# BRAIN SUBSTRATES EXPLAIN DIFFERENCES IN THE ADOPTION AND DEGREE OF FINANCIAL DIGITALIZATION

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# Content

## NON-TECHNICAL SUMMARY

Over the last thirty years, neuroeconomists have identified brain activity patterns that explain part of the bounded rationality of economic decisions. Concurrently, digital channels have emerged and altered the way individuals gather information and make financial transactions. Digital channels have emerged as key alternatives to individuals to make financial decisions. According to the World Economic Forum (2018) financial digitalization may improve the efficiency and speed of retail financial services. However, if other consequences of the changes in financial digitalization remain largely unchecked, by 2030 the client choice and the level of risk in the financial system will be dramatically altered. In particular, power of data aggregation of digital suppliers will threaten the safety and protection of financial customers.

A number of studies have shown that due to cognitive constraints and a low average level of financial literacy, many savings, investing and borrowing decisions of individuals violate sound financial principles. Relatedly, a fundamental characteristic of digital channels is the online (non-human) nature of the interaction compared to the human interaction attached to offline services. Hence, introducing the digital dimension on financial decision-making is non-trivial as people differ substantially in the way they undertake their financial digitalization choices.

This study provides a neural characterization of financial digitalization decisions and shows that brain activity distinctively informs differences in the adoption of digital financial channels. It explores if usage patterns of digital financial channels and instruments are associated to psychological and biological indicators.

We show that brain substrates are associated with the adoption and degree of financial digitalization decisions. Brain imaging results reveal that higher level of insecurity, the emotional processing of trust and structural differences are related to the use of digitalized vs non-digital financial channels. This finding has considerable implications as digital financial interactions may alter the control, convenience and safety perception of financial decisions in ways that have not been yet considered by policy makers or providers of financial services. Overall, this evidence seem critical for the design of public policies to ehanced financial inclusion through technology and the service distribution strategies of private financial institutions.

# BRAIN SUBSTRATES EXPLAIN DIFFERENCES IN THE ADOPTION AND DEGREE OF FINANCIAL DIGITALIZATION*

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## Abstract

Digitalization alters the way individuals gather information and make financial transactions based on criteria such as the trustworthiness and perceived risk of digital channels. This study provides a neural characterization of financial digitalization decisions and shows that brain activity distinctively informs differences in the adoption of digital financial channels. It explores if usage patterns of digital financial channels and instruments are associated to psychological and biological indicators; it uses functional magnetic resonance imaging (fMRI) to investigate if financial digitalization decisions are linked to the evoked brain response to the safety associated to video images of financial transactions through digitalized and non-digitalized channels; it conducts trust and risk neuro-experiments to identify their impact on financial digitalization decisions; and it analyzes if brain structure is linked to financial digitalization behavior. The findings suggest high and low-

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frequency users exhibit differences in brain function and also in volume and fractional anisotropy values. A higher frequency of use of financial digital financial services is associated to higher brain activation linked to insecurity (higher sensitivity to punishment scores, lower safety neural evoked responses during the video task and altered white matter microstructure in a processing information structure). Additionally, high-frequency users of financial digital channels exhibit enhanced activation of brain areas linked to emotional processing during the trust game. These findings have important implications for the design of public policies to ehanced financial inclusion through technology and the service distribution strategies of private financial institutions.

## BACKGROUND AND MOTIVATION

Financial decisions are at the core of fundamental dimensions of economic complexity in modern societies, including financial education, the related bounded rationality of economic decisions and its impact on wealth and equality. Digital channels have emerged as key alternatives to individuals to make financial decisions. According to the World Economic Forum (2018) financial digitalization may improve the efficiency and speed of retail financial services. However, if other consequences of the changes in financial digitalization remain largely unchecked, by 2030 the client choice and the level of risk in the financial system will be dramatically altered. In particular, power of data aggregation of digital suppliers will threaten the safety and protection of financial customers. Digitalization alters the way individuals gather information and make financial transactions based on criteria such as the trustworthiness and perceived risk of digital channels.

A number of studies have shown that due to cognitive constraints and a low average level of financial literacy, many savings, investing and borrowing decisions of individuals violate sound financial principles (see, *inter alia,* Benartzi and Thaler, 2007; Campbell, 2006 and 2016; Sonnemann, Pope and Pope, 2013; Keys *et al.,* 2016; or Frydman and Camerer, 2016). Relatedly, a fundamental characteristic of digital channels is the online (non-human) nature of the interaction compared to the human interaction attached to offline services. Hence, introducing the digital dimension on financial decision-making is non-trivial as people differ substantially in the way they undertake their financial digitalization choices.

It has been shown that although trust plays a role in most economic transactions, it is even more relevant in online or, more generally, digital settings (Bart *et al.,* 2005; Wang and Emurian, 2005). There have been some wide studies analyzing the relationship between trustworthiness and the activation on brain regions in human-based offline settings, mainly by conducting trust neuro-experiments (Baumgartner *et al.,* 2008; Delgado, Frank and Phelps, 2005; King-Casas *et al.,* 2005; Krueger *et al.,* 2007). More recently, there have also been some analyses on trustworthiness and related brain activations in online interactions (Dimoka, 2010; Riedl *et al.,* 2014). The main findings in these studies demonstrate that brain regions such as the striatum, cingulate and prefrontal structures enhance digital/online trustworthiness, whereas the amygdala and the insular cortex are more activated in discredibility and malevolence economic situations.

As most financial decisions entail risk, a change in the channels that define the environment for the transaction and information exchange seems important. Most of the neural analyses of risk correspond to individual investor's trading in stock and debt markets and the relationship between risk and return. Häusler *et al.* (2018) show the role of the activity in the anterior insula during the assessment of risky *vs.* safe choices in an investing task. Earlier analyses also suggest the ventral striatum activity is associated with riskier investment profiles while the activity in the anterior insula is associated with low risk investment profiles (Knutson *et al.,* 2003; Kuhnen and Knutson, 2005, 2011; Knutson and Bossaerts, 2007; Preuschoff, 2008; Rudorf, Preuschoff and Weber, 2012). Similarly, the activity in the anterior insula has been related to risk-related sensations of uncertainty and pain (Preuschoff, 2006).

Other factors related to financial risk are impulsiveness and reward mechanisms. In certain environments, unconscious brain processes drive impulsive behavior (Hubert *et al.,* 2013). The brain regions involved in this processes are mostly nested within the so-called 'reward system' that registers stimulus and deception related to expectations on certain events and processes (see Elliott, Friston and Dolan, 2000). Earlier fMRI studies have also shown the striatum is related with the processing and anticipation of rewards (O'Doherty *et al.,* 2004; Fareri, Chang and Delgado, 2012). Digital channels incorporate potential reward mechanisms (time saving, lower fees) compared to traditional (physical) channels and may also stimulate different impulsiveness responses than an offline channel. Breiter *et al.* (2001) shows that the nucleus accumbens, the sublenticular extended amygdala (SLEA) and the hypothalamus are involved in the processing of the prospects of monetary or economic rewards in a similar vein as reactions to tactile stimuli, gustatory stimuli, or euphoria-inducing drugs. Similarly, medial-frontal regions also contribute to mental states that participate in high-level decisions, including economic choices (Gehring and Willoughby, 2002).

In the context of human *vs.* non-human economic interactions, Huettel *et al.* (2006) demonstrate that people often prefer the known (established human relationships) over the unknown (new human nor non-human relationships), sometimes sacrificing potential rewards for the sake of surety. Their fMRI experiments show individuals' preferences for risk (uncertainty with known probabilities) and ambiguity (uncertainty with unknown probabilities) predict brain activation associated with decision-making. Activation within the lateral prefrontal cortex was predicted by ambiguity preference, whereas activation of the posterior parietal cortex was predicted by risk preference. Whether the choice of financial digital channels entails uncertainty for the individuals and the activation of brain-related trust or risk-reward mechanisms remain unexplored.

While a number of studies have dealt with how brain activity informs financial risk-taking behavior, little is known about its impact on financial digitalization decisions. This is particularly relevant if financial digitalization choices are not only motivated by revealed risk and trust attitudes towards digital financial channels but also by brain activation patterns across heterogeneous groups in terms of financial digitalization adoption. We aim to explore the neuropsychological factors and brain substrates that underpin financial digitalization decisions. The identification follows four steps. We first explore if adoption patterns are associated to psychological and biological indicators (including impulsiveness and sensitivity to reward). Secondly, we use functional magnetic resonance imaging (fMRI) to investigate if financial digitalization decisions are linked to the evoked brain response to the safety associated to video images of financial transactions through digitalized and non-digitalized channels. Third, we conduct trust and risk neuro-experiments to identify their impact on financial digitalization decisions. Finally, we analyze if brain structure distinctively explains financial digitalization behavior.

## METHODS

### Participants

One hundred and twenty-one healthy adults, aged between 18 and 33, participated in this study. They were recruited through media advertisements and all of them completed an online survey on their finantial habits. They were classified in three groups according to the frequency of use of online financial services: 40 with weekly use (High frequency group, HFU), 40 with monthly use (Low frequency use, LFU) and 41 that never or almost never use (NU). Importantly, the age range offers some consistencies across groups. First of all, most users have a bank account (90% in the NU and 100% in the LFU and HFU groups). Secondly, the overwhelming majority of participants are aware of the online possibilities of their bank accounts (95% in the NU group and 100% in the other two groups). Third, the number of users of non-bank digital channels (*e.g.* Paypal) monotonically increases with the general frequency of use of bank digital channels (28% in the NU group, 43% in the LFU and 51% in the HFU). The use of tradicional payment methods is similar across groups (use of debit cards is 75% for NU, 86% for LFU and 88% for HFU). Fourth, the variety in the use of digital financial transactions also increases monotonically with the frequency of use. In particular, 0% of the NU participants use at least than 3 different digital services (check account balance, online transfer, online purchase, bill payment), while this increases to 19% in the LFU and 62% in the HFU). This suggests frequency of use and variety of use are highly correlated.

The groups did not differ significantly in terms of age, sex, employment or monthly familiar income (See Table 1). Magnetic Resonance Imaging (MRI) contraindications (*e.g.,* claustrophobia, ferromagnetic implants) or abnormalities in the MR images were determined as exclusion criteria.

All participants had normal or corrected-to-normal vision. The study was approved by the Ethics Committee for Research in Humans of the University of Granada (Spain) and was conducted in accordance with the Declaration of Helsinki. All participants signed written informed consent.

Table 1

**DESCRIPTIVE STATISTICS OF THE STUDY POPULATION GROUPED ACCORDING TO THEIR FREQUENCY OF USE OF DIGITAL FINANCIAL SERVICES**

| | Never (n=41) | Low frequency (n=40) | High frequency (n=40) | P-value |
|---|---|---|---|---|
| Age | 21.29 (2.90) | 22.20 (3.15) | 21.93 (2.53) | 0.367 |
| Sex | 21 men<br>20 women | 20 men<br>20 women | 15 men<br>25 women | 0.394 |
| Workers | 12.20% | 30% | 25% | 0.139 |
| Family income | | | | 0.250 |
| < 600 € | 3 (7.3%) | 7 (17.5%) | 1 (2.5%) | |
| 600 – 1,000 € | 7 (17.1%) | 7 (17.5%) | 6 (15.0%) | |
| 1,000 – 1,500 € | 12 (29.3%) | 7 (17.5%) | 9 (22.5%) | |
| 1,500 – 2,000 € | 6 (14.6%) | 6 (15.0%) | 9 (22.5%) | |
| 2,000 – 3,000 € | 10 (24.4%) | 7 (17.5%) | 10 (25.0%) | |
| 3,000 – 5,000 € | 3 (7.3%) | 3 (7.5%) | 5 (12.5%) | |
| > 5,000 € | 0 | 3 (7.5%) | 0 | |

## PROCEDURE

An online survey was published to ask general population about their financial habits. The main structure of the survey followed the Survey of Consumer Payment Choice (SCPC) conducted by the Federal Reserve Bank of Boston. However, our survey incorporated comprehensive information about consumers' digital preferences and not just about payment services. Furthermore, the survey included information about a set of factors that, based on theoretical foundations for technology acceptance, explains the adoption and use of digital channels (*e.g.,* perceived usefulness, cost, complexity, convenience, and risk). Controlled quotas for a representative sample of the population were established based on age, sex, and location. All participants in the survey were offered the opportunity to participate in a second session in which some tests were administered and an MRI session would be held.

At the beginning of the MRI session, and before scanning, tests assessment and tasks training were conducted by a master´s degree clinical psychologist. At the end of the instructions, all subjects had to complete a questionnaire in order to check that they had understood the instructions. Afterwards, participants underwent the MRI scanning session that includes two fMRI tasks, a T1-weighted structural acquisition and a diffusion tensor imaging (DTI). Regarding the fMRI tasks, in the first one they had to watch some videos related with economic transactions, and the second one was a computer version of the trust and risk game. The MRI session lasted around one hour. At the end of the experiment, subjects were paid based on a publicly announced exchange rate of 25 points = 1 €.

## TESTS ADMINISTERED BEFORE SCANNER

The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) (Torrubia *et al.,* 2001) is a 48-item questionnaire that comprises two subscales to measure the constructs of sensitivity to reward (SR) (24 items) and sensitivity to punishment (SP) (24 items). This questionnaire has demonstrated internal consistency; construct validity, and significant associations with reward and punishment relevant brain systems.

The urgency, premeditation, perseverance and sensation seeking scale (UPPS-P) was also applied to obtain an impulsive behaviour scale, using a brief Spanish version (Cándido *et al.,* 2012). This questionnaire allows a multi-dimensional assessment of impulsivity, including five different traits: (1) negative urgency; (2) positive urgency; (3) sensation-seeking; (4) lack of premeditation; and (5) lack of perseverance. It has shown adequate psychometric properties (Cronbach’s α values ranging from 0.61 to 0.81).

The length ratio of the index finger (2D) to the ring finger (4D) (2D:4D ratio) was used as a biomarker of prenatal sex hormone exposure (prenatal androgen and estrogen levels). It is determined during the fetal period and becomes stable around two years of age (Manning *et al.,* 2000). Higher impulsivity has also been associated with smaller 2D:4D ratios (Hanoch, Gummerum and Rolison, 2012) and, as such, it has been used in previous economics experiments (Millet*,* 2011). Hence, for robustness purposes, we consider the 2D:4D ratio as an alternative measure of impulsiveness for all participants. Hands of the participants were photographed near a measuring tape and length of the second and forth fingers were calculated using a graphic editor software.

## fMRI Tasks

### Videos

We used eighteen videos belonging to nine categories, five of them included financial transactions outdoors (*i.e.*: get cash from an ATM, pay with cash, with a credit card, with a mobile phone or with a watch), two of them represent transactions via PC (*i.e.*: bank transfer and paying with PayPal) and the remaining two were on pleasant and unpleasant animals. All videos lasted 15 seconds and were presented twice to each participant. Immediately after each video, the intensity of the security experienced was self-rated on a 1–4 number scale that appeared for 5s (where 1 is 'unsafe' and 4 is 'extremely safe').

### Trust and Risk Game

In order to explore whether the frequency of use of financial digital channels is associated with interpersonal trust, we implement a fMRI adaptation of the trust and risk games designed by Kosfeld *et al.* (2005).

*Trust Game*: The game consisted of one investor and one trustee. Participants always played the investor's role. Participants were told that they were always matched with a randomly selected different person in each trial (*i.e.,* we used strangers matching protocol). To enhance the credibility and the interpersonal appeal of the game, participants were told that the trustee was another participant of the research project, who had been randomly selected from the pool of previous participants. In each trial, participants received an initial endowment of 12 points and investors could send 0, 4, 8, or 12 points to the trustee. The transferred points were tripled by the experimenter. Then the trustee had the option of sending any amount between zero and his/her total amount available back to the investor. Investors were told that trustees had already made a decision for each possible transfer. Then our participants made their decisions by pressing one of the four buttons that we provided (indicated by the number expressed in points to be transferred).

*Risk Game*: Participants faced the same choices as in the trust game. However, participants were paired with a random computer mechanism in the role of trustee, and this was common information. If participants decided to transfer points, they knew that a computer would decide whether return points or not. They were told that the probability of returning was based on the probability distribution generated by trustees' decision in the trust game. This manner, participants faced the same probability of returning both treatments, but in the risk game there is no room for interpersonal expectations (such as trust, betrayal or reciprocity).

Subjects played for 24 trials. Participants alternated games in each round. In the odd rounds they played the Trust Game, and in the odd rounds they played the Risk Game. Although they had this information from the beginning, in each round the type of game was highlighted. Participants did not receive in each trial any feedback regarding points returned by either trustee or computer. After the first 12 rounds, participants received information regarding the number of times that her/his pair, either person or computer, had returned points. At the end of experiment participants received information about the total points obtained in each trial of both Trust and Risk Game.

In the Trust Game, if the investor transfers points to the trustee and the latter reciprocates, both participants end up with higher amount of points. However, the trustee also has the option of violating the investor's trust by not returning points. In this case, the investor loses all the points he/she sent to the trustee, an event that investors typically interpret as a betrayal of trust (Bohnet and Zeckhauser, 2004). Since sending points is costly for the trustee, a selfish trustee will never reciprocate the investor's trust because investor and trustee interact only once in the experiment.

The key difference between the Trust and the Risk games is that the latter is an one-player game. While in the Risk Game the investor's risk depends on a random mechanism, in the Trust Game it arises from the uncertainty regarding the social interaction with a real person in the role of trustee.

## IMAGING ACQUISITION AND PREPROCESSING

Brain data were collected with a 3 Tesla Magnetom Tim Trio scanner (Siemens Medical Solutions, Erlangen, Germany) equipped with a 32 –channel receive– only head coil. T2*-weighted echo-planar imaging (EPI) sequences were acquired during each functional task with the following parameters: Repetition time (TR): 2000 ms; echo time (TE): 25 ms; flip angle: 80º; field of view (FOV): 238 mm; number of slices: 35; voxel size: 3.5 x 3.5 x 3.5 mm; gap: 0.7 mm; number of volumes: 390 and 410 for the trust and the video task respectively. Images were collected axially and parallel to the AC-PC plane.

For the structural analyses, a sagittal three-dimensional T1-weighted image and a diffusion tensor imaging sequence were obtained. The parameters were as follows: 3D image: TR: 2300ms; TE: 3.1ms; flip angle: 9º; FOV: 256 mm; number of slices: 208; voxel size: 0.8 x 0.8 x 0.8 mm; DTI acquisition: TR: 9,400ms; TE: 88ms; FOV: 256mm; number of slices: 72; voxel size: 2.0 x 2.0 x 2.0; 30 volumes with diffusion weighting (b=1,000 s/mm$^2$) and one volume without diffusion weighting (b=0 s/mm$^2$).

Functional images were preprocessed using the Statistical Parametric Mapping (SPM12) software (Wellcome Department of Cognitive Neurology, Institute of Neurology, Queen Square, London) running under Matlab R2017 (MathWorks, Natick, MA, USA). Preprocessing included realignment to the first image of the time series, unwarping, slice-timing correction, outlier detection, coregistration to the structural image of each participant, normalization to an EPI template in the Montreal Neurobiological Institute (MNI) space, and spatial smoothing by convolution with a 3D Gaussian kernel [full width at half maximum (FWHM) = 8mm].

T1 image processing were conducted using the recon-all automated processing pipeline in Freesurfer (version 6.0). Cortical and subcortical volumes were automatically calculated based in the Destrieux atlas (Destrieux *et al*., 2010) and the subcortical Freesurfer parcellation (Fischl *et al.,* 2002).

Diffusion tensor images were preprocessed using FSL (Jenkinson *et al.,* 2012) and included head motion and eddy-current induced artifacts correction, rotation of the gradient directions table and brain extraction. Fractional anisotropy (FA) and mean diffusion (MD) maps were calculated using the dtifit function. The automated AutoPtx (Groot *et al.,* 2015) pipeline was used to run probabilistic tractography for some of the main system fibers in each individual. Complete details of the process are described elsewhere (Groot *et al.,* 2015)

All images were inspected for artifacts after acquisition. Outputs were also checked to discard outliers and incorrect processing.

## STATISTICAL ANALYSES

### Behavioral analyses

Behavioural data were analysed with the Statistical Package for the Social Sciences version 20 (SPSS; Chicago, IL). Between-group differences in demographic, neuropsychological and biological variables were tested using one-way ANOVAs, following by post-hoc two sample t-tests.

## Neuroimaging analyses

### *Functional analyses*

In the video task, we modelled a parametric regressor using the scores each participant rated each video. We defined a positive contrast where the higher activation represents a higher degree of security. In the trust and risk game we defined a trust > risk contrast of interest, to explore the brain activation linked to the trustworthiness. Task regressors were convolved with the SPM8 canonical hemodynamic function. To prevent motion artifacts, the six parameters of movement calculated as well as the identity of the volumes labeled as outlier during preprocessing were entered as regressors of no interest in all first-level analyses. Then, the individual first level-contrast images were used to conduct two one-sample ANOVAs to calculate between-group differences.

In order to restrict the results of the comparison between groups to brain areas related to safety or unsafety feelings and trustworthiness, the between groups analyses were masked by the sum of the maps of activation and deactivation during the tasks for each group. A brain mask of 18,758 voxels were used in the video task whereas a voxels mask of 27,863 voxels were used in the trust and risk game. Those masks mainly involved brain areas previously related with economic processes (*e.g.*: lateral prefrontal cortex, striatum, insula, cingulum).

Results were corrected for multiple comparisons with a combination of voxel intensity and cluster extent thresholds. The spatial extent threshold was determined by 1000 Monte Carlo simulations using AlphaSim as implemented in the SPM REST toolbox (Song *et al.,* 2011). Input parameters included the mask corresponding to each task, an individual voxel threshold probability of 0.005, and a cluster connection radius of 5 mm, considering the actual smoothness of data after model estimation. A minimum cluster-extent of 54 voxels and 59 voxels were estimated for the video task and the trust and risk game respectively.

### *Structural analyses*

For the T1 analyses, we explore differences in brain cortical and subcortical volumes between groups using one-way anovas and two-sample groups t-tests. Based in existing literature and in our functional results, structural analyses were restricted to some regions of interest, (*i.e.*: frontal regions, striatum, insula, cingulum, amygdala and hippocampus). Total intracranial volume was used as confound variable in these analyses.

Regarding DTI analyses, we conducted one-way Anovas followed by between groups t-tests comparisons in callosal fibers (i.e.: forceps minor and major), limbic system fibers (*i.e.*: cingulate and parahippocampal parts of the cingulum), association fibers (superior and inferior longitudinal fasciculus) and the corticospinal tract.

### *Correlation analyses*

Brain regions showing significant differences between groups in functional or structural analyses were correlated with behavioural scores from tests and fMRI tasks.

# RESULTS

## Behavioral measures

### *Neuropsychological and biological measurements*

As shown in Table 2, we found no significant between-group differences in the ANOVA analyses in any of the three tests (SPSRQ, UPPS-P and D2:D4). Conversely,

Table 2

**Results of the neuropsychological and biological tests**

| | All | Never (NU) | Low frequency (LFU) | High frequency (HFU) | P-value |
|---|---|---|---|---|---|
| SPSRQ | | | | | |
| Sensitivity to Reward | 11.02 (4.09) | 10.93 (3.76) | 11.60 (4.53) | 10.55 (3.97) | 0.512 |
| Sensitivity to Punishment | 10.46 (5.46) | 10.44 (5.66) | 9.23 (4.89) | 11.73 (5.62) | 0.122 |
| UPPS-P | | | | | |
| Negative Urgency | 10.93 (2.94) | 11.49 (3.12) | 10.70 (2.76) | 10.60 (2.90) | 0.330 |
| Positive Urgency | 9.80 (2.08) | 10.32 (2.52) | 9.63 (2.00) | 9.45 (1.89) | 0.138 |
| Lack of premeditation | 7.81 (2.54) | 7.46 (2.47) | 8.15 (2.43) | 7.82 (2.71) | 0.479 |
| Lack of perseverance | 7.48 (2.64) | 7.05 (2.66) | 7.54 (2.48) | 7.85 (2.76) | 0.390 |
| Sensation seeking | 9.43 (2.41) | 9.63 (2.29) | 9.28 (2.55) | 9.35 (2.43) | 0.788 |
| D2:D4 Ratio | 0.964 (0.040) | 0.964 (0.044) | 0.957 (0.041) | 0.970 (0.033) | 0.355 |

paired within-group comparisons showed that the HFU group significantly scored higher in sensitivity to punishment than the LFU group (p=0.041).

## fMRI BEHAVIORAL MEASURES

### Video task

Security scores for each type of video are reported in Table 3. Between groups analyses did not show significant differences. We additionally compute the mean values for the traditional financial transaction (*i.e.*: Cash, ATM & Card) and the online (*i.e.*: transfer, PayPal, Phone, Watch) separately. No significant differences were found for these variables.

Table 3

**Security scores for all participants and by group**

| | All | Never (NU) | Low frequency (LFU) | High frequency (HFU) | P-value |
|---|---|---|---|---|---|
| Cash | 3.21 (0.68) | 3.18 (0.60) | 3.26 (0.70) | 3.20 (0.74) | 0.858 |
| ATM | 3.07 (0.70) | 3.21 (0.51) | 3.12 (0.78) | 2.89 (0.77) | 0.106 |
| Card | 2.82 (0.70) | 2.92 (0.66) | 2.77 (0.70) | 2.76 (0.74) | 0.540 |
| Transfer | 2.72 (0.79) | 2.54 (0.80) | 2.86 (0.81) | 2.74 (0.75) | 0.173 |
| PayPal | 2.64 (0.74) | 2.58 (0.72) | 2.67 (0.82) | 2.67 (0.69) | 0.821 |
| Phone | 2.24 (0.86) | 2.16 (0.83) | 2.40 (1.01) | 2.15 (0.72) | 0.347 |
| Watch | 2.03 (0.86) | 1.99 (0.79) | 2.14 (1.00) | 1.97 (0.76) | 0.639 |
| Traditional | 3.04 (0.43) | 3.10 (0.39) | 3.05 (0.41) | 2.95 (0.47) | 0.263 |
| Online | 2.41 (0.61) | 2.32 (0.60) | 2.52 (0.67) | 2.38 (0.56) | 0.328 |

### Trust and Risk Game

Although we found no significant between groups differences in the average amount of money invested in each condition (see Table 4), results for both LFU group and HFU group are in line with the betrayal aversion theory in the experimental literature. People take risks less willingly when the agent of uncertainty is another person rather than nature (Bohnet *et al.,* 2008). However, interenstingly, the NU group exhibited the opposite behavior. That is, the non-users group seemed to be more willing to invest when interacting with a real person in the role of trustee (5.13 *vs.* 4.76). In fact, if we consider the distance between investment in Trust and in Risk trials as a measure of betrayal aversion, we can observe that this difference is almost significative between NU and LFU groups (p=0.063).

TABLE 4

**AVERAGE INVESTMENT IN THE TRUST AND RISK TRIALS**

| | All | Never (NU) | Low frequency (LFU) | High frequency (HFU) | P-value |
|---|---|---|---|---|---|
| Trust | 4.93 (2.37) | 5.13 (2.53) | 4.74 (2.50) | 4.92 (2.10) | 0.771 |
| Risk | 5.18 (1.95) | 4.76 (1.76) | 5.45 (2.04) | 5.34 (2.01) | 0.235 |
| Betrayal aversion | 0.25 (2.59) | -0.37 (2.96) | 0.71 (2.75) | 0.42 (1.87) | 0.155 |

## Neuroimaging results

### *Functional results*

#### *Video task*

Between groups comparison revealed that the LFU group showed higher activation in the ventromedial prefrontal cortex in comparison to the other two groups. Additionally, they showed higher activation in the right precentral cortex and in the right nucleus accumbens in comparison to the NU group (see Table 5 and Figure 1).

TABLE 5

**BRAIN REGIONS SHOWING SIGNIFICANT DIFFERENCES BETWEEN GROUPS DURING THE VIDEO TASK**

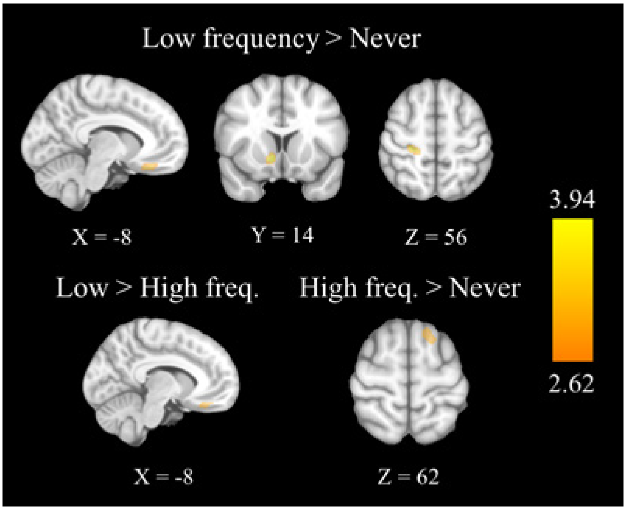
| Brain region | Side | MNI Coordinates | | | Cluster size | t-value |
|---|---|---|---|---|---|---|
| | | X | Y | Z | | |
| HFU > NU | | | | | | |
| Superior Frontal Gyrus | Left | -14 | 20 | 60 | 76 | 3.94 |
| LFU > NU | | | | | | |
| Ventromedial Prefrontal Cortex | Left | -10 | 28 | 22 | 79 | 3.76 |
| Precentral Cortex | Right | 24 | -28 | 56 | 63 | 3.41 |
| Nucleus Accumbens | Right | 10 | 10 | -8 | 54 | 3.34 |
| LFU > HFU | | | | | | |
| Ventromedial Prefrontal Cortex | Left | -10 | 32 | -20 | 56 | 3.46 |

Correlation analyses showed significant positive association between the brain activation of the nucleus accumbens in the LFU group and the scores of security of the online financial transaction videos (r=0.489, p=0.001), whereas this relation were non significant and negative in the HFU (r=-0.182, p=0.281) and the NU group (r=-0.063, p=0.701).

The HFU group showed higher activation in the superior frontal gyrus compared to the group that never use online financial services. Correlation analyses showed that brain activation in this area is negatively related to the scores of security, so the higher activation, the lower feeling of security in all groups (r=-0.267, p=0.004) (see Table 5 and Figure 1).

Figure 1

Brain regions showing between groups differences during the video task. Right hemisphere is displayed on the left. The color bar indicates t-value




### *Trust and risk Game*

During the trust trials (Table 6 and Figure 2) –in comparison with the risk trials– the HFU group showed higher activation of the precentral, postcentral and the supplementary motor area than the other two groups.

## Table 6

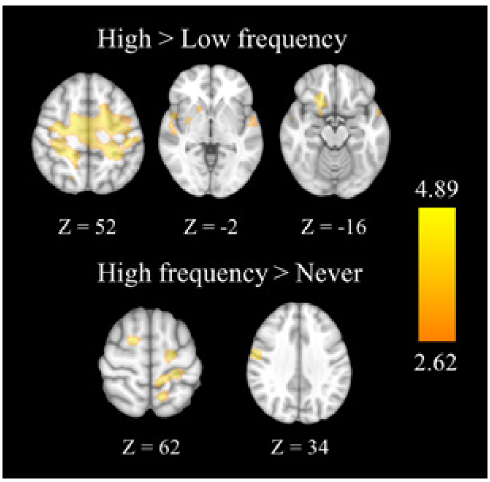
### Brain regions showing significant differences between groups during the trust and risk game

| Brain region | Side | MNI Coordinates | | | Cluster size | t-value |
|---|---|---|---|---|---|---|
| | | X | Y | Z | | |
| HFU > NU | | | | | | |
| Postcentral Gyrus | Left | -22 | -36 | 54 | 334 | 3.82 |
| Precentral Gyrus | Right | 60 | -2 | 34 | 98 | 3.54 |
| Pre-Supplementary Motor Area | Right | 18 | 2 | 60 | 101 | 3.50 |
| Precentral Gyrus Left | Left | -36 | -12 | 50 | 117 | 3.48 |
| Precentral Gyrus Left | Left | -20 | -14 | 62 | 59 | 3.39 |
| HFU > LFU | | | | | | |
| Precentral Gyrus | Right | 30 | -12 | 52 | 6 925* | 4.89 |
| Postcentral Gyrus | Left | -24 | -38 | 52 | 6 925* | 4.88 |
| Supplementary Motor Area | R/L | 8 | -22 | 58 | 6 925* | 4.24 |
| Putamen | Right | 30 | 8 | 14 | 809* | 4.71 |
| Insula | Right | 34 | -6 | 14 | 809* | 4.59 |
| Superior Temporal Gyrus | Right | 56 | 2 | -12 | 809* | 3.71 |
| Orbitofrontal Cortex | Right | 20 | 24 | -14 | 302* | 4.38 |
| Nucleus Accumbens | Right | 18 | 10 | -4 | 302* | 2.84 |
| Superior Temporal Gyrus | Left | -54 | -26 | 16 | 126 | 3.63 |
| Insula | Left | -30 | -8 | 14 | 117 | 3.62 |

* Differences between groups are statistically significant at 5%.

## Figure 2

### Brain regions showing between groups differences in the Trust>Risk contrast during the trust and risk task. Right hemisphere is displayed on the left. The color bar indicates t-value



## *Structural results*

### *T1 results*

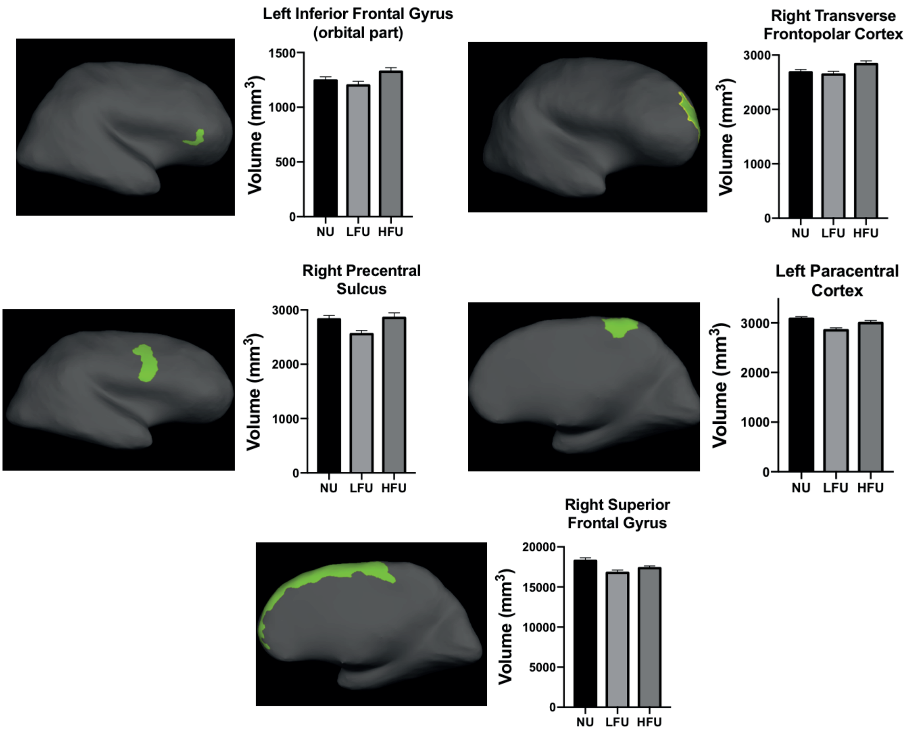
Participants of the HFU group showed a higher volume of the left inferior frontal gyrus (orbital part) and the right transverse frontopolar cortex compared with the LFU (p=0.018 and p=0.018) and the NU groups (p=0.024 and p=0.004).

The LFU group showed lower volumes in the left paracentral cortex and the right precentral sulcus (inferior part) compared with the HFU (p= 0.043 and p=0.006) and the NU groups (p=0.005 and p=0.091).

Finally, the group of participants that never use online financial services showed higher volumes of the right superior frontal gyrus compared with LFU group (p=0.008) but not HFU group (p=0.169) (see Figure 3).

Figure 3

Brain regions showing differences in volume between groups



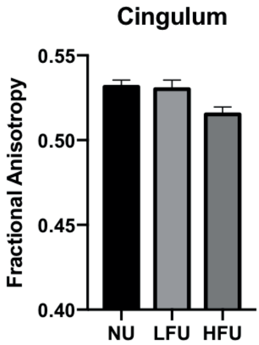
*DTI results*

The HFU group showed decreased values of FA in the cingulate part of the cingulum compared with the LFU group (p=0.024) and the NU group (p=0.014) (see Figure 4).

No significant correlations were found between the brain volumes or the FA values and the behavioral variables.

Figure 4

Fractional anisotropy values extracted from the cingulate part of the cingulum




## DISCUSSION

The aim of the current study is to explore the relation between brain function and structure and digital financial behavior. The main finding is that we observe a number of brain substrates that are related to financial digitalization adoption decisions that are not revealed by any other economic, physcological or biological tests. In particular, we find that high frequency users of digital financial channels display enhanced motor, frontal, insular and striatal activity linked to trustworthiness, increased regional volumes in frontal areas and higher sensitivity to punishment scores. They also show lower FA values in the cingulum. Conversely, low frequency users show higher prefrontal and striatal activity linked to security while watching economic transactions and lower motor brain regions volumes.

Regarding the video task, previous studies have linked the ventromedial prefrontal cortex (vmPFC) activity to safety signals (Eisenberger *et al.,* 2011, Harrison *et al.,* 2017). Furthermore, activation of the nucleus accumbens and also vmPFC have been directly related with processing of several rewarding stimuli (Sescousse, 2013). Our results show higher activation of these areas in the low frequency users. Specifically, the higher activation in the nucleus accumbens is related to higher safety feelings while they are watching new online transaction methods. Overall, these results indicate that even in the absence of significant differences in the scores of safety after watching videos, the LFU group shows a brain evoked pattern of greater security and reward while watching them, specially while watching the new digital/contactless methods of payment. Regarding the other two groups, the HFU shows a higher activation of the superior frontal gyrus in comparison with the NU group, but this activation is related with lower scores of safety. Hence, the HFU group exhibits a brain pattern associated to lower safety during the video task.

Overall, during the trust and risk game, high frequency users shows an enhanced somatomotor activation compared with the other two groups and specifically, enhanced insular, orbitofrontal and striatal activity compared with low frequency users. Higher sensitivity to punishment scores and higher orbitofrontal and insular activity during the trust and risk game in the high frequency users is consistent with a previous study that shows higher activation in the OFC is related to fear and enhanced insular activity with distrustworthness during economic transactions (Dimoka, 2010). From this point of view, HFU presents an emotional pattern of decision when they are faced with a trust-based decision making. Moreover, lower activation of reward and behavioral adaptation regions, dorsal striatum, were previously found in participants that receive oxytocin during the trust, but not risky phase of the game, similar to our low frequency users, in comparison to those with high use (Baumgartner *et al.,* 2008). Higher levels of oxytocin has been widely related with increased trustworthiness (Kosfeld *et al.,* 2005). Lastly, higher activation of motor areas has been consistently linked to unfairness processing during the ultimatum game (Gabay *et al.,* 2014).

No significant statistical relationships were found between brain volume differences and measured behavioral variables in our tests. From a speculative perspective, left inferior frontal gyrus function was related with response inhibition (Swick, Ashley and Turken, 2008), so the higher volume in the HFU group can be associated to a higher use of this area on a daily basis. On the other hand, the lower volume found in the LHU group in motor areas could be associated to empathy and the the mirror network (Bernhardt and Singer, 2012) or cognitive control (Nachev, Kennard and Husain, 2008). However, these significant results disappear when controlling for multiple comparisons. Future studies should explore these differences, maybe using a region of interest approach, taking into account the preliminary results obtained in the present study.

Fractional anisotropy is a measure of the microstructural integrity of the white matter and lower values have been linked to axonal degeneration and demyelination. The cingulate is one of the main fiber bundle of the brain and connect many cortical and subcortical regions. Low FA values in the cingulum have been related to several pathologies and cognitive dysfunctions (Bubb, Metzler-Baddeley and Aggleton*,* 2018), so the reductions in FA in the HFU groups seem to be related to less structural connectivity between distant brain areas. The lack of significant correlation between FA values and behavioral variables does not allow to determinate how this alteration influence economic processing but it could be a factor that influences the processing of information within the brain.

Finally, we do not find any behavioral difference between the groups in any of the impulsivity tests. General impulsivity traits does not explain the differences in the use of financial digital services, but according to our imaging results, feeling of security, or insecurity and trustworthiness are better predictors of this different behavior.

In summary, a higher sensitivity to punishment scores, a lower safety neural evoked responses during the video task and a worse capability of processing information (based on the DTI results), suggest that the higher frequency of use of financial digital financial services could be linked to higher sensations of insecurity. Moreover, high-frequency users show enhanced activation of brain areas linked to emotional processing during the trust game. These findings are relevant to inform decision-making in both public policy and private financial strategies. On the public arena, the attempts to promote financial inclusion through digitalization should consider these differences across indivduals. On private side, customer segmentation and relationship building by financial institutions should also consider these trust, security and emotional patterns.

This study has important strengths. To our knowledge is the first study that explore neural substrates of online financial users and provides evidence of functional and structural brain differences between different patterns of use. Brain differences were also supported by correlational results that combine brain and behavioral outcomes. Furthermore, we obtained results from three different MRI techniques, including two fMI tasks, using robust and well stablished methodologies and analysis protocols. Finally, the groups were selected from a large database of potential participants and were well matched in sociodemographic characteristics. Among the avenues for further research in this context, it will be interesting to split users based on their use of online methods (*e.g.*: bank, online payments as PayPal) and how they use (*e.g.*: only to check their account or for other reasons). Future studies should take this into account and explore neural basis of patterns of use of specific financial digital channels.

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