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How old brain functions constrain modern features of economies – And how to see this

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Abstract

Approaches by neuroscience to the production and handling of material artifacts has recently found support for a ‘cultural cortical recycling’ hypothesis (Stout et al. 2008). This hypothesis had already been robustly established for symbolic artifacts such as letters and numbers (Dehaene and Cohen 2007). In both cases, specific cortical maps dedicated to basic perceptual and/or motor functions appear to have been re-used at a relatively recent point in human history (on temporal scales too brief for any anatomical evolution of the brain to take place), allowing new cultural capacities to develop. Such functional recycling both facilitates and constrains the processing of these artifacts. It also presumably plays a role in their emergence and morphogenesis. I present theoretical arguments and preliminary behavioral and neurobiological findings in support of the speculation that the historical emergence and typical neural processing of coins – as both material and symbolic artifacts – might be explained by a similar hypothesis.

My goal here, however, is to provide the empirical and theoretical background to testing this hypothesis from the perspective of behavioral economic anthropology. This might lead to collaboration with anthropologists in designing and making operational future experiments that could be performed easily online or in the field.

Keywords: cultural cortical recycling; coins; money emergence; categorization tasks; response times; field experiments.

Sacha Bourgeois-Gironde is a philosopher and an experimental economist. He is interested in understanding the emergence of modern economic environments and artifacts. His main question is about the biological, and especially neurobiological, resources that have been put to use by humans to shape and adapt to their economic environments. He is running several experiments to try to understand these adaptive processes and the constraints on lay economic cognition and behaviour. He has published empirical, philosophical and formal work to make sense of some typical cognitive biases and behavioral anomalies within that perspective. He is currently professor of philosophy at Aix-Marseille University, a member of Aix-Marseille School of Economics and an associate researcher at the Institut Jean-Nicod, École Normale Supérieure.

1. Introduction

Neural plasticity probably allowed humanity to adapt and even to generate modern post-Neolithic cultural environments, but these changes could not be accompanied by genetic and anatomical modifications in so short a time. These modern environments were, however, enhanced by brain plasticity in that typically adaptive genetic and neurobiological features selected on a long-run evolutionary basis were not eliminated. On the contrary, these could well have been re-used, or recycled, in order to process emerging artifacts stimulated by cultural practice. I present an argument here for use in the field of economic anthropology similar to the hypothesis Dehaene and Cohen (2007) developed about reading and arithmetic in cognitive neuroscience.

There is only limited evidence in support of this hypothesis in economic anthropology and that is open to various interpretations. So far, studies in neuroeconomics have not been designed explicitly to test it. Neuroeconomics has been defined as the study of neurobiological mechanisms underpinning decision-making in situations involving – taken separately and together -- uncertainty, variable temporal horizons and other-regarding strategies (Sanfey et al. 2006). I would add that neuroeconomics might use a new 'archeological' tool (based on the whole set of brain-imaging techniques) to unravel the older (from an evolutionary point of view) neural pathways that continue to underpin our decision processes. This would illuminate how the brain had to adapt to new social contexts by recycling these ancient neural pathways and putting them to novel use. As a result of these neural adaptive processes, for some recent cultural artifacts (like numbers and maybe monetary instruments) and situations (like exchanges in modern economic settings like markets for goods and labor), their 'cortical niches' might be constrained by genetic factors. Plasticity is realized within certain limits and new cultural acquisitions are made possible within those limits. The emergence of a given cultural artifact or behavioral pattern is then both facilitated and constrained by its alleged cortical niche.

2. The hypothesis of cultural cortical recycling

The hypothesis of cultural recycling of cortical maps was put forward to make sense of a seeming paradox in neurobiology. As Dehaene and Cohen (2007) put it: "Part of the human cortex is specialized for cultural domains such as reading and arithmetic, whose invention is too recent to have influenced the evolution of our species. (…) To explain this paradoxical cerebral invariance of cultural maps, we propose a neuronal recycling hypothesis, according to which cultural inventions invade evolutionarily older brain circuits and inherit many of their structural constraints". In what does the recycling consist and what sort of inherited constraints may affect the neural processing of cultural inventions?

The concept of a cortical map is central to Dehaene and Cohen's hypothesis. Maps are invariant brain structures which encode cultural items and supervene on basic neuronal layouts. Seen working at various scales, these cortical maps reflect the representational structure of a targeted cultural item in an isomorphic way. Structures of encoded items and corresponding cortical mappings may be of different topological types. With regard to reading, for example, we intuitively understand what this isomorphism amounts to in the case of letters. Strings of letters belong to a continuous two-dimensional metric space and their structure is reproduced on the surface of the cortex. Retinotopy, more generally, refers to the spatial organization of the cortex in response to visual stimuli, which has been observed to form a map of the visual field (Tanaka 2003). Here the topology is simple and the isomorphism may be implemented at different neuronal scales. The topology may also be more complex, but isomorphism may still be uncovered (Tanaka 2003, Dehaene 2005).

Neuronal layouts are shaped by evolution and are genetically constrained. Epigenetic factors in the early phase of an individual's development will finalize the cortical structures, which then react to external stimuli in an invariant way. There occurs a compromise between genetic constraints, cortical relative plasticity and the frequency and tractable structure of encountered stimuli. Dehaene and Cohen (2007) list the potential constraints that might underlie the organization of visual cortical maps in reaction to orthographic stimuli. Those constraints determine the way a given stimulus is processed, as well as potential biases in processing the relevant information. The two determining components of cultural cortical recycling are the presence of a specific mapping process supervening on a pre-structured cortical map and observation of inherited constraints in the processing of a novel cultural item.

Evidence of recycling may be interpreted as the convergence of neural activations on specific patterns in a preexisting and functionally dedicated cortical map. Dehaene and Cohen (2007) report such evidence of converging neural responses in the acquisition of reading skills. At early stages of learning, the neural activities associated with reading are not scattered in an orderly fashion over the ventral visual system. They progressively find an optimal location in the so-called "visual word form area" after reading has become a routine skill. In the process, cells of that area are recycled in order to decode automatically the precise stimuli of a given writing system. Where a cultural cortical map fits both is determined by the structure of the stimuli to be treated and determines some features of that treatment. Biases in neural processing of novel cultural items, when they are attributable to the constraints of a cortical niche that already exists, may give reliable signs that some sort of cultural 'exaptation' of that cortical structure has actually taken place. In the case of reading, inherited biases point in two directions: constraints might be transposed into typical behavior (eye movements, limits to the simultaneous processing of several individual stimuli or anomalies like dyslexia etc.) and into a co-adaptive evolution of the stimuli, given their potentially optimal processing by the brain. In spite of cross-cultural variations, writing systems present a limited number of internal organizational forms -- a high degree of sameness in terms of the invariant shape, position and size of letters – showing perhaps processing constraints and the forms of cultural stimuli have converged. This cultural cortical recycling hypothesis' double provisional conclusion seems to be not only that the brain 'exapted' some of its evolutionary older neural pathways in order to process novel cultural items; but also that the latter might have evolved to be optimally apprehensible by the brain.

Cultural artifacts may have acquired typical shapes and other material features not only because those shapes and features were apt realizations of some general functions they were destined to fulfill, but because this material organization was optimally tractable by a plastic, but functionally constrained, cortical map. Moreover, we may speculate that the success of a few cultural items, seen through their dissemination and stabilization across places and cultures, as well as their durability, may have been fostered by the existence of such recycled cortical maps, which would be the general anthropological conclusion to draw. I will now be more specific and consider whether it is plausible to extend this hypothesis to the emergence of money considered as a medium of exchange, referring at this juncture at our co-authored study on the neural basis of categorizing coins (Tallon-Baudry et al. 2011), which points towards a cultural cortical recycling hypothesis in the case of monetary artifacts.

3. Neural anchoring of material culture

Recent cultural neuroscience (Chiao and Ambady 2007) seeks to identify the neural structures that are shaped by cultural environments. It generally deals with only one aspect of the cultural cortical recycling hypothesis, namely the influence of repeated cultural exposure to typical stimuli on the early development of corresponding cortical maps (when these can be identified). In this respect, however, it is crucial to connect cultural environments – and especially their material or artificial aspects – with brain structures. Cultural neuroscience, understood in this way as how material and cultural contexts more generally shape the brain, differs from the opposite approach that would investigate how some cultural invariants might be identified and ultimately related to neuronal constraints. If such a reduction could be granted, it would put us in a position to use the methods and data of neuroscience to understand the emergence and history of human artifacts and cultural institutions. I do not aspire to such “ideal” mapping of human social creations onto brain structures. My contention is that some experimental facts, when adeptly acquired, shed light on how the brain’s functional architecture and its genetically limited plasticity have constrained structural aspects of artifacts and institutions. This approach has been advocated by Renfrew, Frith, and Malafouris (2008) when they state that the use of neuroscience techniques and results may improve archaeologists’ analysis of past material cultures. They adapt the concept of “extended cognition” to such an analysis, adding the notion that artificial environments are cognitive prostheses which individual brains jointly shape and wherein they fit.

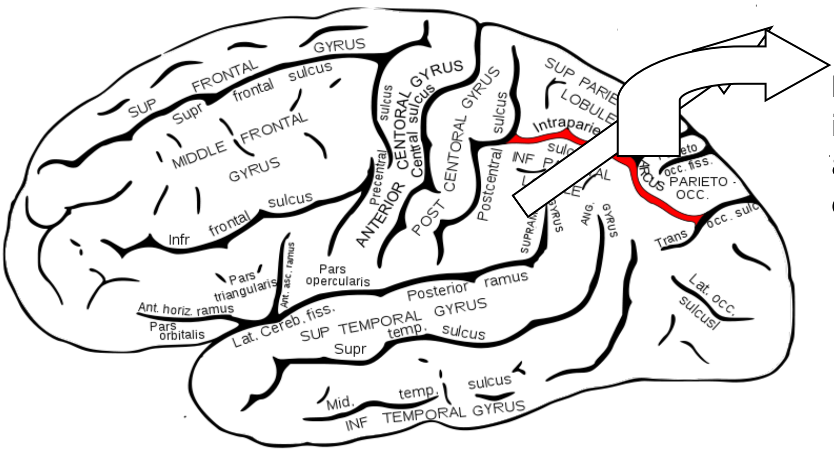
The stabilization and success of a given material culture, undertaken by a close group of human brains perhaps over a few generations, may be strongly correlated to the same neurobiological processes (such as the convergence of cortical maps toward optimal recycling neuronal sites). Determining the speed and ease of cultural learning may then have archaeological consequences. The study of past material cultures from a neurobiological point of view may offer a more precise, direct and challenging way of uncovering possible correlations between archeological typologies (Gosden 2008). It could reveal slow changes in artifacts over many human generations and, in early developmental stages of the brain, the speed of convergence toward a relevant cortical area that will eventually be selected to deal with a given artifact. Think of lithic cultures and of coinage, the time and resistance it took to introduce alternative monetary means, coins still remaining the prototypical material form of money (Snelders et al. 1992). Is there a possible correlation between the pace and type of historical evolution of stone tools and the neurobiological mechanisms that could support a cultural recycling process in this case?

Stout et al. (2008) have shed some light on the neural and evolutionary foundations of human primitive tool-making skills. They carried out a PET study involving inexperienced subjects who were progressively trained in carving stone tools. Evidence that would point to a likely cultural recycling hypothesis in this case would consist of inter-individual convergence toward a neuronal "niche". That neuronal niche would superimpose on a preexisting cortical map that it would make sense to "parasitize" when routinizing that task. Finally, inherited structural constraints in processing the intended artifact might be observed. These results, however, only partially support the cultural cortical recycling hypothesis in the case of tool-handling. Having acquired the stone tool-making ability, subjects showed varied neural activities in several parieto-frontal perceptual-motor systems. Among these activities of the neural motor system, one was specific to humans and specialized in the perception and recognition of three-dimensional shapes in motion. As no other specific human neural activities associated with planning and strategy were observed, the authors concluded that low-level fine-tuned processes, rather than higher cognitive ones, would suffice for the neural processing of 'affordance perception' and tool-use. This low-level process, rather than more cognitively demanding processes of abstract conceptualization, could well be crucial for the launching of a cultural innovation. Even though the latter carries a lot of very abstract and conventional connotations in other respects, I expect that the very emergence and success of a cultural innovation depends on its fit with a preferentially low-level neural structure.

Another criterion of recent cortical recycling is that, particular proto-historic cultural innovations (such as reading, writing, numbers, money, modern tools and symbols, etc.) could not have influenced the anatomy of the brain in the short evolutionary time since their inception. They may simply be an upshot of specific brain extensions, in contrast with a former anthropological stage or by comparison with primate brains. But if invariant cortical maps and specific neurobiological niches are observed with respect to the processing of these novel cultural items, given that the latter cannot have influenced brain anatomy, this is likely to be explained by a cultural cortical recycling hypothesis. But in that case, they would in turn likely be morphologically constrained by the functional specificities of the re-used older brain circuits they are parasitic on. But this is where the hypothesis of specific cortical maps being recycled in connection with the processing of cultural items becomes tricky. Interpreting systematic observations that seemingly support such an hypothesis may be ambiguous; and one needs first to determine whether evidence points to specific human brain extensions or to the functional reshuffling of evolutionarily older neural pathways.

As an instance of such interpretive indeterminacy, Orban et al. (2006) reviewed comparative fMRI studies of the intra-parietal sulcus (IPS). They confirmed that the human IPS, which has its anatomical counterpart in monkeys, contains functional regions specific to humans. In particular, it includes a region uniquely sensitive to the perception of three-dimensional shapes in motion, as also noted by Stout and his colleagues (2008). At this stage, human brain extension is expected to be correlated with functional specification. Despite the link to monkeys, this may have developed in a specific way in humans: and then re-used or recycled in the context of cultural innovation. The first anatomical and functional extension made possible apprehension of moving objects which was the optimal cortical niche to parasite for a technological ‘affordance ability’ to emerge.

IPS primarily serves the perception of 3-dimensional moving objects.



It presumably became involved in tool-handling across recent human evolution.

FIG 1: basic plausible functional shift in tool use; underlined in red: the intra-parietal sulcus.

Technology is a dual system in the sense that it encompasses both low-level motor procedures – some of them requiring highly specific neutrally-wired functions – and more abstract, cognitively demanding aspects, such as planning, teleological thought and maybe symbolism. Crucially, tool-handling primarily taps into the low-level procedures and, to the extent that there is a pre-established optimally relevant cortical map locally available, a functional shift may be hypothesized with respect to tools. We might ask whether similar conditions may be hypothesized in relation to other cultural artifacts, in particular those relevant to economic environments in which I am primarily interested. Not, of course, that there were not any economic environments before the advent of money, but money defines what we could call a “modern economic environment”, in that it is one where omnipresent face-to-face bargaining relationships are mediated by inert symbolic proxies. In the same way as tools, money encompasses a very material level (if we consider, precisely, money’s materializations) and a highly abstract and conventional one (it is interesting to note that money presides over the increased abstraction of human relationships by means of a material artifact). An analogy with cultural cortical recycling in tool-processing would mean that low-level neural mechanisms are preferentially triggered when dealing with money, in contrast with the immediate involvement of neural circuits that would correspond to the treatment of its more abstract features, and that these low-level mechanisms are grafted onto optimally relevant older neural pathways. Even though there is little direct neurobiological evidence supporting cultural cortical recycling of money-processing, economic and anthropological models of the emergence of money, as well as behavioral anomalies with respect to money and their neural bases, may point towards such a hypothesis.

4. Issues in money emergence

Theoretical economics does not assign any role to an intrinsically useless object such as fiat money. For example, the general equilibrium economy of Arrow-Debreu is completely devoid of any medium of exchange. In real-world economies, however, money not only exists but expectations of inter-temporal variations in the value of money are an important part of monetary transmission mechanisms. Kiyotaki and Wright’s (1989) model (henceforth KW) provides an understanding of money’s role in an economy and incidentally of the mechanisms that may have presided over its emergence. In a KW economy, there is a mismatch between the goods an agent produces and those she wishes to consume. This discrepancy requires the agent to accept a mediator to acquire her own consumption goods (see Figure 2). If trade occurs, it yields a positive payoff, otherwise an agent has to wait and bear the storage costs of his produced good. Agents aim at inter-temporal maximization of the gains from trade and minimization of storage costs. To see how agents’ behavior evolves in a KW economic environment, this model has been applied in a number of laboratory settings. These experiments show that the marketability of an object plays an important role in its acceptance as a medium of exchange; and in some situations agents could not discern these aspects and thus chose sub-optimally (Duffy and Ochs 1999, Duffy 2001). It has also been observed that an intrinsically worthless piece of fiat money may circulate as a medium of exchange as long as one of its feature is the lowest storage cost; if it is not the least costly to store goods, then its circulation as a medium of exchange less than that predicted by the theory (Duffy and Ochs 2002).

Some recent work in the psychology of money has distinguished between instrumental and hedonistic attitudes and behavior towards money (Lea & Webley 2006). It seems that money as a tool – taken essentially as a medium of exchange for purchasing desired goods – is conceptually primitive; hedonistic qualities of the purported good being derived from acquisition and consumption. But it has been noticed that money *per se* possesses hedonistic qualities that may sometimes outweigh an instrumental perspective (Vohs et al. 2006). An important question with regard to the study of money emergence is whether money was (and still is) primarily processed by brain structures that connect it to the value of what it is exchanged for, or whether it tends to be valued for itself independently of these intended items. If such an independent valuation phenomenon may be observed, we might wonder why and specifically whether money takes advantage of functionally relevant prewired circuits. If we adopt the purely instrumental view of money as being devoid of intrinsic value, the question becomes to understand how worthless tokens could be adopted as a universal means of exchange.

In the KW theoretical model of money emergence, perceptions of value are mediated by expectations concerning other agents' behavior. The fact that a good of no intrinsic value is adopted indicates that it acquires value through rational expectations, i.e. through strategic considerations that presumably tap into the most evolved parts of the frontal lobes associated with planning and control, but also into brain areas associated with coordinating behavior, joint intention and action, and mental abilities (Coricelli & Nagel 2009). If, on the contrary, behavioral and neural data with respect to money may be understood as those high-level processes being short-circuited by lower processes, it would alter our view of money emergence in terms of the KW model, or at least lead to a closer focus on the respective contribution of value perception and strategic input to the emergence of a medium of exchange in an experimental environment.

A conceptual shift away from the determination of value by exchange to its derivation (even of an intrinsically worthless object) from the conventions governing monetary exchange is clearly a heterodox move in economics. It has been adopted by Aglietta and Orléan (2002) in a seminal work relying on several anthropological sources. Archaeological data may also provide hints to answering this question about the relationship between valuation and social coordination, especially since the material remnants of money use present features that are likely shaped and were shaped by the neural systems most systematically and primitively involved in money-use. In that respect, the case of electrum coinage is interesting, since its introduction generated a tension between value-perception and social convention (Wallace 1987). Coins in 600BC Lydia were exclusively minted from electrum, a natural alloy of a variable proportion of gold and silver. But given the inconsistent and indeterminable gold content of electrum coins, its intrinsic value for users was uncertain.

Electrum coinage may be viewed more precisely as showing that intrinsic value is not what grants money its market value, at least not since its inception as coinage. Electrum coins were of carefully standardized weight, implying that, regardless of its metallic content, each coin was assigned a particular value by monetary authorities warranting its redemption. Interestingly, coins were still made from an allegedly precious metal, perhaps not so much because their intrinsic value determined the use of these coins, but because it enhanced their perception as valuable items, as if the prevailing social convention could not guarantee it by itself. We may hypothesize, after this brief review of the heavily discussed topic of early coinage, that, on the one hand, the use of something bearing value may certainly take advantage of having the trappings of intrinsic value but the latter is not essential for its adoption as a valued means of exchange; on the other hand, its value, whether this is intrinsically or extrinsically grounded, is the most easily and perceptually processed feature of monetary artifacts.

5. Low-level money functional processing

If this hypothesis is correct, there should be observable conflicts between value-processing and conventional understandings of money, pointing towards the possible prevalence of low-level processing of monetary stimuli. Recent neural data on the money illusion may point into that direction. ‘The money illusion’ means that an increase in income is valued positively, even when prices go up by the same amount, leaving real purchasing power unchanged. The nominal value of money is not connected to its real value or, rather, there is a bias in the assessment of real economic transactions induced by an undue consideration of their nominal evaluation. This means that some features of the real economic structure in which an agent trades may remain unperceived by them in spite of their willingness to trade. This stands in contradiction, first, to the prediction of economic theory that an individual judges the value of money by its purchasing power rather than by its nominal value and, second, to the experimental economics norm of expecting behavioral anomalies to be eliminated through experience of market interactions.

Until recently, little was known about the mechanisms that make people tend to use a suboptimal heuristic and fall prey of the money illusion. Shafir, Tversky and Diamond (1997), in a behavioral study, tried to understand why individuals do indeed use nominal values as a heuristic to infer real values of transactions, thereby failing, in contexts where the real incentive structure has been modified in an inflationary or deflationary direction, to optimize their monetary utility. In the past few years, Weber et al. (2009) have used fMRI to investigate whether the brain shows this money illusion. Subjects were submitted to two distinct experiments that were identical in their real economic structure, but variable in nominal terms. Participants earned low or high amounts of money that could be used to buy items from two catalogues respectively offering low and high prices for identical items. In the absence of a money illusion, no region of the brain typically associated with the processing of value should be sensitive to this purely nominal variation. On the contrary, the experimenters found that a crucial area of the brain-reward circuitry (the ventromedial prefrontal cortex, vmPFC) associated with the valuation and anticipation of goods, exhibited a money illusion. Its level of activity was significantly greater under high-price conditions as opposed to low prices, despite the unchanging real incentive structure. The following picture and graph show how the vmPFC was correlated with the degree of money illusion revealed by participants’ evaluation of simple economic transactions.

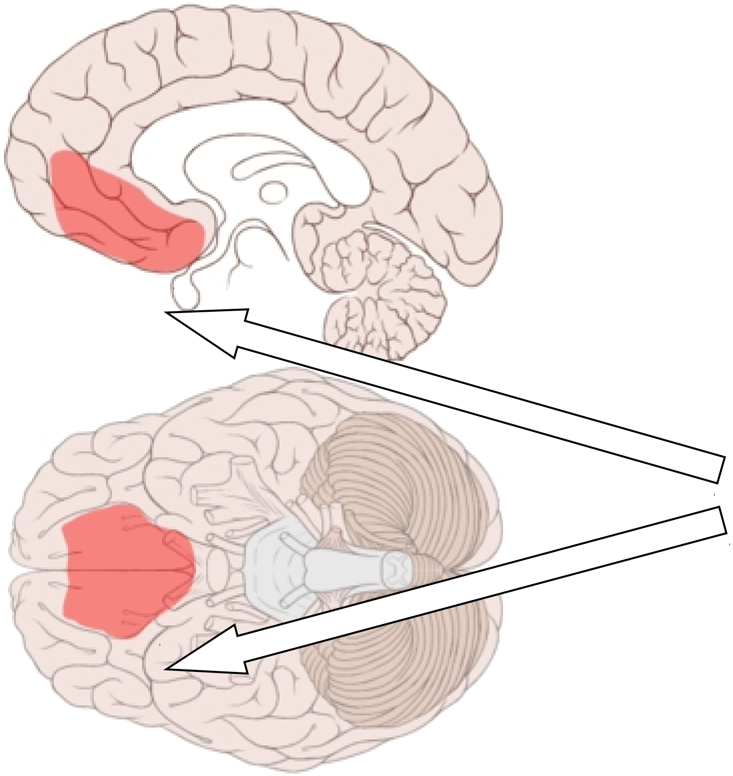


Figure 2

This study's findings show that money was processed at the lower level of reward-related brain activity in the vmPFC. This suggests that the money illusion is deeply anchored at a biological infra-individual level and that its neural treatment favors hedonistic features of value rather than an instrumental and more abstract conventional approach to the use of money.

Although money seems to be primarily treated as a reward and secondarily as a tool, thereby indicating the prevalence of low-level neural processes, this doesn't necessarily mean that the neural processes have taken advantage of old neural pathways that could optimally extend their functions to that specific processing end. Moreover, money is not just any reward; it is a reward – and is primarily treated as such – to the extent that it acquires some value through conventional institutions. We would need to figure out what behavioral and neural evidence could point to a neural mechanism reflecting this characteristically arbitrary feature of money, namely how the features of money are processed outside of contexts of conventional reward and trade.

In Tallon-Baudry, Meyniel, and Bourgeois-Gironde (2011), we demonstrate the existence of symbolic activities in the fusiform gyrus associated with visual categorization of particular monetary stimuli.

We were interested in how money is identified by the brain outside of contexts of reward. What kind of object is it? It is difficult to dissociate money from reward, as we saw, and its perception outside such contexts may well be strongly influenced by the use we usually make of it to obtain reward or in regarding money itself as the primary reward. In spite of this, we decided to investigate the way the brain identifies money in non-rewarding situations. Moreover, unlike physiological rewards, monetary stimuli are cultural artifacts, and our starting point was to ask how monetary stimuli are identified in the first place. We translated this question into another that makes it answerable through the use of magneto-encephalography (MEG) recordings of cortical activities: how and when does the brain identify a valid currency, rather than "where", since we were not concerned at the outset with investigating localization.

By "valid currency" or "valid coin", we meant, in our experiment, a coin that is (or was in 2010) endowed with current purchasing power. We took advantage of the formation of the Eurozone in 2002 to compare neural responses to valid coins (we used Euros and Australian $ for this) and invalid coins (French Francs and Finnish Marks, which were put out of circulation in 2002). The other factor built into this choice of types of stimuli is familiarity with these coins (minimally previous acquaintance) or lack of it. We made sure that the subjects were familiar with Euros and Francs (and were old enough in 2002 to have traded with the former French currency) and had never been in visual or economic contact with Australian $ and Finnish Marks. The experiment we invited our participants to perform was a one-back re-identification task. Namely, coins were successively presented on the computer screen and participants had to click on the mouse when they saw the same coin twice in a row. We did not directly test the factors we built in our choice of stimuli or the hypotheses we had in mind. The indirectness of our paradigm is an important methodological asset, in that if significant effects are shown with respect to our parameters and hypotheses, the conclusions we draw thereby escapes any criticism that we would have forced those effects on the participants.

Before running this experiment, we had expectations that are important to spell out briefly, given that they involve psychological and neural abilities lying at the core of observations and the associated methodology that we intend subsequently to transpose to other relevant contexts, where anthropological knowledge would be vital. We were aware that coins are both material and symbolic objects, endowed with economic properties by tacit, or most often explicit, social agreement. What we defined as coin-validity bears some analogy with the relation between a word and its meaning. Symbolic categories such as coins and words are therefore different from ecological categories, like faces, food, animals, which are based on visual similarities rather than being conventional carvings of reality. Given the partially symbolic properties of our monetary stimuli, we expected that these properties would be decoded by certain brain structures with a minimal 300ms delay. Categorizing a letter string as forming a valid lexical instance of one's natural language takes at least this time. On the other hand, categorizing natural objects such as faces occurs in the human ventral visual pathway within about 150ms. We expected money to be categorized at a speed more like words than faces.

What we observed was dramatically different from what we expected. As we report in detail in Tallon-Baudry et al. (2011), both familiar and unfamiliar coins were readily recognized and differentiated in the ventral human pathway. This suggests that there preexists a neural representation of money in subjects sufficiently generic and abstract to accommodate new instances of this category. Our main result then was that familiarity with certain categorical instances of valid or invalid coins is not a requirement for money categorization along this abstract dimension. Our second, quite unexpected, result was that in our experiment stimuli are categorized as valid or invalid money within a time window located between 150-175ms. Such processing speed is usually found in the case of natural categories defined, as I said, by visual properties, not social agreement. This result suggest that the human ventral visual system is well able to deal with symbolic environments, or at least certain objects such as coins, on the basis of general knowledge rather than long reinforced experiential channels.

From a neural point of view, our findings may show that the ventral visual pathway, a system previously thought to analyze visual features such as shape or color and to be influenced by daily experience, was also able to use conceptual attributes such as monetary validity to categorize familiar as well as unfamiliar visual objects by tapping into the same neural mechanisms and just as automatically. The symbolic abilities of the posterior fusiform region could therefore constitute an efficient neural substrate to deal with culturally defined symbols, independently of experience, which probably fostered money's cultural emergence and success in the first place. Natural candidates that come to mind are items such as faces, food or, again, tools. As with tools themselves, and the prior emergence of a motor module associated with three-dimensional moving affordances, we simply conclude that a special neural cortical map located in the ventral stream may have been selected through long-run evolution in order to detect whether faces or foods, or anything contributing to the individual's survival in her environment, are of a "valid" or an "invalid" sort. This primitive cortical map may have been re-used in the processing of money-stimuli and supported their emergence and the shapes they historically initially took. This neural nesting of money would then help to explain behavioral anomalies that have been often recognized for this culturally central human artifact.

6. Conclusion

A series of experiments in various cultural contexts and using different coins would be needed to validate this interpretation of our findings. Our initial study, still speculatively pointing towards the plausibility of a cultural cortical recycling hypothesis in the case of monetary artifacts, must be extended in new directions. Among such questions I would mention the following:

- Is money the only conceptual category that can receive a fast, automatic, reinforcement-free treatment by the visual system? At least another conceptual (or semi-conceptual) category (alive/not alive) shows a neuronal organization independent of learning. It is most unlikely that the neural pattern we observed stems from a module functionally dedicated to money. It is a far too recent invention (about 3000 years) to have influenced brain evolution. If any cortical process has taken place in the case of money, it probably encompasses a more general or more variegated symbolic category than monetary validity only.

- More generally, our results suggest that, on a par with other cultural inventions, cultural capacities do not necessarily develop on the basis of higher-level, flexible, distributed neural mechanisms, but may consist in automatic routines taking place in dedicated neural territories originally associated with other more directly ecological goals. This point, yet to be confirmed, needs more systematic investigation (not necessarily involving brain-imaging) of the acquisition of behavioral measures in categorization patters and response times, referring to tasks in contrasting cultural vs. ecological contexts, more precisely, in contexts requiring anthropological expertise.

- Whichever primitive mechanism money processing is rooted in, the fact that an object conventionally defined as social is treated so automatically, fluidly and within circuits and mechanisms evolutionarily dedicated to ecological items such as faces or food, must have contributed to its cultural emergence and success. Of course, there is a gap between this preliminary result and the more general hypothesis that cultural success in human history (artifacts, institutions, abilities, behaviors?) must be rooted in similar neurobiological recycling processes.

[In order to start to address these open questions we plan to propose online and easy to perform on field experiments that could help to corroborate (or disconfirm), by means of acquisition of basic behavioral measures (items classification, categorization and response times in those tasks), the plausibility of a cultural cortical recycling hypothesis in the case of money as a medium of exchange, a store of value and a unit of account. It means that the three classical functions of money should be systematically explored, separately. Tasks, schematically, will involve pictures (if online) and maybe actual items (if in the field) of monetary artifacts (familiar or unfamiliar, valid or invalid), food, faces (familiar or exotic, friendly, edible, hostile, rotten, etc.) that we will ask the subject to categorize. We measure response times in those tasks by means of precise chronometric devices. The main prediction that short response times point toward automatic cognitive processes in categorization or associative (putting two objects together according to some criterion) tasks, which will be interested to observe whether they are the case in visual settings involving cultural vs. ecological artifacts.]

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