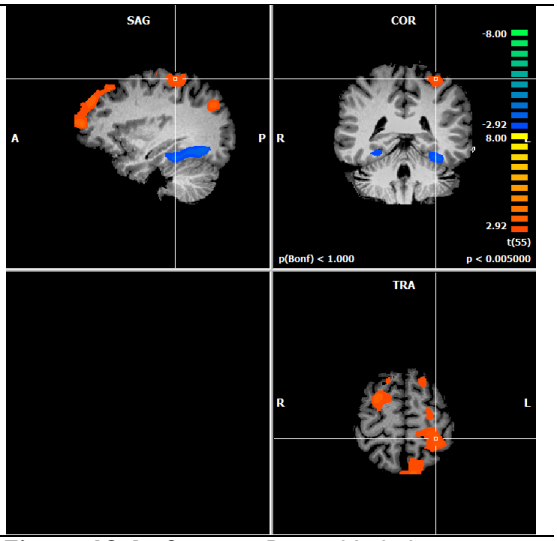

Figure 12.6 - Superior Parietal Lobule

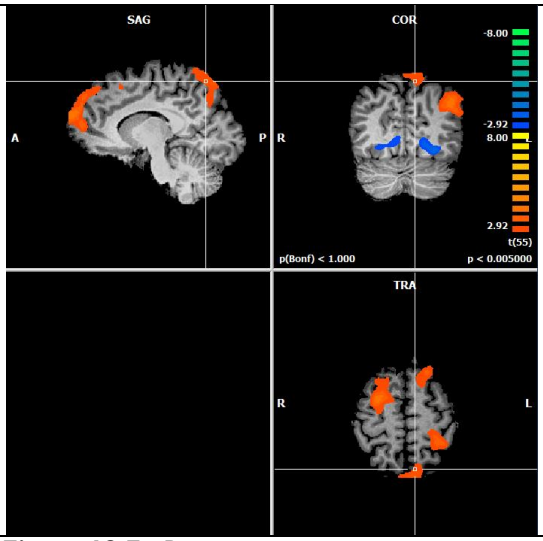

Figure 12.7 - Precuneus

Figure 12 - Significant BOLD activations for the contrast of ***high + medium vs low* sacrifice.** RFX analysis ($-2.92>t_{55}>2.92$, $p<0.005$ corrected, minimum cluster threshold: 2160). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

The contrast of the extreme conditions, *high vs low* sacrifice was also performed. Positive clusters were found in orbitofrontal cortex bilaterally, left superior frontal gyrus, left parietal lobule and left angular gyrus (See **figures 13.1-13.5**). Results are detailed in the **table 2.**

Table 2: *high vs low* sacrifice. Regions were identified from a RFX analysis ($-2.92>t_{55}>2.92$, $p<0.005$ corrected, minimum cluster threshold 1458). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Orbitofrontal Cortex BA 11	R and L	20	37	-15	4.313097	0.000067
Superior Frontal Gyrus - Prefrontal	L	-19	65	24	5.056349	0.000005

Cortex BA 10 and Anterior Cingulate BA 32						
Superior Parietal Lobule BA 7	L	-7	-71	54	3.847237	0.000313
Superior Parietal Lobule BA 5	L	-31	-35	54	3.987574	0.000199
Angular Gyrus BA 39	L	-37	-71	30	4.671555	0.000020

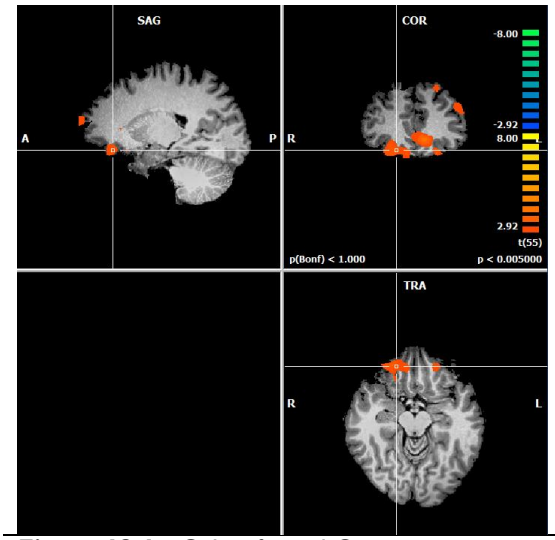

Figure 13.1 - Orbitofrontal Cortex

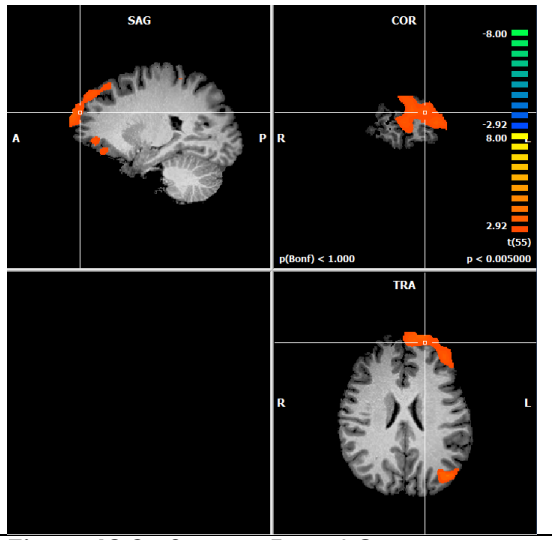

Figure 13.2 - Superior Frontal Gyrus – Prefrontal Cortex and Anterior Cingulate

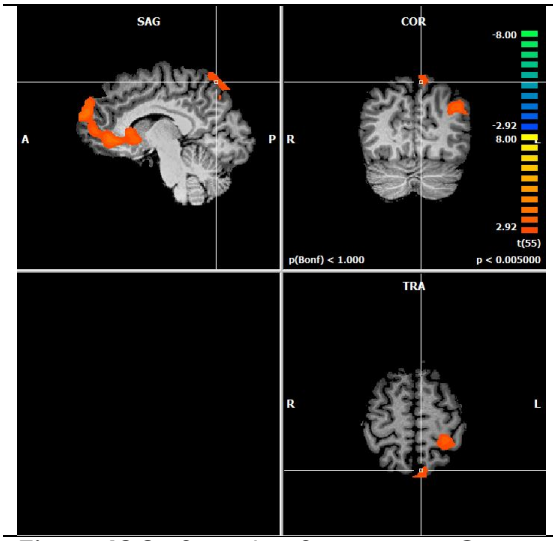

Figure 13.3 - Secondary Sensorimotor Cortex

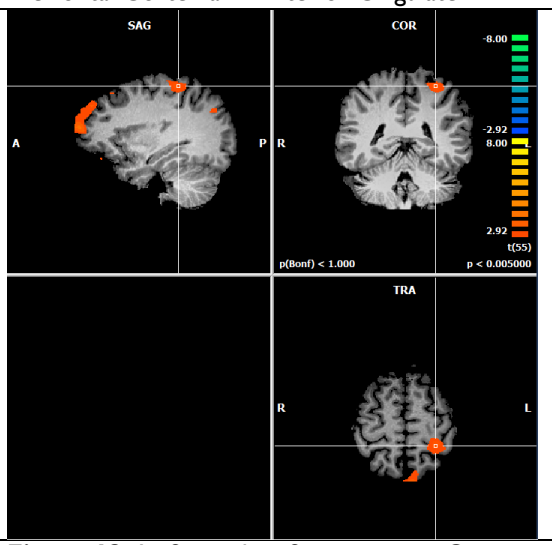

Figure 13.4 - Secondary Sensorimotor Cortex

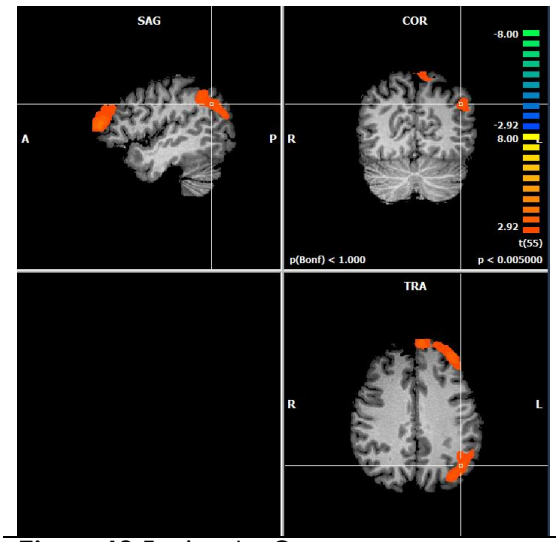

Figure 13.5 - Angular Gyrus

Figure 13 - Significant BOLD activations for the contrast of ***high + medium vs low* sacrifice between.** RFX analysis ($-2.92>t_{55}>2.92$, $p<0.005$ corrected, minimum cluster threshold 972). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

3.2 Group differences for Levels of Sacrifice

Group differences were tested for the contrast *high + medium vs low* sacrifice (ANOVA group analysis, 2 levels for the between-subjects factor: AAC or Control, as described in the methods chapter). Positive clusters were found in the right posterior insula, right fusiform gyrus, right inferior frontal gyrus, left superior frontal gyrus until anterior cingulate cortex and temporal pole bilaterally (See **figures 14.1-14.5**). Results are detailed in the **table 3**.

Table 3: ***high + medium vs low sacrifice between AAC and Controls.*** Regions were identified from a RFX analysis ($-1.97>t2_{275}>1.97$, $p<0.05$ corrected, minimum cluster threshold: 972). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Posterior Insula BA 13	R	35	-20	24	2.639962	0.008765
Fusiform Gyrus BA 20	R	41	-38	-13	3.118645	0.002010
Inferior Frontal Gyrus – Pars Orbitalis BA 47	R	29	28	3	2.826476	0.005052
Superior Frontal Gyrus – Prefrontal Cortex BA 10 and Anterior Cingulate Cortex	L	-1	22	0	2.912657	0.003878
Temporal Pole BA 38	R and L	-31	4	-30	2.973660	0.003204

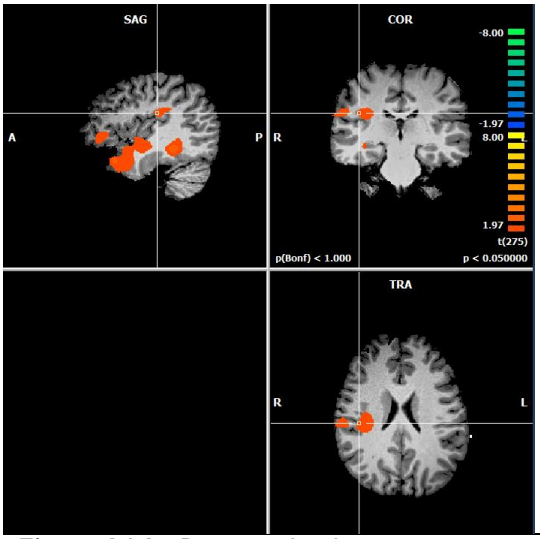

Figure 14.1 - Posterior Insula

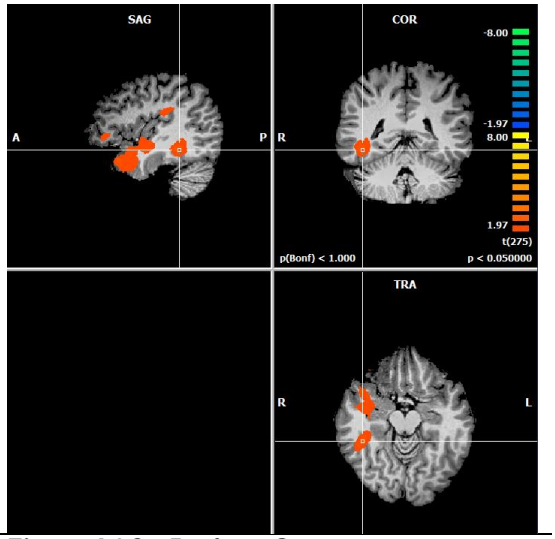

Figure 14.2 - Fusiform Gyrus

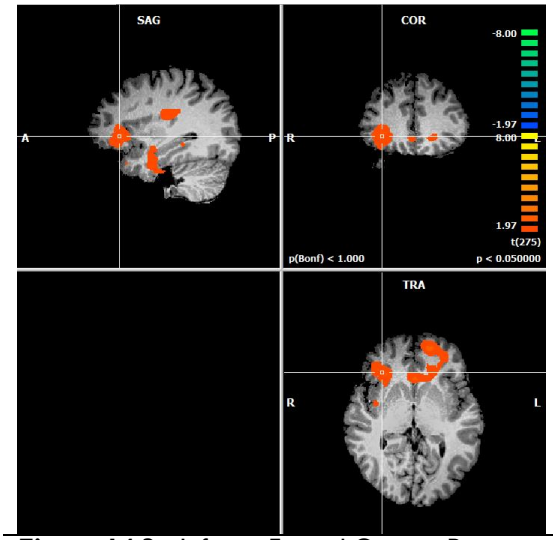

Figure 14.3 - Inferior Frontal Gyrus – Pars Orbitalis

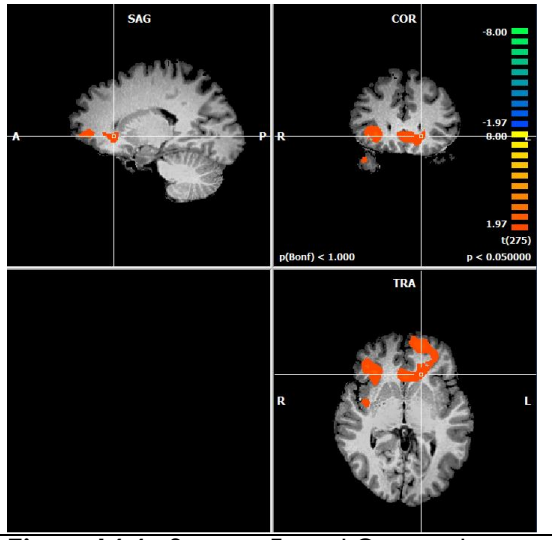

Figure 14.4 - Superior Frontal Gyrus and Anterior Cingulate Cortex

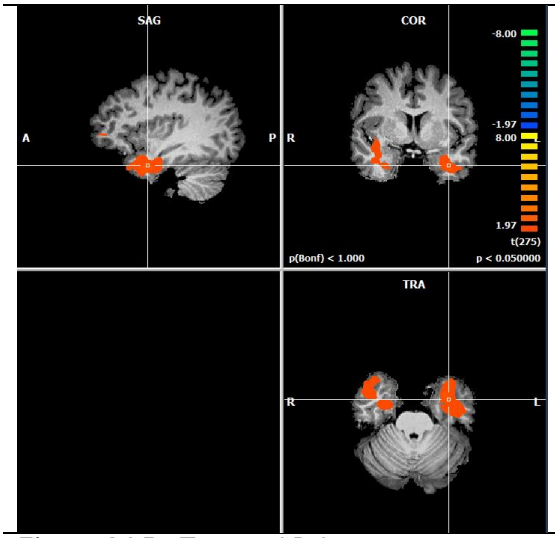

Figure 14.5 - Temporal Pole

Figure 14 - Significant BOLD activations for the contrast of ***high + medium vs low* sacrifice between AAC and Controls.** RFX analysis ($-1.97>t_{275}>1.97$, $p<0.05$ corrected, minimum cluster threshold 972). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

Group differences were tested for the contrast *high + medium vs low* sacrifice (ANOVA group analysis, 2 levels for the between-subjects factor: *FCP or Control*, as described in the methods chapter). Negative cluster was found in the right posterior cingulate cortex (See **figure 15.1**). Results are detailed in the **table 4**.

Table 4: ***high + medium vs low sacrifice between FCP and Controls.*** Regions were identified from a RFX analysis ($-2.06>t_{275}>2.06$, $p<0.04$ corrected, minimum cluster threshold: 2132). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Posterior Cingulate Cortex BA 31	R	14	-59	21	-3.137853	0.001887

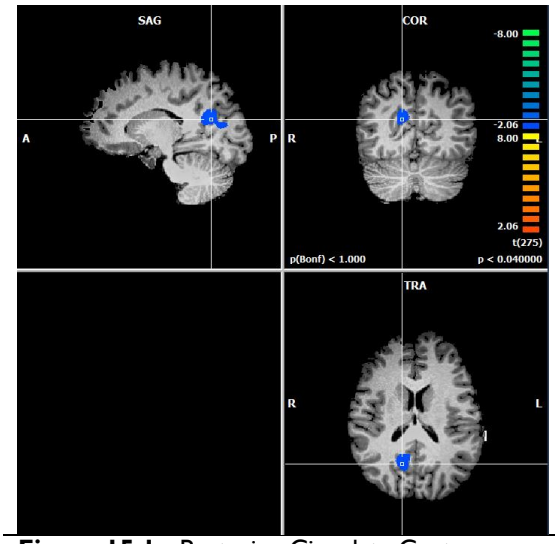

Figure 15.1 - Posterior Cingulate Cortex

Figure 15 - Significant BOLD activations for the contrast of ***high + medium vs low*** **sacrifice between** ***FCP and Controls.*** RFX analysis ($-2.06>t_{275}>2.06$, $p<0.04$ corrected, minimum cluster threshold 2133). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

Group differences were tested for the contrast *high + medium vs low* sacrifice (ANOVA group analysis, 2 levels for the between-subjects factor: *FCP or AAC*, as described in the methods chapter). Negative cluster was found in Putamen bilaterally (See **figure 16.1**). Results are detailed in the **table 5**.

Table 5: *high + medium vs low sacrifice* between *FCP and AAC*. Regions were identified from a RFX analysis (-2.59>t_{275}>2.59, p<0.01 corrected, minimum cluster threshold: 5643). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Putamen	R and L	38	-5	6	-3.120903	0.001995

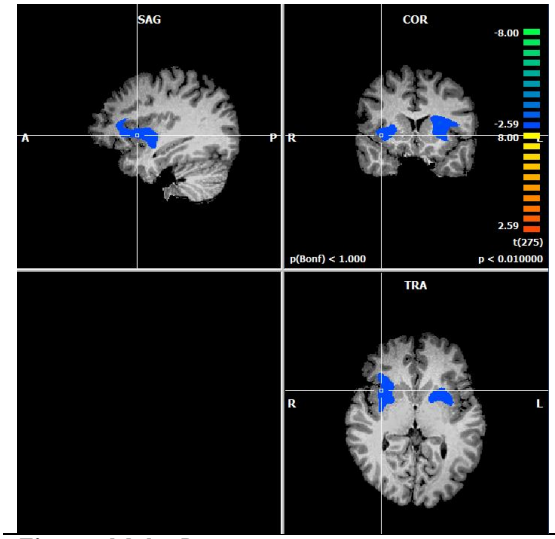

Figure 16.1 - Putamen

Figure 16 - Significant BOLD activations for the contrast of ***high + medium vs low* sacrifice between *FCP and AAC*.** RFX analysis (-2.59>t_{275}>2.59, p<0.01 corrected, minimum cluster threshold 5643). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

3.3 Main Effects on Fanaticism

For the whole pool of participants group differences were tested for the main effects (ANOVA group analysis, 2 levels for the between-subjects factor: *Fanatics or Non Fanatics*, 3 levels for the within-subjects factor: *high, medium and low sacrifice*, as described in the methods chapter). Positive clusters were found in the left anterior cingulate gyrus, left medial frontal gyrus, left temporal pole. The same contrast evidenced a negative cluster in the superior temporal gyrus bilaterally, middle frontal gyrus bilaterally, primary and secondary visual cortices bilaterally, right precuneus, left

medial frontal gyrus, left inferior temporal gyrus, left precentral gyrus and left temporal pole (See **figures 18.1-18.13**). Results are detailed in the **table 7**.

Table 7: ***main effects between Fanatics and Non Fanatics.*** Regions were identified from a RFX analysis ($-3.62>t_{275}>3.62$, $p<0.003710$ corrected, q(FDR)=0.01, minimum cluster threshold: 378). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Superior Temporal Gyrus BA 22	R and L	59	-2	3	-4.824457	0.000002
Middle Frontal Gyrus - Prefrontal Cortex BA 9	R and L	47	22	43	-5.373309	<0.000001
Primary and Secondary Visual Cortices BA 17 and 18	R and L	-13	-71	3	-9.729061	<0.000001
Secondary Visual Cortex BA 19	R	11	-89	-27	-4.998827	0.000001
Precuneus BA 7	R	0	-67	36	-4.768287	0.000003
Anterior Cingulate Cortex BA 32	L	-10	22	-3	4.999528	0.000001
Medial Frontal gyrus - Prefrontal Cortex BA 10	L	-16	49	-1	4.438169	0.000013
Medial Frontal Gyrus - Premotor Cortex BA 6	L	-28	22	57	-6.601006	<0.000001

Inferior Temporal Gyrus BA 20	L	-31	-26	-28	-5.127472	0.000001
Temporal Pole BA 38	L	-37	7	-36	5.072757	0.000001
Precentral Gyrus - Primary Motor Cortex BA 4	L	-46	-17	54	-4.205361	0.000035
Temporal Pole BA 38	L	-55	13	-6	-5.190320	<0.000001
Superior Temporal Gyrus BA 22	L	-61	-8	0	-4.166287	0.000041

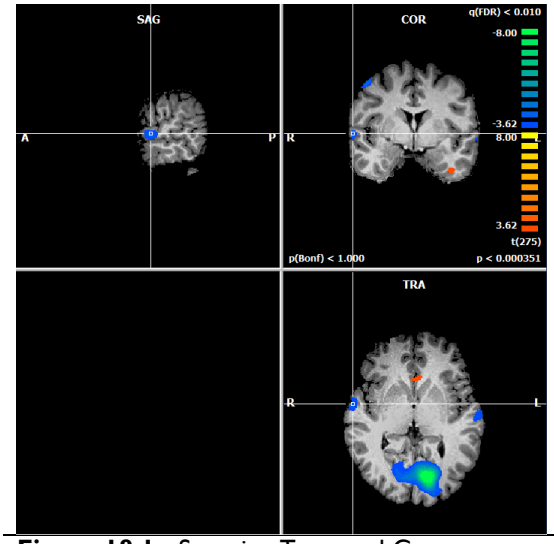

Figure 18.1 - Superior Temporal Gyrus

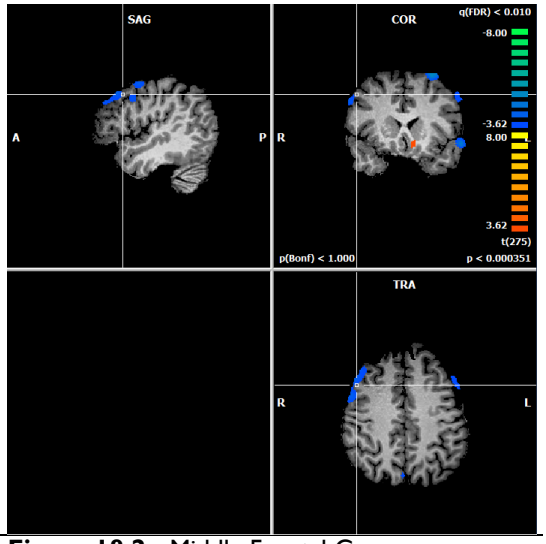

Figure 18.2 - Middle Frontal Gyrus – Prefrontal Cortex

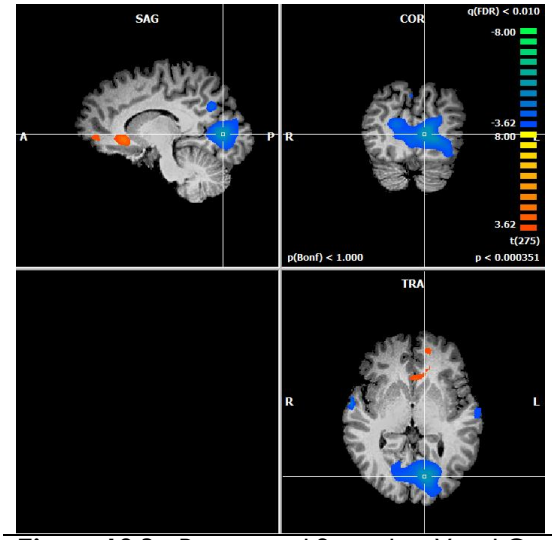

Figure 18.3 - Primary and Secondary Visual Cortices

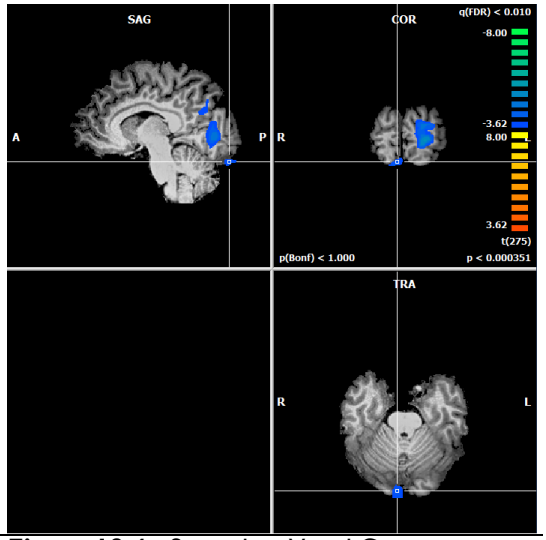

Figure 18.4 - Secondary Visual Cortex

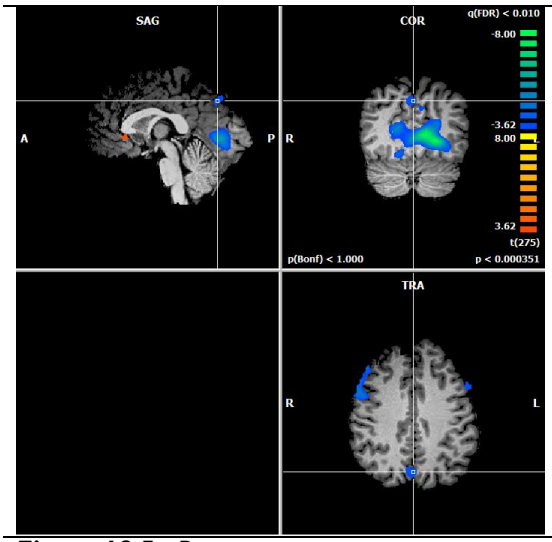

Figure 18.5 - Precuneus

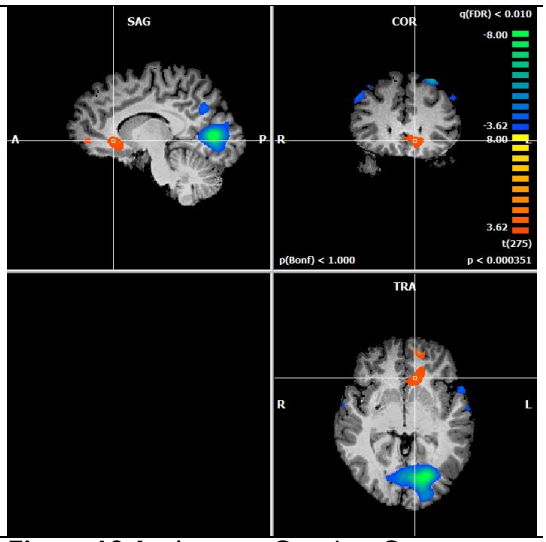

Figure 18.6 - Anterior Cingulate Cortex

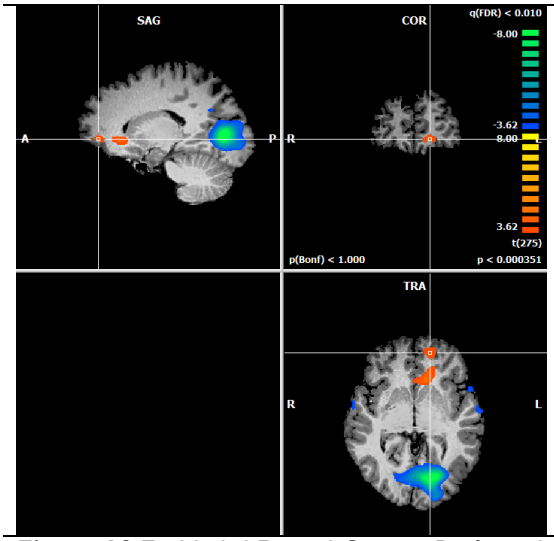

Figure 18.7 - Medial Frontal Gyrus – Prefrontal Cortex

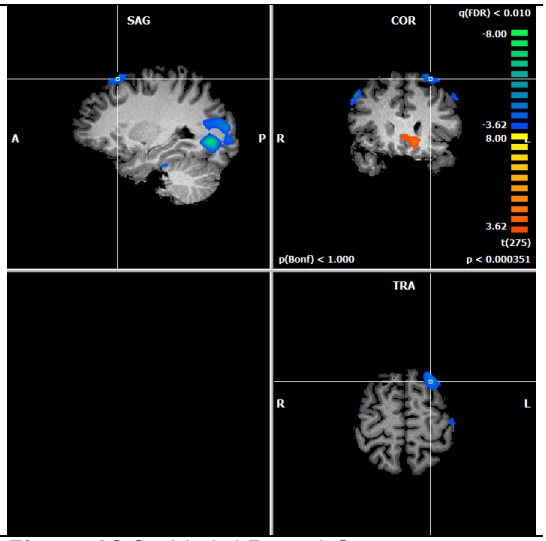

Figure 18.8 - Medial Frontal Gyrus – Premotor Cortex

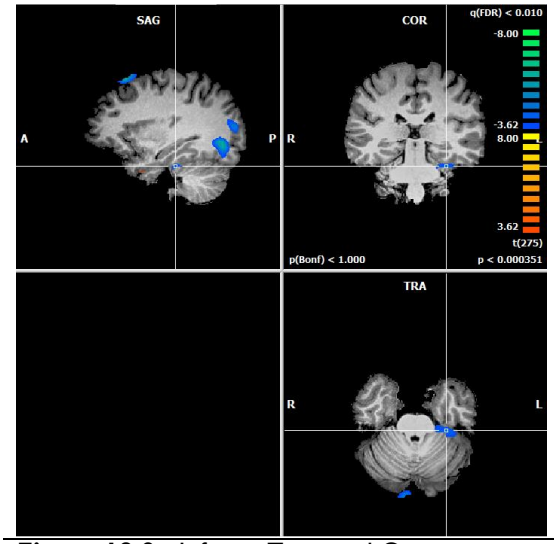

Figure 18.9 - Inferior Temporal Gyrus

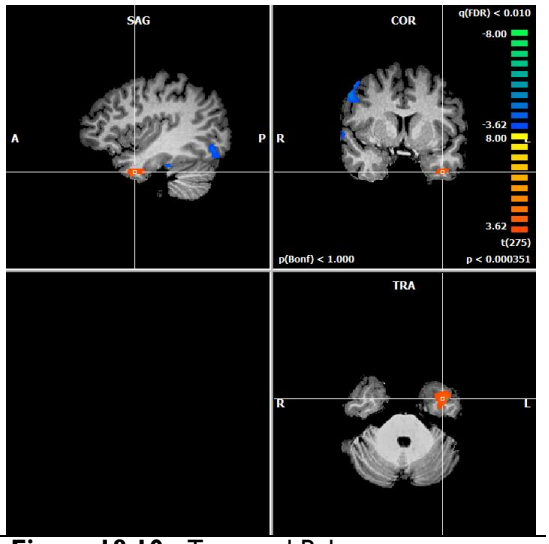

Figure 18.10 - Temporal Pole

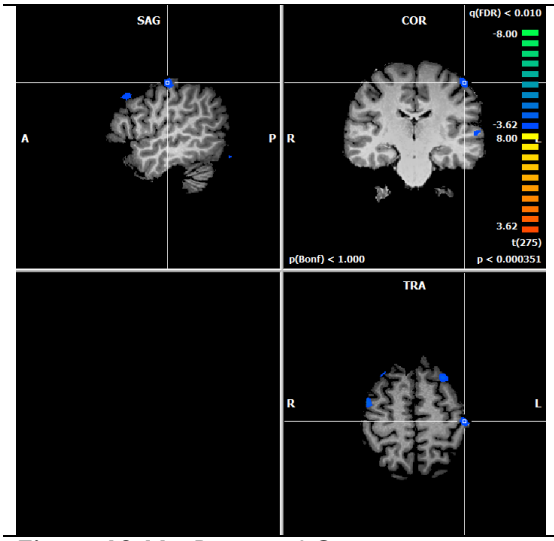

Figure 18.11 - Precentral Gyrus

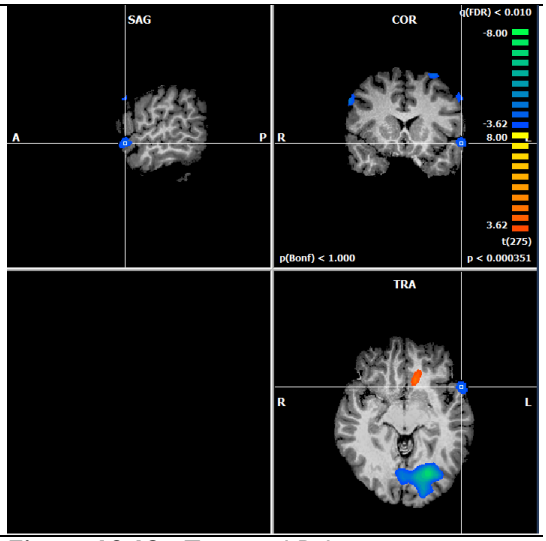

Figure 18.12 - Temporal Pole

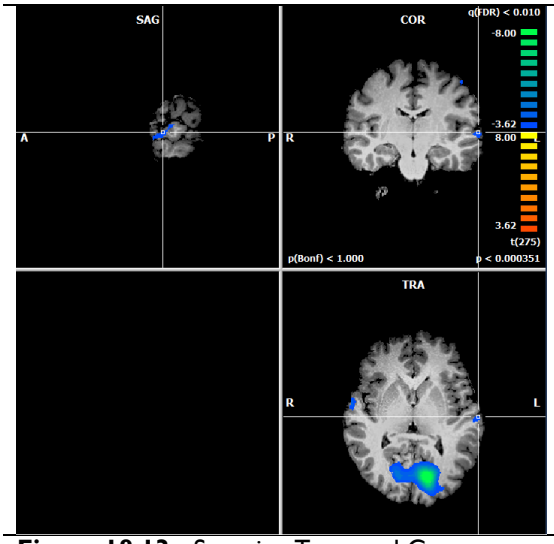

Figure 18.13 - Superior Temporal Gyrus

Figure 18 - Significant BOLD activations for the contrast of ***main effects*** **between** ***Fanatics and Non Fanatics*****.** RFX analysis (-3.62>t_{275}>3.62, p<0.003710 corrected, q(FDR)=0.01, minimum cluster threshold 378). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

3.4 Main Effects on Fanaticism in Strong and Weak Teams

For the pool of participants having Académica as favourite club, group differences were tested for the main effects (ANOVA group analysis, 2 levels for the between-subjects factor: *AAC Fanatics* or *AAC Non Fanatics*, 3 levels for the within-subjects factor*: high, medium and low sacrifice*, as described in the methods chapter). Positive clusters were found in the right angular gyrus, right orbital gyri, right lateral ventricle, left precentral gyrus and left temporal pole. The same contrast evidenced a negative cluster in the bilateral superior frontal gyrus, left primary and secondary visual cortices, left precuneus, left superior frontal gyrus, left supplementary motor area and left inferior temporal gyrus (See **figures 19.1-19.9**). Results are detailed in the **table 8**.

Table 8: ***main effects between AAC Fanatics and AAC Non Fanatics*****.** Regions were identified from a RFX analysis (-3.81>t_{145}>3.81, p<0.004056 corrected, q(FDR)=0.02, minimum cluster threshold: 300). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Angular Gyrus BA 39	R	59	-50	37	4.300272	0.000031
Orbital Gyrus	R	35	43	-3	6.202729	<0.000001
Superior Frontal Gyrus BA 6	R and L	-1	7	58	-4.984365	0.000002
Primary and Secondary	L	-28	-83	9	-8.553617	<0.000001

Visual Cortices (BA 17 and 18)						
Precuneus BA 7	L	-19	-59	48	-5.583767	<0.000001
Superior Frontal Gyrus – Prefrontal Cortex BA 10	L	-23	67	18	-4.658757	<0.000001
Lateral Ventricle	R	-28	-41	3	5.332956	<0.000001
Supplementary Motor Area - Frontal Cortex BA 6	L	-25	22	58	-5.290111	<0.000001
Precentral Gyrus – Frontal Cortex BA 6	L	-46	-5	27	4.721433	0.000005
Temporal pole BA 38	L	-52	7	-15	4.316489	0.000029
Inferior Temporal Gyrus BA 20	L	-55	-41	-21	-5.072138	0.000001

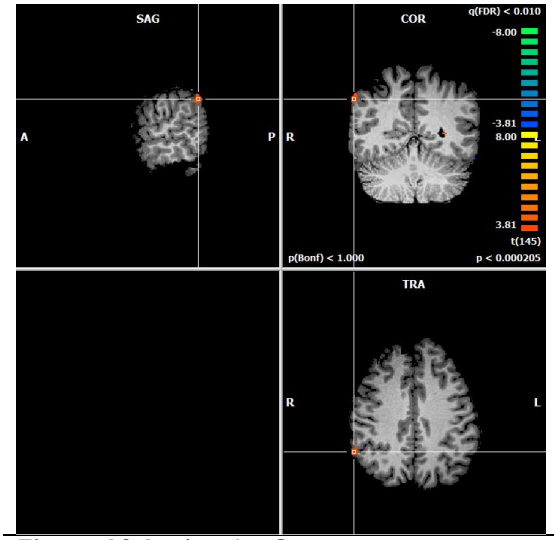

Figure 19.1 - Angular Gyrus

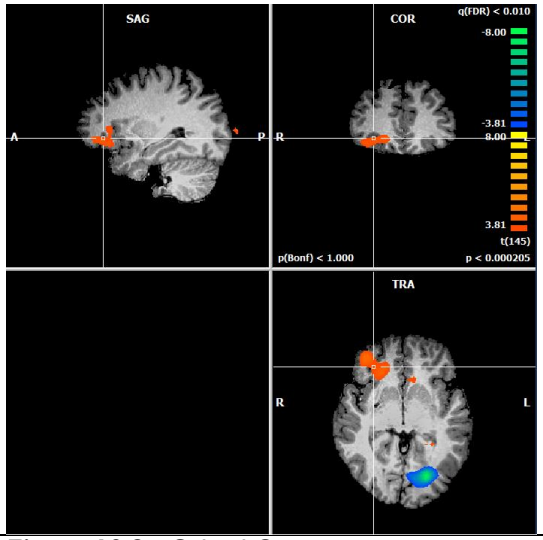

Figure 19.2 - Orbital Gyrus

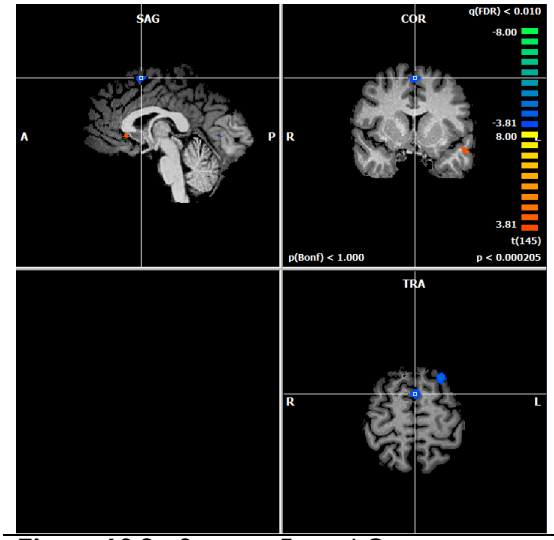

Figure 19.3 - Superior Frontal Gyrus

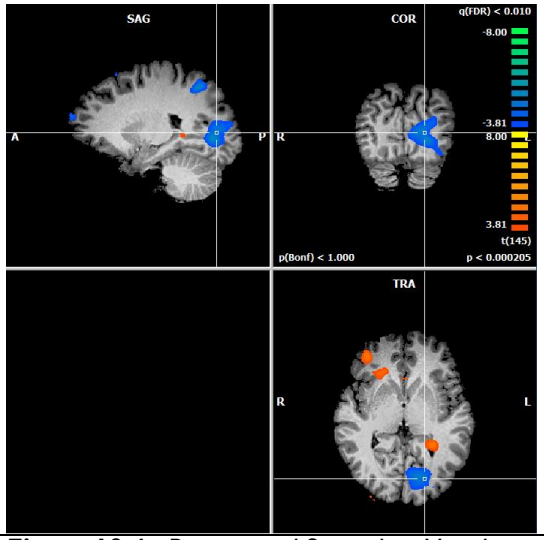

Figure 19.4 - Primary and Secondary Visual Cortices

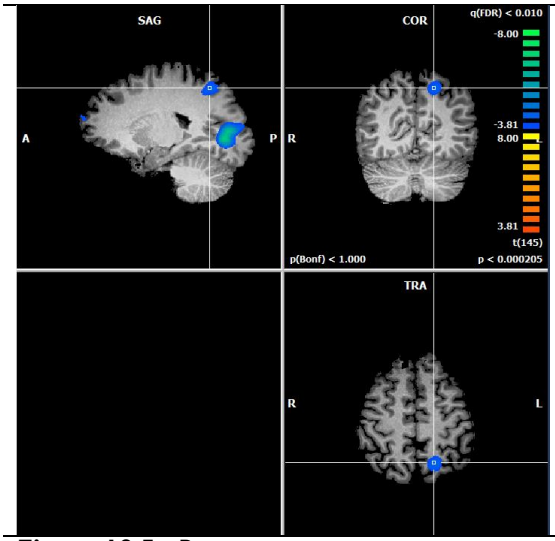

Figure 19.5 - Precuneus

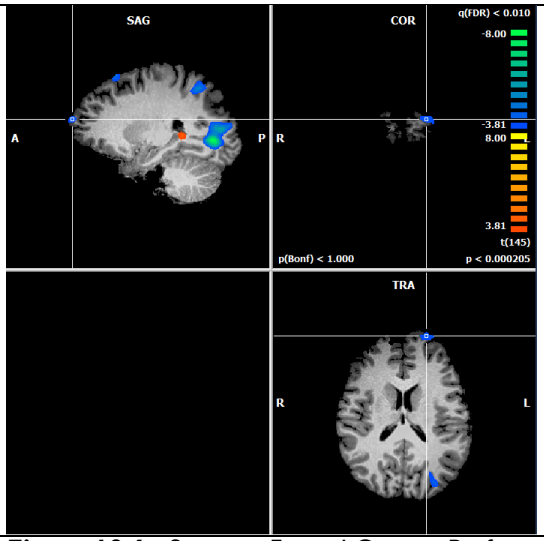

Figure 19.6 - Superior Frontal Gyrus – Prefrontal Cortex

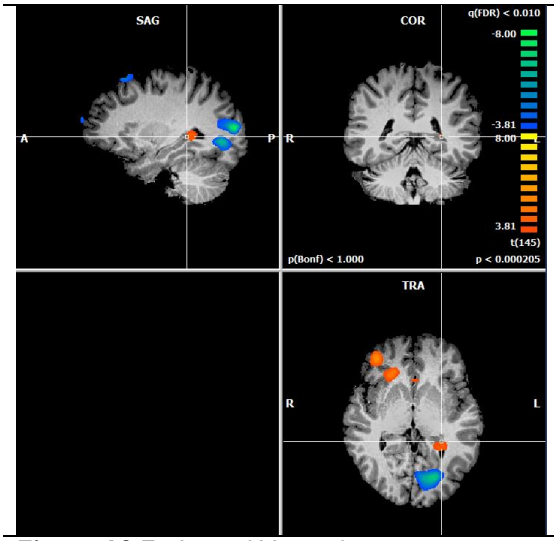

Figure 19.7 - Lateral Ventricle

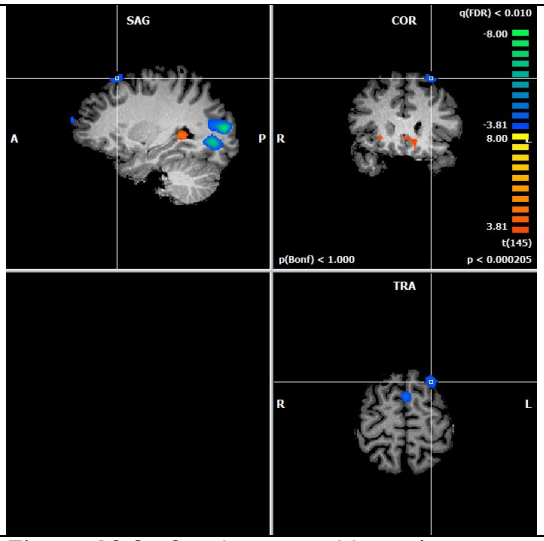

Figure 19.8 - Supplementary Motor Area –

Frontal Cortex

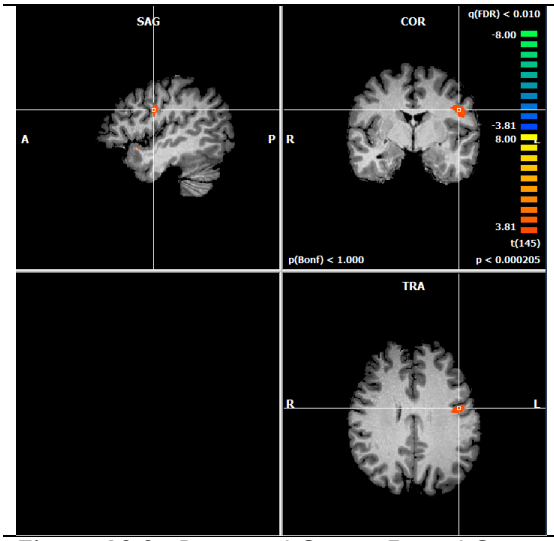

Figure 19.9 - Precentral Gyrus - Frontal Cortex

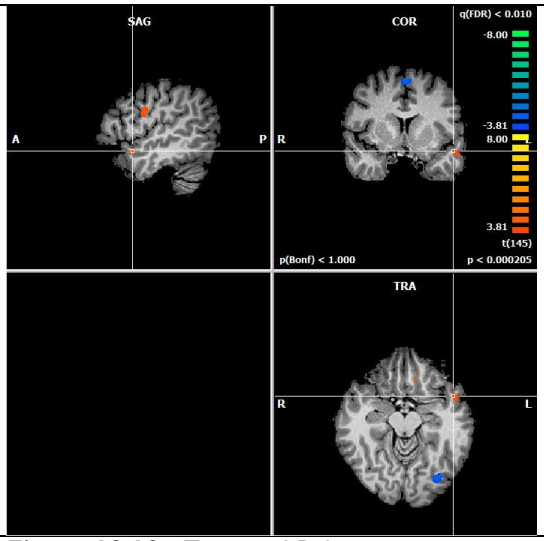

Figure 19.10 - Temporal Pole

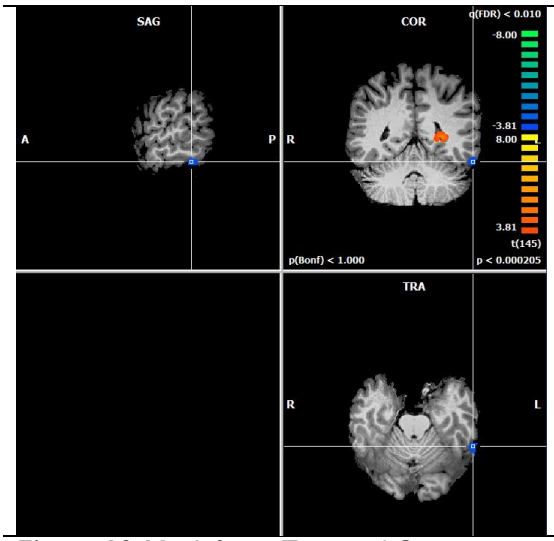

Figure 19.11 - Inferior Temporal Gyrus

Figure 19 - Significant BOLD activations for the contrast of ***main effects* between *AAC Fanatics and AAC Non Fanatics*.** RFX analysis (-3.81>t_{145}>3.81, p<0.004056 corrected, q(FDR)=0.02, minimum cluster threshold 300). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

For the pool of participants having Porto as favourite club, group differences were tested for the main effects (ANOVA group analysis, 2 levels for the between-subjects factor: *FCP Fanatics* or *FCP Non Fanatics*, 3 levels for the within-subjects factor*: high, medium and low sacrifice*, as described in the methods chapter). Negative clusters

were found in the right middle frontal gyrus, secondary visual cortex bilaterally, left superior frontal gyrus, left postcentral gyrus and left superior temporal gyrus (See **figures 20.1-20.6**). Results are detailed in the **table 9**.

Table 9: ***main effects between FCP Fanatics and FCP Non Fanatics.*** Regions were identified from a RFX analysis ($-3.99>t_{125}>3.99$, $p<0.002199$ corrected, q(FDR)=0.01, minimum cluster threshold: 378). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	t	p
Middle Frontal Gyrus - Premotor Cortex BA 6	R	54	13	33	5.186573	0.000001
Middle Frontal Gyrus – Prefrontal Cortex BA 8	R	30	31	51	5.044155	0.000002
Secondary Visual Cortex BA 18	R and L	-13	-71	3	6.418013	<0.000001
Superior Frontal Gyrus - Prefrontal Cortex BA9	L	-34	46	40	5.357062	<0.000001
Postcentral Gyrus - Primary Somatosensory Cortex BA 3 and BA 2	L	-40	-14	36	5.605968	<0.000001
Superior Temporal Gyrus BA22	L	-55	13	-6	4.847386	0.000004

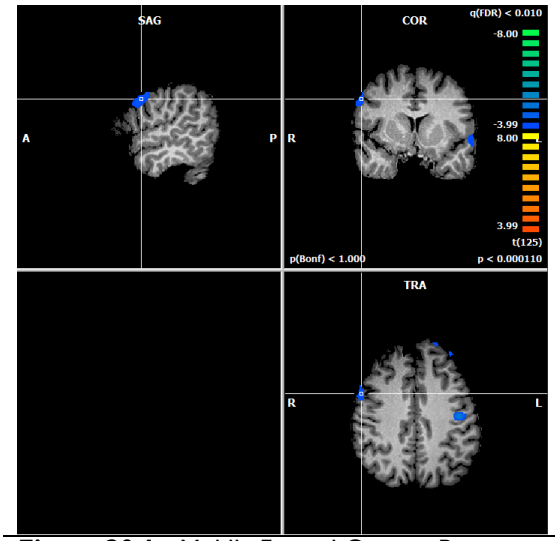

Figure 20.1 - Middle Frontal Gyrus – Premotor Cortex

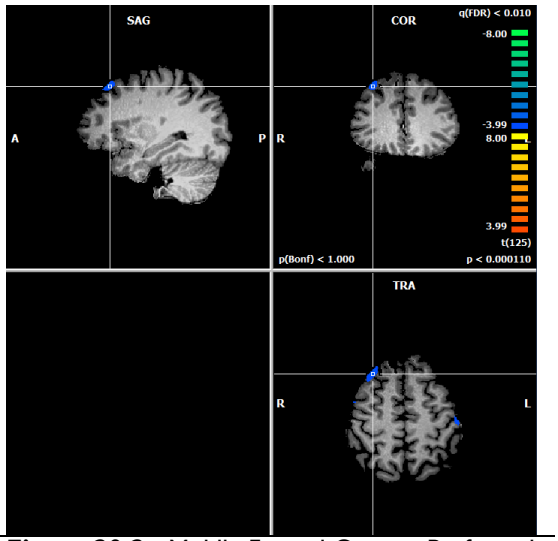

Figure 20.2 - Middle Frontal Gyrus – Prefrontal Cortex

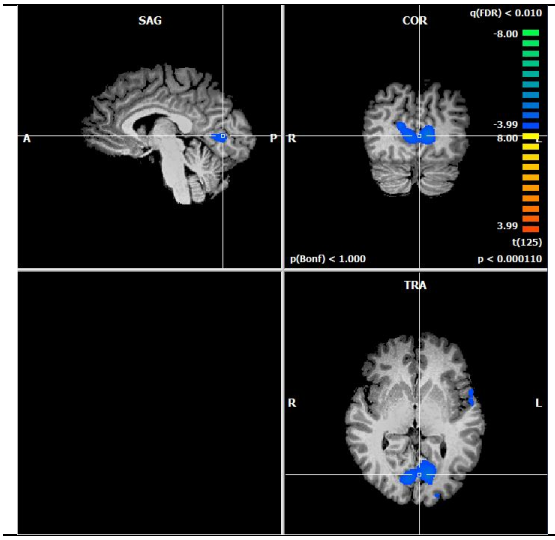

Figure 20.3 - Secondary Visual Cortex

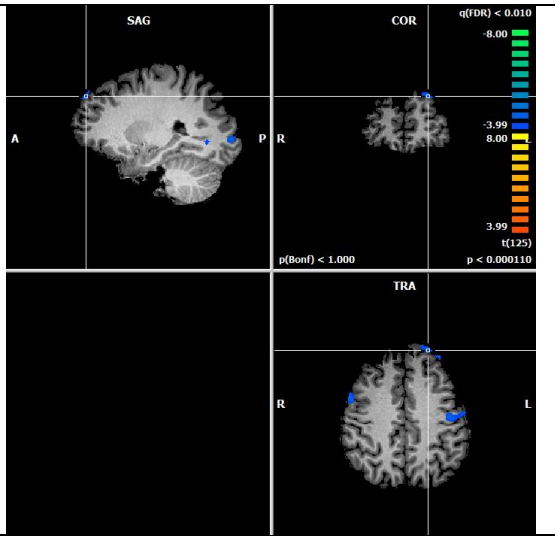

Figure 20.4 - Superior Frontal Gyrus – Prefrontal Gyrus

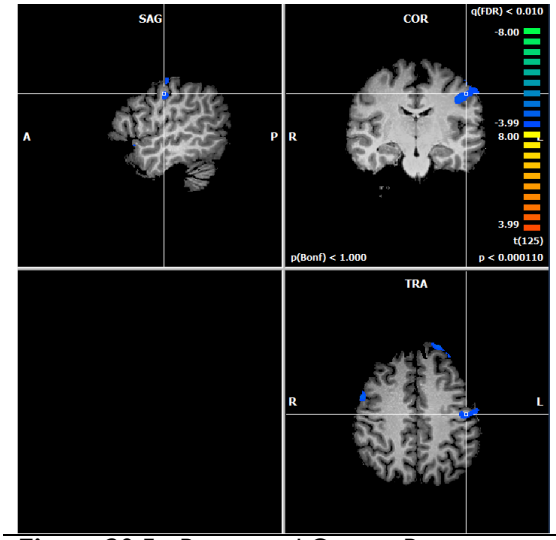

Figure 20.5 - Postcentral Gyrus – Primary Somatosensory Cortex

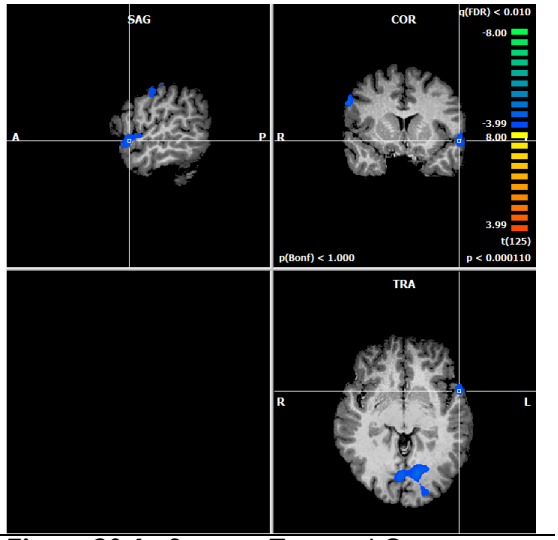

Figure 20.6 - Superior Temporal Gyrus

Figure 20 - Significant BOLD activations for the contrast of ***mains effects* between *FCP Fanatics and FCP Non Fanatics*.** RFX analysis (-3.99>t_{125}>3.99, p<0.002199 corrected, q(FDR)=0.01, minimum cluster threshold 378). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

3.5 Correlations with Group Fanaticism Scores

For the pool of participants having Académica as favourite club, correlation between the contrast *high vs low* sacrifice and *FSFS scores* was tested. Negative cluster were found in the right anterior insula and anterior cingulate cortex bilaterally (See **figures 21.1-21.2**). Results are detailed in the **table 10**.

Table 10: Correlation between monetary sacrifices *FSFS scores and high + medium vs. low contrast in Académica subjects.* Regions were identified from a RFX analysis ($-0.42>r_{28}>0.42$, $p<0.02$ corrected, minimum cluster threshold: 1377). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	R	p
Anterior Insula	R	38	25	12	-0.574474	0.000877
Anterior Cingulate Cortex BA 32	R and L	2	28	3	-0.591232	0.000581

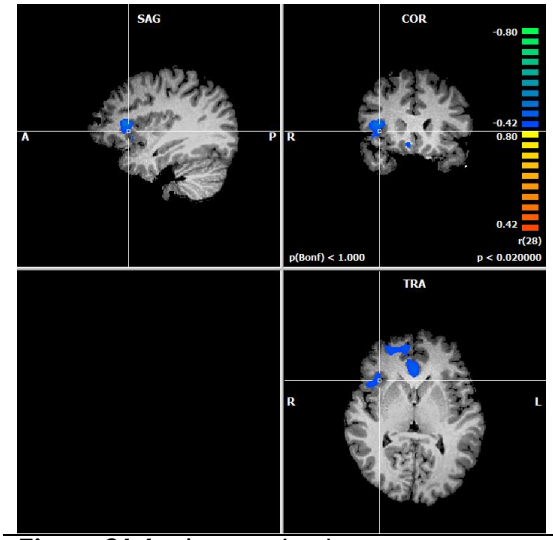

Figure 21.1 - Anterior Insula

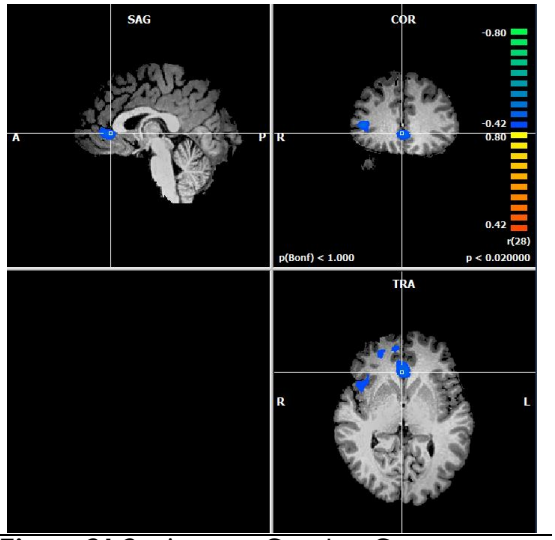

Figure 21.2 - Anterior Cingulate Cortex

Figure 21 - Map of significant correlations between ***FSFS scores in and high + medium vs. low contrast Académica subjects.*** RFX analysis ($-0.42>r_{28}>0.42$, $p<0.02$ corrected, minimum cluster threshold 1377). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

For the pool of participants having Porto as favourite club, correlation between the contrast *high vs low* sacrifice and *FSFS scores* was tested. Positive clusters were found in the right insular cortex, lateral ventricle bilaterally, superior frontal gyrus bilaterally, medulla, left extra-nuclear white matter and temporal pole. The same

contrast evidenced a negative cluster in (See **figures 22.1-22.7**). Results are detailed in the **table 11**.

Table 11: Correlation between monetary sacrifices and *FSFS scores and high + medium vs. low contrast in Porto subjects*. Regions were identified from a RFX analysis ($-0.45>r_{24}>0.45$, $p<0.02$ corrected, minimum cluster threshold: 351). The peak voxel of each cluster is described by its t and p values and its coordinates in the Talairach space.

Region	Hemisphere	Peak X	Peak Y	Peak Z	r	p
Insular Cortex BA 13	R	32	-5	24	0.587123	0.001615
Lateral Ventricle	R and L	20	-38	9	0.740911	0.000015
Superior Frontal Gyrus - Prefrontal Cortex BA 10	R	8	71	13	0.889090	<0.000001
Medulla	R and L	-4	-35	-36	0.833098	<0.000001
Caudate Nucleus	L	-16	4	21	0.596517	0.001298
Superior Frontal Gyrus - Prefrontal Cortex BA 10	L	-22	68	18	0.708200	0.000052
Temporal Pole	L	-34	-2	-27	0.630860	0.000550

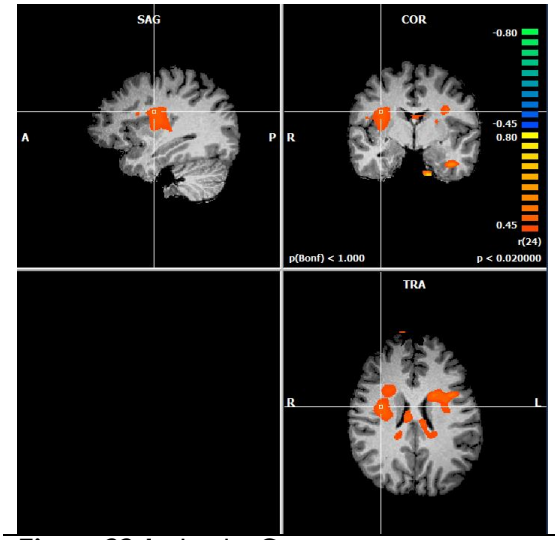

Figure 22.1 - Insular Cortex

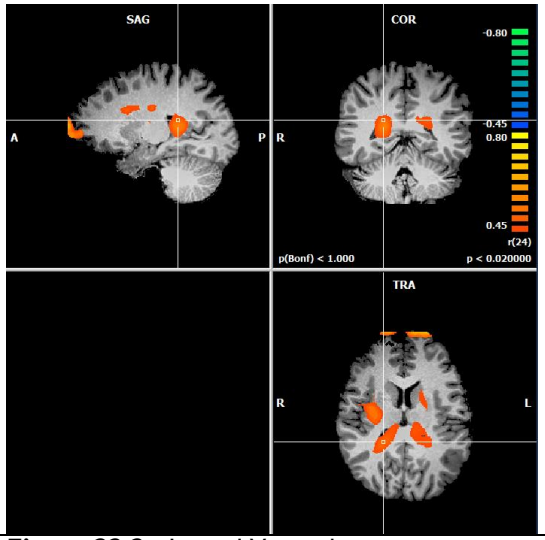

Figure 22.2 - Lateral Ventricle

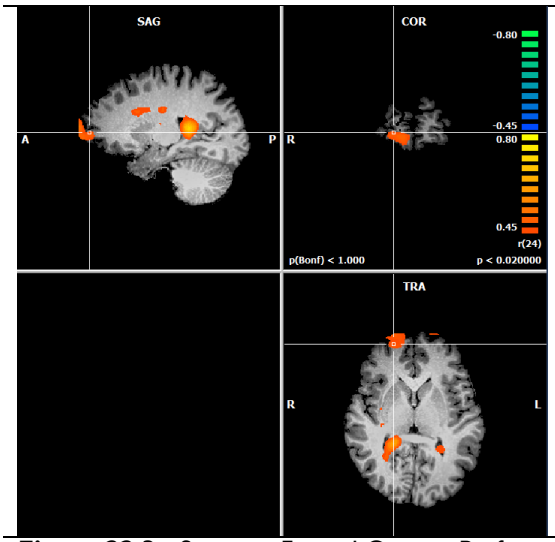

Figure 22.3 - Superior Frontal Gyrus – Prefrontal Cortex

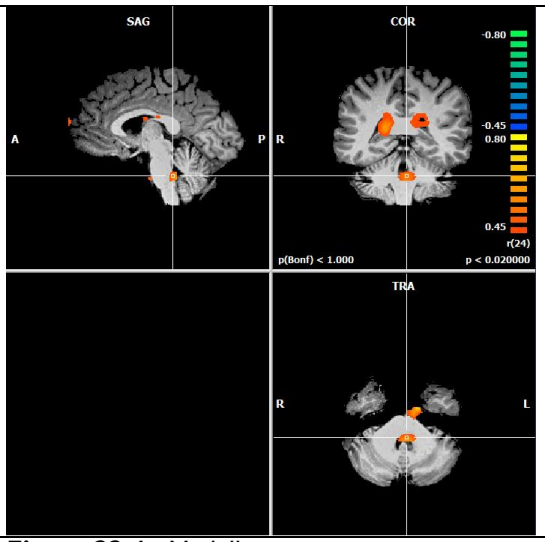

Figure 22.4 - Medulla

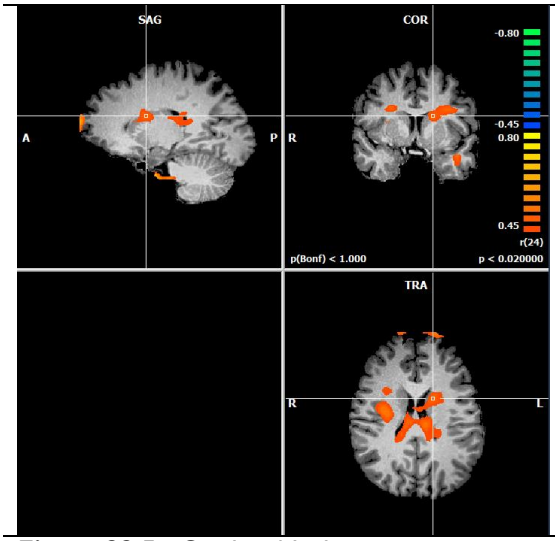

Figure 22.5 - Caudate Nucleus

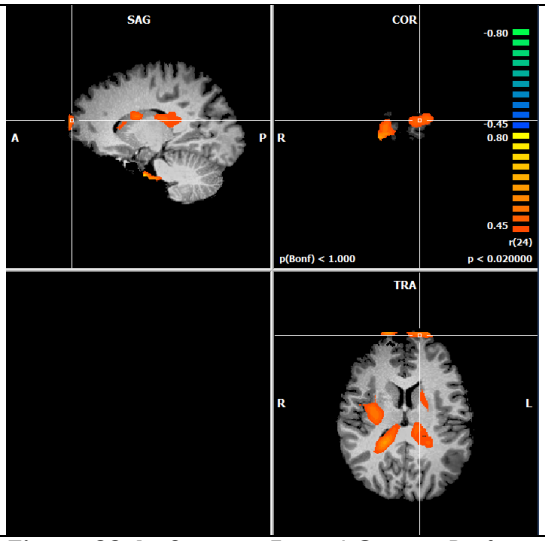

Figure 22.6 - Superior Frontal Gyrus – Prefrontal Cortex

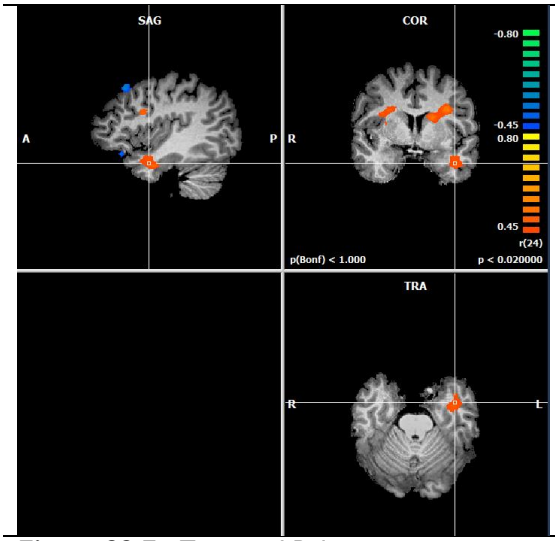

Figure 22.7 - Temporal Pole

Figure 22 - Map of significant correlations between ***FSFS scores and high + medium vs. low contrast in Porto subjects.*** RFX analysis ($-0.45>r_{24}>0.45$, $p<0.02$ corrected, minimum cluster threshold 351). Statistical maps are projected in a single subject's brain just for visualization purposes. Left side of each spatial cut refers to the right side of the brain.

Chapter 4

Discussion

4.1 Levels of sacrifice

The results indicate that distinct neural networks underlie the willingness to sacrifice own monetary resources to support the affiliative sense of team belongingness. Areas associated to reward processing and cognitive control are recruited while the individuals process the importance (translated by a monetary value) of specific football matches. Prefrontal cortex, orbitofrontal cortex and superior parietal lobule are important hubs in this process.

The first step to understand the neural bases of monetary sacrifice, here in the context of ingroup love, is to compare the brain activity underlying different levels of sacrifice, despite subject club preference or fanaticism level. In the present study, the sacrifice is measured by the amount of own money that the subject is willing to spend to assist specific football matches. For this reason, the first analysis is a comparison between levels of sacrifice given by the participant's responses values, (see the criteria for levels definition in the methods section). T-tests comparing *high + medium versus low* and *high versus low* responses of all subjects (n=56) showed a common pattern of increased activation in areas reportedly associated to decision making processes. Both contrasts elicited increased brain activity in two regions of the left superior parietal lobule (BA 5 and BA 7) and regions of prefrontal cortex (BA 9 and 10). In addition to the common pattern, the contrast *high + medium vs low* also evidenced positive brain activity in the superior frontal gyrus BA 6 and precuneus, whereas *high vs low* maps evidenced changes in the orbitofrontal cortex BA 11 (Fig 13.1) and an extension reaching anterior cingulate cortex from the left prefrontal cortex cluster.

Orbitofrontal cortex (OFC), along with other areas, is thought to play an important role in the expected affective value definition of a stimulus [7, 13]. In the present task, one can assume that OFC is involved in the computation of the monetary sacrifice that a specific football match is worth to. However, the decision making process is thought to involve other cognitive areas that receive that input of OFC [7]. Prefrontal cortex is a key region in many aspects of processing of emotional stimuli and decision making. Nevertheless, other parietal areas showed to be recruited during the process of decision making on sacrifice. Anterior cingulate cortex is associated to conflict monitoring in the engagement of cognitive control [41].

It is worth noting the participation of regions associated to decisions involving conflict and reward [42] and goal-intensive processing [43]. Since dilemmas that generate higher willing to sacrifice own monetary resources activate more those cerebral areas associated to deliberation, one can assume that those dilemmas induce greater conflict and indecision levels during decision making processes. Furthermore, many of these regions are also involved in the processing and management of emotions associated to decision mechanisms. Structures like prefrontal cortex (BA 9/10), superior frontal gyrus (BA 6) and secondary sensorimotor cortex (BA 5/7), found here to be related to the willing to monetary sacrifice, have been object of investigation [44] and at this point we can consider consensual their role in emotional integration in decision-making. This regulatory mechanism for affective control is crucial in contexts involving football passion such the one in this study. Thus, we can interpret the increased signal detected for high value responses, as clear evidence of the great weight that emotions have in this type of decisions [12].

4.2 Group differences for Levels of Sacrifice

Individuals sacrifice their own resources to support the preferred team, without any monetary or material return (what does not mean that they do not feel somehow rewarded). The results presented here evidenced that decision making on sacrifice is processes differentially depending on the level of fandom and the category

of preferred team: strong team fanatics (FCP), weak team fanatics (AAC) or fans (Controls). Ventromedial prefrontal cortex recruitment is in line with the literature that assigns to it a role in reward value storing. Regions such as putamen, cingulate cortices related to integration of both cognitive and motivational/emotional information, displayed a different relevance depending on the subjects' team category.

The comparison between *higher and medium against lower sacrifices* revealed some differences depending on group. Participants from AAC group (weak team fanatics) had an increased fMRI signal over Controls (fans) in the right inferior and left superior frontal gyrus (BA 47), sub regions of orbitofrontal cortex, the latter one extends to the subgenual part of anterior cingulate cortex and also posterior insula (BA 13). On the other hand, the analysis between FCP (strong team fanatics) and Controls (fans) showed a deactivation in the right posterior cingulate cortex. Whilst for FCP vs. AAC, decreased activity in the putamen for both hemispheres was found in the stronger team. On a deeper assessment of these results, positive activations in posterior insular cortex could be interpreted as an augmented influence of emotional factors during decision making in the AAC group comparing to those who did not manifest such appreciation for football (Controls). Besides common knowledge of insular role in decision making involving risk-taking situations [45], it is also known to be involved in emotional processing. Considered a limbic-related cortex, insula role in subjective emotional experience has become target of interest in many studies including activities of deliberation and conflict [46]. Additionally, the presence of anterior left portion of cingulate cortex reinforces the contribution that emotional factors have when facing deliberative challenges in this context. As part of limbic lobe, cingulate cortex mediates interactions between emotion and memory in decision tasks [47], which makes sense considering all the episodic recalls that this specific task can bring to mind of those familiar to football environments. Therefore, one can expect that when comparing subjects from different groups, one of the groups manifests major influence by affective factors, given the strong feeling that football generates. Furthermore, that effect would be speculated to be more prevalent in subjects who attribute greater importance to football in their lives (fanatics over fans), as it was evidenced by AAC vs. Controls contrast. Although this wasn't observed in statistical maps related to FCP vs. Controls subjects. Once again, we remember these subjects

are connoted as one of the most fanatic and numerous football groups in Portugal due to recent success which leads to a larger participation in club activities, and for that reason categorized as "strong team" in this study. Comparison between FCP (strong team fanatics) and Controls (fans) evidenced significant differences in brain activity of right posterior segment of cingulate cortex. In this case, the Controls group showed higher activity than FCP group, perhaps suggesting that the more engaged participants activate less this part of the default mode network. Furthermore, results concerning FCP (strong team fanatics) vs. AAC (weak team fanatics) contrast exhibited a bilaterally negative cluster in putamen. As part of dorsal striatum and highly connected to limbic system, putamen is implicated in selection and initiation of very habitual actions, through the mediation of sensorimotor, cognitive, and motivational/emotional information [47].

4.3 Main Effects on Fanaticism

The comparison of fanatics versus non fanatics evidenced differences in important hubs of the decision making processing. Namely, anterior cingulate cortex and prefrontal cortex, which play important roles in conflict monitoring and cognitive control, respectively.

One of the objectives of this study was to evaluate whether fanaticism level, in general, affects neural activity underlying the decision process, regardless club preference. Participants were separated into Fanatics and Non Fanatics with all the sacrifice levels (*low, medium and high*) comprehended in the analysis for an overall main effects comparison. This contrast revealed negative activation bilaterally in middle frontal gyrus (BA 9) and in the left medial frontal gyrus (BA 6). While prefrontal areas are already an "usual suspect" throughout some tests in the present study, the negative activation in left medial frontal gyrus (BA 6) reveals another piece of the complex mechanisms working beneath the decision process. Considering the involvement of this area in the judgment, by influencing the final decision through implicit emotional information [44], it's intriguing to observe a greater brain activity in

this area for participants with smaller affective to football, and a stronger rational approach (the reason vs emotion dilemma). Subjects in the fanatic group revealed decreased activity in superior temporal gyrus (BA 22) on both hemispheres. This highly cognitive area was recently associated to establish contingency base decision making strategies in tasks involving prediction where the previous answers affects the following one [48, 49]. Since the experimental paradigm of this study didn't involve any prediction exercise, this activation could indicate some kind of increased ponderation during the deliberation process for Non Fanatic participants, while Fanatic individuals could be characterized as more spontaneous and impulse given the nature of the decision. Precuneus (BA 7), part of parietal lobule is involved in the integration of implicit information [44] and goal-intensive processing in decision making [43]. On the other hand, two clusters in left anterior cingulate cortex and prefrontal cortex were the only regions more active in subjects considered as fanatics.

4.4 Main Effects on Fanaticism in Strong and Weak Teams

The analysis between Fanatics and Non Fanatics was performed with the intent of getting the most generic knowledge of in which manner ingroup fervour could affect mental mechanisms that module the decision making behaviour. In addition to understand the overall tendency of these effects, it appeared interesting to investigate this same factor considering only subjects belonging to the same club. By doing so, we hope to understand if the distinction between fanatic and regular fan manifests through the same mental processes in the case of fans from a minor club and those belonging to major one. In what concerns the analysis assessing the condition of fanatic versus being a regular fan of those who support Académica, results reinforce the involvement of frontal areas as key players on complex cognitive processes such as having to perform a monetary sacrifice to receive a sentimental significant outcome. Superior frontal gyrus in both hemispheres, left supplementary motor area and left precentral gyrus (BA 6) and left prefrontal superior frontal gyrus (BA 10) had a decreased activity in Académica fanatics over Académica fans. Areas of frontal and prefrontal cortex already had been found by Deppe M. and his colleagues to be under activated when

studying the influence of brands on economic decisions [44] and the participants' favourite brand was one of the options. Making the parallelism between the favourite brand used in Deppe M. et al study and the condition of being a zealous football fan, results point to the lesser involvement of this frontal areas. On the other hand, in that study [44], the presence of the target favourite brand also showed increased activity in the inferior precuneus while the opposite occurred in the left precuneus (BA 7) of Académica fanatics. The analysis assessing the fanatic title of individuals from a strong team (Porto) showed the same effect of decreased activity in frontal and prefrontal regions, right prefrontal and left/right superior/middle and right frontal gyrus, as observed in those belonging to weaker team (Académica). Besides these clusters, negative activation located in the left superior temporal gyrus, an area referred as important to establish contingency strategies in decision making, could indicate a lesser prudent and more impulsive approach to the decision [48] as observed in Fanatics vs. Non Fanatics group independent contrast.

4.5 Correlations with Group Fanaticism Scores

The affection that someone has for a club can be measured by the amount of sacrifice that that person is willing to do for the sake of it. Sacrifices can be demonstrated in many ways. Here, we use quantities of money spent to watch football games as unity of economic sacrifice. The impact that the sacrifice level exercises on neural mechanisms during the performed task was also measured by studying the relationship between the average answer value, as the representation of the monetary effort, of each participant and fMRI data recorded. Correlation tests were performed independently for each club as described in the methods for the reasons presented in the methods section. Correlation involving subjects from the weaker team (Académica) showed a negative correlation in right anterior insula ($R = -0.57$) and in the anterior cingulate cortex ($R = -0.59$). Taking into account the implication of these areas in mediation of emotional stimuli, and conflict monitoring on decision on decision making contexts, it's natural to observe different activities regarding the different levels of affection that distinct degrees of fanaticism generate. The same

statistical test was executed on subjects from the strong team (Porto). The results showed a gradual increased involvement of prefrontal areas in both hemispheres for the proportional increase of fanaticism level. The high correlation coefficients in this area, 0.89 for the right and 0.71 for the left hemispheres, supports once again the major role of these regions on tasks involving decisions related to monetary sacrifices. Right insula was also more active for increasing levels of fanaticism score. Elevated correlation in caudate nucleus (R = 0.83), an important area related to reward anticipation [41] and motivation-dependent responses [50], suggest reward orientated thinking for the most fanatics subjects. Insular cortex showed a positive correlation (R = 0.58), which could indicate that emotional factors have a greater influence in the decision of subjects from Porto.

Chapter 5

Conclusions

5.1 Final Conclusions

This work was developed with the purpose to identify the neural mechanism underlying the decision making of the willing to monetary sacrifice, towards a rewarding outcome in the form of watching a football match. Further, it was assessed in which way the fact of belonging to stronger team in comparison to a weaker could affect that physiological response. The option to use football teams and theirs fans, as representation of brands and consumers, is justified by the emotional connection between them. In addition, this transposition is favored by the fact that we could use money spending as unity, since it is a measurable variable and is used in the transactions in both contexts.

First of all, the experimental paradigm used in this study seemed to fulfil satisfactorily the objectives of the study. The performed task allowed to stimulate brain areas far documented to decision making, and other related functions, as well as to differentiate neural mechanisms depending on the levels of sacrifice or the nature of the fans.

The amount of monetary sacrifice disposed by participants generated distinct involvement of brain areas during the deliberation moment. Moderate and extreme sacrifices induced a greater activity in prefrontal, orbitofrontal and parietal regions when comparing to lower sacrifices, evidencing the increased involvement of areas of associated to reward processing and cognitive control. Furthermore, when comparing

the most extreme responses (high versus low), increased activation of anterior cingulate was found, which can mean higher levels of conflict for highest sacrifice.

The analysis of preferred team's category (strong team fanatics (FCP), weak team fanatics (AAC) or fans (Controls)) showed substantial differences in the process of decision making on sacrifice. Weak team fanatics showed increased activity in orbitofrontal cortex, anterior cingulate and insula in comparison to control fans, which point to a higher recruitment of emotional related areas to make a decision. On the other hand, strong team fanatics do not showed this higher recruitment of areas. Instead, the group showed decreased activity in the posterior cingulate part of DMN, when compared with controls, and in the putamen, when compared with the weak team fanatics. This can mean that the decision making on the willing to monetary sacrifice in downregulated for the strong team fanatics.

Accessing the fanatic condition regardless club preference proposes an impulsive and less prudent behaviour of this type of individuals, based on the negative activations in two important hubs of rational decision making brain regions, the anterior cingulate cortex and the prefrontal cortex.

Results also demonstrate that being a fanatic within the context of a stronger club is not very different from within a weaker club. A common pattern of decreased activity in frontal and prefrontal areas was visible for subjects of both teams which was reported as associated to dilemmas involving favourite brands. Strong team fanatics also evidenced deactivation in superior temporal gyrus, a high level cognitive area in decision making processes.

Gradually increasing Fanaticism levels manifest by those individuals belonging to a weak team require less recruitment of insula and anterior cingulate. In the case of members from a strong team, greater involvement of prefrontal areas and caudate nucleus indicate a very reward orientated thinking in this type of dilemmas.

Summarizing, situations provoking a greater sacrifice constitute a greater challenge in terms of making a decision. When facing the hardest dilemmas, the subjects related to a weak team demonstrated a more broad neural response in

networks underlying memory and emotional vs rational decision conflicts, while those belonging to a strong team tend to downregulate the neural response while deciding on dispending big amounts of money for their club. The categorization of Fanatic is associated to impulsive decisions that did not require much deliberation.

5.2 Limitations & Future Work

This work aimed to investigate a series of brain neural mechanisms underlying a complex cognitive process such as the decision making on monetary sacrifice. The fMRI is a valuable tool in neuroscience. Even though, it is important the cross validation of different researches so the brain processes are better can be better understood. In this work in particular, some results showed the involvement of unexpected brain areas, where further studies can help to explain their roles in this task.

Considering the unique specifications of football and its relationship with the correspondent supporters, it is possible that the neural correlates associated to decision, cannot be fully reproducible in brands/consumers context. Nevertheless, one could acknowledge a very good approximation in this study between these two scenarios.

The method used to define the three levels of sacrifice can be debatable due to its subjectivity. In some subjects cases there wasn't an evident dispersion of values (especially in controls) which complicated the classification of the answers. The comparisons of both *high + medium vs. low* and *high vs. low* were performed with the intent of minimize this problem.

Main effects on identification groups (*FCP, AAC* and *Control*) could be an interesting aspect to investigate in further works. This type of analysis could elucidate about the overall differences between group subjects when facing all levels of sacrifice.

Future works should be endorsed using different contexts than football in order to complement these findings.

References

1. Mathur, V.A., et al., *Neural basis of extraordinary empathy and altruistic motivation.* Neuroimage, 2010. **51**(4): p. 1468-75.

2. Dovidio, J.F. and S.L. Gaertner, *Intergroup Bias*, in *Handbook of Social Psychology*. 2010, John Wiley & Sons, Inc.

3. Caruso, E.M., N.L. Mead, and E. Balcetis, *Political partisanship influences perception of biracial candidates' skin tone.* Proceedings of the National Academy of Sciences, 2009. **106**(48): p. 20168-20173.

4. Levine, M., et al., *Identity and emergency intervention: how social group membership and inclusiveness of group boundaries shape helping behavior.* Pers Soc Psychol Bull, 2005. **31**(4): p. 443-53.

5. Hein, G., et al., *Neural Responses to Ingroup and Outgroup Members' Suffering Predict Individual Differences in Costly Helping.* Neuron. **68**(1): p. 149-160.

6. Duarte, I., H. Jorge, R. Cayola, C. Ferreira, M. Castelo-Branco, *[Under revision] Tribal love: the neural correlates off passionate engagement in football fans.* 2016.

7. Declerck, C.H., C. Boone, and G. Emonds, *When do people cooperate? The neuroeconomics of prosocial decision making.* Brain and Cognition, 2013. **81**(1): p. 95-117.

8. Emonds, G., et al., *The cognitive demands on cooperation in social dilemmas: an fMRI study.* Soc Neurosci, 2012. **7**(5): p. 494-509.

9. Rilling, J.K., et al., *The neural correlates of the affective response to unreciprocated cooperation.* Neuropsychologia, 2008. **46**(5): p. 1256-66.

10. Suzuki, S., et al., *Neural basis of conditional cooperation.* Soc Cogn Affect Neurosci, 2011. **6**(3): p. 338-47.

11. Knoch, D., et al., *Diminishing reciprocal fairness by disrupting the right prefrontal cortex.* Science, 2006. **314**(5800): p. 829-32.

12. Sanfey, A.G., et al., *The Neural Basis of Economic Decision-Making in the Ultimatum Game.* Science, 2003. **300**(5626): p. 1755-1758.

13. Knutson, B., et al., *Distributed neural representation of expected value.* J Neurosci, 2005. **25**(19): p. 4806-12.

14. Singer, T., et al., *Brain responses to the acquired moral status of faces.* Neuron, 2004. **41**(4): p. 653-62.

15. Rilling, J.K., et al., *The neural correlates of theory of mind within interpersonal interactions.* Neuroimage, 2004. **22**(4): p. 1694-703.

16. Colman, A.M., *Cooperation, psychological game theory, and limitations of rationality in social interaction.* Behav Brain Sci, 2003. **26**(2): p. 139-53; discussion 153-98.

17. Sally, D., *Conversation and Cooperation in Social Dilemmas: A Meta-Analysis of Experiments from 1958 to 1992.* Rationality and Society, 1995. **7**(1): p. 58-92.

18. Henrich, J., et al., *"Economic man" in cross-cultural perspective: behavioral experiments in 15 small-scale societies.* Behav Brain Sci, 2005. **28**(6): p. 795-815; discussion 815-55.

19. Dawes, C.T., et al., *Neural basis of egalitarian behavior.* Proc Natl Acad Sci U S A, 2012. **109**(17): p. 6479-83.

20. Harbaugh, W.T., U. Mayr, and D.R. Burghart, *Neural responses to taxation and voluntary giving reveal motives for charitable donations.* Science, 2007. **316**(5831): p. 1622-5.

21. Erk, S., et al., *Cultural objects modulate reward circuitry.* Neuroreport, 2002. **13**(18): p. 2499-503.

22. Paulus, M.P. and L.R. Frank, *Ventromedial prefrontal cortex activation is critical for preference judgments.* Neuroreport, 2003. **14**(10): p. 1311-5.

23. McClure, S.M., et al., *Neural correlates of behavioral preference for culturally familiar drinks.* Neuron, 2004. **44**(2): p. 379-87.

24. Christine M. Born, T.M.M., *Brand Perception - Evaluation of Cortical Activation Using fMRI*, in *Radiological Society of North America 2006 Scientific Assembly and Annual Meeting*. 2006.

25. Bauer, H.H., N.E. Sauer, and P. Schmitt, *Customer-based brand equity in the team sport industry: Operationalization and impact on the economic success of sport teams.* European Journal of Marketing, 2005. **39**(5/6): p. 496-513.

26. Keller, K.L., *Conceptualizing, Measuring, and Managing Customer-Based Brand Equity.* Journal of Marketing, 1993. **57**(1): p. 1-22.

27. Zagnoli, P. and E. Radicchi, *The football-fan community as a determinant stakeholder in value co-creation.* Sport in Society, 2010. **13**(10): p. 1532-1551.

28. Sands, M.J. and A. Levitin, *Basics of magnetic resonance imaging.* Semin Vasc Surg, 2004. **17**(2): p. 66-82.

29. *Classical Response of a Single Nucleus to a Magnetic Field*, in *Magnetic Resonance Imaging*. 2014, John Wiley & Sons Ltd. p. 19-36.

30. R. M. Van Geuns, P.A.W., H. G. De Bruin, B. J. Rensing, P. M. A. Van Ooijen, M. Hulshoff, M. Oudkerk, and P. J. De Feyter, *Resonance Imaging Angiography*. Vol. 42. 1991.

31. Aine, C.J., *A conceptual overview and critique of functional neuroimaging techniques in humans: I. MRI/FMRI and PET.* Crit Rev Neurobiol, 1995. **9**(2-3): p. 229-309.

32. Sprawls, P., *Magnetic Resonance Imaging: Principles, Methods, and Techniques*. 2000: Medical Physics Pub Corp.

33. Santarelli, M.F., Landini, L., & Positano, V. , *Advanced image processing in magnetic resonance imagingTaylor & Francis*. 2005: Taylor & Francis.

34. Ogawa, S., et al., *Functional brain mapping by blood oxygenation level-dependent contrast magnetic resonance imaging. A comparison of signal characteristics with a biophysical model.* Biophys J, 1993. **64**(3): p. 803-12.

35. Matthews, P. and P. Jezzard, *Functional magnetic resonance imaging.* Journal of Neurology, Neurosurgery, and Psychiatry, 2004. **75**(1): p. 6-12.

36. Stippich, C., *Clinical Functional MRI: Presurgical Functional Neuroimaging*. 2007.

37. Scott A. Huettel, A.W.S., Gregory McCarthy *Functional Magnetic Resonance Imaging*. 2008.

38. Amaro, E., Jr. and G.J. Barker, *Study design in fMRI: basic principles.* Brain Cogn, 2006. **60**(3): p. 220-32.

39. Jovicich, J., *Brief Introduction to fMRI*.

40. Ogawa, S., et al., *Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging.* Proc Natl Acad Sci U S A, 1992. **89**(13): p. 5951-5.

41. Kerns, J.G., et al., *Anterior cingulate conflict monitoring and adjustments in control.* Science, 2004. **303**(5660): p. 1023-6.

42. Rogers, R.D., et al., *Choosing between small, likely rewards and large, unlikely rewards activates inferior and orbital prefrontal cortex.* J Neurosci, 1999. **19**(20): p. 9029-38.

43. Fincham, J.M., et al., *Neural mechanisms of planning: a computational analysis using event-related fMRI.* Proc Natl Acad Sci U S A, 2002. **99**(5): p. 3346-51.

44. Deppe, M., et al., *Nonlinear responses within the medial prefrontal cortex reveal when specific implicit information influences economic decision making.* J Neuroimaging, 2005. **15**(2): p. 171-82.

45. Paulus, M.P., et al., *Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism.* Neuroimage, 2003. **19**(4): p. 1439-48.

46. Naqvi, N., B. Shiv, and A. Bechara, *The Role of Emotion in Decision Making: A Cognitive Neuroscience Perspective.* Current Directions in Psychological Science, 2006. **15**(5): p. 260-264.

47. Maddock, R.J., A.S. Garrett, and M.H. Buonocore, *Posterior cingulate cortex activation by emotional words: fMRI evidence from a valence decision task.* Hum Brain Mapp, 2003. **18**(1): p. 30-41.

48. Paulus, M.P., et al., *Prefrontal, parietal, and temporal cortex networks underlie decision-making in the presence of uncertainty.* Neuroimage, 2001. **13**(1): p. 91-100.

49. Paulus, M.P., et al., *Superior temporal gyrus and insula provide response and outcome-dependent information during assessment and action selection in a decision-making situation.* Neuroimage, 2005. **25**(2): p. 607-15.

50. Benningfield, M.M., et al., *Caudate responses to reward anticipation associated with delay discounting behavior in healthy youth.* Dev Cogn Neurosci, 2014. **7**: p. 43-52.