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HAS MONEY TRANSFORMED OUR BRAINS? A GLIMPSE INTO STONE-AGE NEUROECONOMICS

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ABSTRACT

Monetary exchanges supported by coins appeared less than 3000 years ago in Lydia. They don't resort to an evolutionary temporal scale of human brain development as determined by long interaction with natural environments. Yet, we can hypothesize, in the light of several behavioral and brain-imaging experiments, that these eminently cultural artifacts, coins, have established specific neural connections with otherwise evolutionary shaped functional brain areas. This is documented by a seemingly fast and automatic processing of coin monetary validity in the posterior fusiform gyrus, a ventral stream area functionally dedicated to the automatic decoding of ecological items such as human faces and food. This type of evidence triggers a discussion on two accounts. It leads us to reconsider how short-term functional neural adaptations to cultural environments predate long-term neurobiological evolution. Finally, potentially providing new insights on Sahlins' hypotheses about the anthropological emergence of economic activities, it anchors our modern economic behavior and environment into a natural history.

Keywords: Money, Coins, Cultural Cortical Recycling, Marshall Sahlins, Cultural Neuroscience, Economic Anthropology.
JEL Codes: B52, D87, Z13.

Introduction

Money is a recent institution, circa 700 BC in Lydia, for its appearance as coins (Wallace 1987) though, of course, far more ancient if we understand by money any material medium that can facilitate the trade of heterogenous goods and store some value for a period of time. Money supposes a

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complex material organization: its production and its exchange, the choice and calibration of materials that can underlie reliable exchanges, their easy manipulability, and social control to avoid the circulation of fraudulent artifacts. It is also cognitively complex, but in a specific way. Many functions are fulfilled by money: keeping track of transactions, allowing anonymity rather than having to build trusting relationships before accepting exchanges, creating a link towards our future subsistence through a storage of value, speculating about alternative uses and profits. The specificity comes from the fact that money alleviates the cognitive burden on our brains. We do not have to memorize past interactions, we do not have to guarantee personal trust if the artifact is itself reliable, we can decrease our anxiety for the future if we maintain a stock of liquidities. This points towards a characterization of money as a device of externalized cognition.

Marshall Sahlins, in the penultimate chapter of *Stone Age Economics*, underlines this central fact that money sustains relatively anonymous and out-of-group transactions: "Not all tribes provide circumstances for monetary development and certainly not all enjoy primitive money […]. For the potentiality of peripheral exchange is maximized only by some tribes. Others remain relatively inner-directed".[1] Those inter-tribal or "peripheral" relations, in Sahlins's analysis, are the locus of money's functional emergence. It supposes an inter-tribal setting in which tribes are specialized in some production or activities. This specialization, the emergence of particular and diversified competences among certain families or communities, is, for Sahlins, a necessary condition for primitive money.

This first fundamental observation is where we take our starting point. What primitive money encompasses, here, is the interaction between the familiar (and the familial and tribal) and the stranger, the less known, the connection with anonymous others (see Seabright 2010). When tribes are outer-directed, in their periphery, money develops and fulfills its basic functions: unit of account, medium of exchange, and store of value. Money must have some validity beyond the familiar sphere. This will be the first element we borrow from Sahlins in our conceptual and experimental approach below. To anticipate the experimental data we will report, we will say that the use of money, in its primitive function, is inherently associated with the categorization of unfamiliar faces. Money, if we follow Sahlins, became prevalent when encounters involved strangers. Valid money is a substitute for trustworthiness. This substitution, from the necessity to decode facial features to the efficient use of money, seems to us a central event in

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[1] Sahlins M. (2017): 212. This quotation is from the chapter "On the sociology of primitive exchange".

our cultural life that might have made some impact on our neurobiological fabric. Our main point in this paper will be to discuss this possibility.

Another observation, on the basis of Sahlins's ideas about the emergence of primitive money, will help us to embrace those considerations about the interaction between money and faces within a broader view of the neuroscience of material culture. A few recent developments in the field of cultural neurosciences shed light on the joint cultural and biological transformation that accompanied the transition from primitive to modern economics. We consider that money – in the guise of metallic tokens – is what effectively structured that transformation. Metallic tokens introduce a new way of storing value, instead of amassing grain or enclosing cattle for direct exchange purposes. But grain and cattle indicate wealth directly and now the psychological and behavioral effects that wealth generates in its possessor are transposed to arbitrary fixtures. Sahlins characterizes these effects in the following way: "The tribal big-man operates on a fund of power consisting of food, pigs, or the like, stuffs with the common quality that they are not easy to keep around in large amounts over long periods. But at the same time the extractive devices for accumulating these political funds are underdeveloped […]. The dilemma is resolvable by monetary manipulations: by converting wealth into tokens and by calculated deployment of money in loans and exchange, so that a time will come when a massive call on goods can be made and the whole fund of wealth, given away, converted into status".[2]

The argument is intricate but points to the second fundamental mechanism that underlies primitive money, as well as, for that matter, its modern incarnations. This mechanism is abstraction and sublimation of status. It is very important to note that Sahlins does not speak of conventional or fiat aspects of money, as those notions tend to a priori detach money from its immediate and essentially material grounding. Money is certainly a conceptual abstraction but – whatever the so-called immaterial forms it has taken in modern times – is irrevocably associated with a material basis. In the passage we have just quoted, the possession and transmission of a token mirrors – in the mind's eye as well as in the concrete world – the massive transfer of cattle or heavy stuff. The concentration of wealth in an arbitrary and handy object allows for a second transformative act: the increase of status, the perception of acquiring more social weight. Money has to do with those material transfers and personal transfigurations, lending it a talismanic force. It is not only a support of extended cognition; it is an embodied institution.

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[2] *Ibid.*: 212-213.

In this article we try to confirm and extend Sahlins's observations on primitive money through hypotheses, and sometimes data, in cultural neurosciences. In the first section, we report and comment on some results we acquired by means of a brain-imaging study intended to probe the neural correlates of our visual processing of modern coins. Our main result shows how the dissociation of validity and familiarity is indeed central to our perception of money. Moreover, that dissociation in the ventral stream, and particularly in the fusiform gyrus, relates that result to a broader literature on the perception of faces. We are led to speculate on the possibility that a modern artifact, such as coins, may have tapped into cortical mechanisms initially dedicated to the processing of the very ecological items (unfamiliar faces) which were possibly involved in the context of emerging primitive monetary exchanges as envisioned by Sahlins.

We discuss the scope and limits of this "cultural cortical recycling hypothesis" as applied to money in the second section of the paper. We definitely lack enough data to confidently accept the applicability of that neurobiological hypothesis to the emergence of money, in spite of suggestive hints. But it can be deemed of some interest to perform a conceptual 'exercise in cultural neuroscience' to assess its plausibility. This will lead us to necessary clarifications about the interplay between material culture and the brain which we undertake in the third section of the paper. The main problem we discuss there is whether some hypotheses, other than the cultural cortical recycling one, are available to explain the apparent automatic and selective processing of coins in the visual area. The cultural cortical hypothesis typically relies on an assumption (see detailed explanation below by Dehaene and Cohen 2007) that short time scales, such as the historical lapse of time since the appearance of money, cannot involve "deeper" modifications in our neurobiological fabric than the one involved in a cortical recycling phenomenon. We conclude this paper by a series of further questions to be addressed and experimental studies that ought to be performed to account for a neurobiological facilitation of the emergence of money in primitive human communities.

1. Coins and the fusiform gyrus

In this section we report on an experiment which demonstrates a fast and automatic detection of the validity or non-validity of non-familiar coins in a sub-area of the brain visual system, the fusiform gyrus, which has been evolutionarily selected to support the recognition of human faces and edible food (Tallon-Baudry *et al.* 2011). The involvement of this specific brain area in the decoding of monetary validity leads us to speculate about its

having recycled critical ecological functions, critical for human survival in hunter-gatherer societies, such as the perception of facial trustworthiness, and the perception of faces more basically. We were precisely interested in the perception of coins. In those early years of the 'neuroeconomic' field much effort was concentrated on the neural encoding of value and incentives. What we did with money had a different aim. We emphasize this fact, because we were considering at that time, and still are in retrospect, that the investigation of biologically fundamental brain-mechanisms such as those which underlie valuation and motivation, in spite of their seemingly correspondence with basic economic constructs, actually cannot teach us much about the evolution of economic behavior and systems in a more specific sense (for a more developed argument along those lines, see Addessi *et al.* 2020). The main reason motivating this assertion is that valuation and motivation are not specific to economic contexts and situations, unless we dilute the meaning of "economics" to the study of any choice situation in which some unchosen alternatives have to be foregone. The fact that some fundamental biological mechanisms are evidently involved in decision-making, including of the type we can qualify as "economic", is insufficiently determined to justify the labelling of a discipline in terms of "neuroeconomics". In reaction to this too broad acceptance of what economics is supposed to be about (unqualified choices), we precisely feel in accordance with a more restrictive use of the term, which is Sahlins' and which stresses the co-involvement of a type of behavior and a type of social context. Moreover, the interplay of behavioral patterns and social situations can be mediated, as we have noted above, by dedicated artifacts and mechanisms.

For this reason, we were interested in how monetary artifacts are identified by the brain outside of rewarding contexts. Naively, our leading question was what kind of object money is, and how the brain visually categorizes it. Although it might be considered difficult to dissociate money from reward, we control for this fact in two ways: i) by not rewarding the participants relatively to their performance, ii) by using stimuli to which they could associate a potential rewarding use ("valid" coins) as well as stimuli for which no more monetary value could be currently attached (past currencies, "invalid" coins). The required performance concerned both types of stimuli, not only the valid coins. Yet, we do not exclude that repeated associations, prior to the experiment, between rewards and use of coins, when the latter are valid, could have influenced the way we perceive these monetary items. But it is one thing to study the neural reward circuits activated during monetary experiences and another one to investigate how these repeated experiences may have shaped the perception of money as such. For instance, and classically, Stephen Lea and Paul Webley (Lea and

Webley 2006) have discussed the dual psychological aspects and potentially dual neurobiological anchoring of money: as drug and as tool. We were definitely interested in the "tool" aspect, the one that is reflected in the theoretical notion of a "medium for exchange". It is not exclusive of any other type of psychological and neurobiological phenomena than the one we are going to report. As seen in the remarks by Sahlins above: money offers the instrumental solution to a change in social contexts (out-of-group transactions) as much as it provokes a new and possibly self-reinforcing perception of own's social importance.

Our starting point was to know how monetary stimuli are perceived in the first place, whether reward-association have biased that perception or not. To answer this question, we used magneto-encephalography (MEG) recordings of cortical activities during the perception of different monetary stimuli (different coins). This brain-imaging technique allows for good temporal resolution of stimulated brain activity. For a reason that will soon be clear, we were interested in priority in the timing of the decoding of the stimuli rather than in the localization of neural correlates of that decoding, even though we could also retrieve that information. Our initial question was naïve: how much faster a familiar coin is decoded compared to a non-familiar one, based on the seemingly intuitive idea that reinforced experiences facilitate the neural processing of the stimuli concerned.

We used a 2×2 factorial design in the choice of our stimuli. We took advantage of the currency change in the Euro area in 2002 to compare neural responses to valid coins (we used: Euros and Australian $ for this factor) and invalid coins (French Francs and Finnish Marks, which were taken out of circulation in 2002). By "valid currency", or "valid coin", we then meant, in our experiment, a coin that was, at the time of the experiment, endowed with current purchasing power. The other factor is familiarity, consisting in previous manipulation of the relevant coins. We therefore made sure that our participants were familiar with Euros and Francs (that is: were old enough in 2002 to have traded with the former French currency). On the other hand, we checked that our participants had never been in contact, visually or of course economically, with Australian dollars and Finnish Marks, the two "unfamiliar" currencies in our task. The idea was then to observe the interaction of validity x familiarity on the perception of those coins, its neural timing and encoding.

The experimental task 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 computer mouse each time they saw the same coin twice in a row. The choice of the task is again motivated by our intention to observe an effect of the chosen monetary stimuli on the visual area of the brain that would not be medi-

ated by any a priori selection based on the factors we implemented. The categorization of coins could therefore ensue as an indirect effect and not as a direct consequence of the nature of the task itself. We recorded brain activities at the moment of the display of the coins on the screen. Our focus is on this perceptual aspect. For this reason, we discarded from the analysis the stimuli for which the participants had to click on the mouse because they were seen twice in a row. Again, this is a way to exclude any association of "good performance" with the perception of coins and exclude motor-perception interactions in the attempted acquisition of pure visual neural correlates.

Coins are both material and symbolic objects, endowed with economic properties by tacit, or most often, explicit, social agreement. The material features of the different coins we used were homogenized in terms of color and luminosity of the projected stimuli. We presented obverse and reverse / head and tail sides of the coins, but our precise selection of the stimuli aimed to maximize the similarity of the types of features and ornaments that they presented. A coin is the material support of a social convention. Those two aspects relate respectively to familiarity and validity, our two parameters. We made sure that the participants, after a short training session, could correctly identify the stimuli and whether they were valid or invalid coins, without that short session (3 minutes to get 100% correct answers on average) neutralizing the familiarity criterion which was based on several years of actual manipulation of the concerned coins. After this training session, the task, as we described it, was launched.

What we have 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 objects of reality. Given the partially symbolic properties of our monetary stimuli, we were expecting that these properties would be decoded by certain brain structures with a minimal 300ms delay (see e.g. Allison *et al.* 1994). Indeed, categorizing a string of symbols as forming a valid lexical instance of one's natural language takes at least this amount of time. On the other hand, categorizing natural objects such as faces occurs in the human ventral visual pathway within about 150ms. We were therefore expecting categorization of money to be a par with that of words rather than of faces, for instance.

Our observations invalidated these expectations. As we reported in details in Tallon-Baudry *et al.* (2011), familiar and unfamiliar coins were readily recognized and differentiated in the ventral human pathway within a 150ms time-frame. We interpret this fast processing of coins as an indication that there preexists a neural representation of money in people which

is sufficiently generic and abstract to accommodate new non-familiar instances of this category and, therefore, that familiarity with particular categorical instances of valid or invalid coins is not a pre-requisite for money categorization. Our second, and even more unexpected, result is that within that same temporal window of 150-175ms these monetary stimuli could be categorized as valid or invalid coins. More precisely, the degree of brain electromagnetic activity recorded in the visual ventral stream differed significantly depending on whether the subject was looking at a valid coin or an invalid coin. The factor of validity, not familiarity, was the one that modulated the intensity of brain activity associated with the perception of coins. The main effect of validity was moreover observed in the posterior fusiform gyrus, an area notably dedicated to the categorization of faces (Gauthier *et al.* 1999).

As we have said, such fast processing of stimuli is generally found in relation to natural categories, apprehended by their visual properties and not social conventions. It has long been noted that the human visual ventral stream is apt to deal with symbolic stimuli too in a fast way (see for early considerations on this point Schendan *et al.* 1998). It is perhaps more surprising to report a similar phenomenon for cultural items such as coins, especially when the visual categorization is mediated through general knowledge, rather than long reinforced experiential channels. From a neurobiological point of view, our findings may thus indicate that the ventral visual pathway can use conceptual attributes, such as monetary validity, to categorize familiar as well as unfamiliar visual objects and do so by tapping into the same neural mechanisms and with the same degree of automaticity as for ecological non-symbolic items. These observations – although not enough evidence for any sort of definite generalization – may have the merit of provoking a discussion about the use we can make of similar data in an effort to support particular cultural anthropological views. This seems to require to articulate a theory about how changes in material culture may have influenced brain mechanisms, which in turn may have facilitated the adoption of habits and artifacts defining that culture. A further step is to consider whether such a theory could soundly apply to the emergence of money.

2. The hypothesis of cultural cortical recycling

Such a theory seems to be available, although it has never applied to the analysis of monetary artifacts. This is perhaps because neuroscientific interest in money has primarily been directed towards the valuation and motivation aspects rather than the cultural, anthropological, or archeologi-

cal (see Renfrew *et al.* 2008) ones. The hypothesis of cultural recycling of cortical maps was indeed advanced to make sense of a seeming neurobiological paradox. 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". Considering the well identified symbolic abilities of the posterior fusiform region, in which our main effect of validity was located, supported by an anciently wired neural circuitry dedicated to processing human faces and edible food, it would be tempting to speculate on a recycling of that local neural mechanisms to the processing of historically recent cultural items such as coins.

Central to Dehaene and Cohen's hypothesis is the concept of a cortical map. Maps are invariant brain structures that encode cultural items and override basic neuronal layouts. Cortical maps reflect the representational structure of the targeted cultural item in an isomorphic way. With regard to reading, for example, it is intuitively clear what this isomorphism amounts to in the case of letters and symbols more generally. Strings of letters, for instance, belong to a continuous two-dimensional metric space and their structure is replicated on the cortical surface (Dehaene 2003). Retinotopy refers to the spatial organization of the cortex in correspondence to visual stimuli, which has been observed to form a map of the visual field (Tanaka 2003). In some cases, the topology is simple and the isomorphism may be implemented at different neuronal scales. Our experiment on the perception of coins, which did not target that issue – as the suggestion of a cortical recycling hypothesis in that context came as a surprise and still lacks external evidence – cannot report any isomorphic encoding of coins. But as for any other visual stimuli, we cannot exclude it, of course; the main interest for us, however, lies elsewhere.

Where a cultural cortical map fits in the brain is determined by the structure of the stimuli to be processed, and that functional location determines some features of the treatment. Biases in the neural processing of novel cultural items, when they are attributable to the constraints presiding over an already dedicated cortical niche, may form 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 transpose into typical behavior (eye movements, limits on the simultaneous processing of several individual stimuli, or anomalies like dyslexia, etc.) and into a co-adaptive evolution of the stimuli given its potentially optimal processing by the brain.

In spite of cross-cultural variety, linear writing systems (using discrete letters rather than ideograms – the latter inducing a different neural integration and subsequent constraints, possibly in the number and direction of strokes) present a limited number of internal organizational variations, a high level of similitude in terms of shape, position and size invariance of letters, which may indicate that processing constraints and cultural stimuli morphology have converged. The double provisional conclusion of this cultural cortical recycling hypothesis then seems that, not only did the brain exapt some of its evolutionary older neural pathways to process novel cultural items, but also that the latter might have evolved to be optimally apprehensible by the brain. Drawing attention to geometric analogies between edible berries, faces and coins (especially if one considers that the first Lydian metallic monetary items were solidified lacrymoid drops of electrum) would stretch too far into speculative territory the hypothesis of those structural constraints imposed by the functioning of the exapted cortical niche over the physical morphology of the stimuli. However, we can refer to an auxiliary phenomenon to give some indirect support to such a speculation.

Dehaene-Lambertz and colleagues (2018) discuss whether cultural cortical recycling entails a competition for neural resources. When a particular stimulus exapts some preestablished functional mechanism in a cortical area for certain given stimuli, a form of "neural attrition" could affect the processing of those other stimuli. Reading ability acquisition during childhood, these authors argue, induces a reorientation of the cortical area. The question is whether that reorientation comes at the expense of the processing, in that same area, of anciently treated ecological stimuli such as faces. The motive for this question is that the visual form area is finely dedicated to the processing of specific categories: places, words, numbers, faces, tools, body-parts, etc. Dehaene-Lambertz *et al.* showed that the neural activities dedicated to new reading abilities encroached on the neural territory dedicated to tools and neighbored that dedicated to faces. However, increasing behavioral competence in reading did not decrease accuracy in face or tool processing, which remained stable. This observation bears some relevance for the discussion about the theoretical plausibility of a cultural cortical recycling mechanism having taken place in relation to the appearances of monetary artifacts.

First, although money can be said to be a substitute for face categorization and memorization at the time of economic exchanges, it would be extremely detrimental, from the point of view of our social lives, if increased familiarity with the monetary institution entailed a growing incapacity to recognize people's faces. In a sense, through monetary exchanges, we can continue to dedicate as much attention, and neural energy, to the faces we

care about, and the processing of that new cultural stimulus, money, which is necessary to the structure of relations in an expanded human circle. This is what precisely helps to stabilize the resources dedicated to the processing of faces, which perhaps could not expand beyond a certain threshold of identification and memorization, even though that number might be high (Dunbar 1993; Jenkins *et al.* 2018). At this juncture we would like to consider a second theoretical consequence – one that should be subjected to relevant experimentation – of Dehaene-Lambertz and her co-authors' finding. Although a new stimulus does not capture neural territory at the expense of a formerly dominant stimulus in that part of the brain, it might be interesting to consider whether this fact is related to the idea that the processing of these stimuli is subjected to common structural constraints. This would unfold from a principle of parsimony, of facilitation of those diverse stimuli processing by means of maximally joint neural mechanisms that encompass them together. If in turn the success of a new cultural item in finding its cortical niche is correlated with this form of neural parsimony, the idea that coins – the processing of which we have noted in our experiment largely overlaps with that of faces – inherit some morphological features from the posterior fusiform gyrus treatment of human faces, to be sure in a very derivative way.

These certainly speculative remarks may echo some more experimentally grounded recent work related to the development of other cultural stimuli. De Beeck and colleagues, in particular, study how other cultural stimuli develop according to a strong principle of selectivity in the human occipitotemporal cortex (De Beeck *et al.* 2019). There is a direct relevance of that study and the conclusions of the authors about the interpretation of a key aspect of what we have reported in our own experiment (Tallon-Baudry *et al.* 2011). We have observed – and were duly surprised by this main observation – that the fast and automatic categorization of coins in the visual area was independent of any long-term perceptual training and of any form of familiarity with the coins, since totally new items were neutrally processed in the same way as familiar one, and only according to their abstract validity. What De Beeck and colleagues show is precisely that besides visual reinforcement for the establishment of a cortical niche – or, say, a selective functional cortical area – dedicated to the neural processing of specific stimuli such as faces, word forms, numbers, scenes, and we are tempted to add, coins, what matters, are different underlying factors in the functional organization of the brain. These factors operate at two distinct levels. One is that the encompassing by a specific cortical area of various specific stimuli does not depend on a single neural capacity (e.g. visual processing) but on a domain-general mechanism, flexible enough, to adapt to various stimulus. That level is relevant for our concerns. We make

a similar point when we report that coins are categorized according to their "validity" rather than familiarity. Validity is precisely a domain-general notion. Even for unknown stimuli, categorization by the criterion of validity was efficient. But validity extends across categories of stimuli and can be common to the categorization of any stimulus, for instance in terms of its prototypicality. Another level in De Beeck and colleagues' account of the development of selective functional areas and the constraints that underlie their location is the consideration of the connection to those areas within a broader organization of the brain, in particular their connectivity to non-visual regions. In the case of money, we can consider that reward areas such as the ventral striatum, which have been widely investigated in relation to monetary motivation, may have contributed, through high connectivity with the visual system, to a high selectivity of coin processing in the ventral stream.

As an interim conclusion on the plausible applicability of the cultural cortical recycling hypothesis to the fast and automatic processing of coins that we have experimentally evidenced, we can only conclude that multiple factors seem to converge in favor of its plausibility: automaticity, functional overlap with the processing of faces in the posterior fusiform gyrus, plausible common morphological similarities as a consequence of structural-functional constraints, behavioral substitution and/or complementarity between coins and faces in social interactions. We now turn to other aspects of that problem and to possible alternative approaches to it, while keeping the same overall concern in mind; namely, to understand how much of a neurobiological response to an economic problem money is.

3. Time scales and species boundaries in the emergence of a monetary culture

Neuronal layouts are shaped by evolution and are genetically constrained. Epigenetic factors in the early phase of the individual's development will finalize the cortical structures, which then react to external stimuli in an invariant way. There is a compromise between genetic constraints, cortical relative plasticity, and the frequency and tractable structure of encountered stimuli. Dehaene and Cohen list the potential constraints that could underlie the organization of visual cortical maps in relation to orthographic stimuli. Those constraints determine the way a given stimulus is processed as much as potential biases in processing the relevant information. This form of neural plasticity made us adapt and at the same time contributed to the emergence of modern post-Neolithic cultural environments. In their seminal paper, Dehaene and Cohen find a possible motiva-

tion for their cultural cortical recycling hypothesis in the fact that invariant neural processing of novel cultural stimuli occurs while they assume that the brain is unlikely to have undertaken genetic and anatomical modifications during that short lapse of time since the appearance of those cultural items.

This assertion can be bypassed in two ways.[3] First, we could consider that cultural traits – behavioral phenotypes – and their stabilization in rapidly culturally evolving environments, as was the case in the periods where complex economic environments (Sahlins' out-of-groups exchange interactions) emerged, did not involve any genetic inheritance mechanisms. Bonduriansky and colleagues argue for the prevalence of such mechanisms in contexts of rapid environmental changes (Bonduriansky *et al.* 2012). But more exactly, the mechanism they argue for is sequential. At the onset, those rapid environmental changes favor rapid non-genetic transmission of adaptive behavioral traits (in our context, say the behavioral coordination over the use of a new cultural artifact). This context sets up phenotypic changes. But, secondly, these changes can facilitate fast genetic adaptations to the new environment, and stabilize the transmission of those adaptive traits in those fast-changing environments. Bonduriansky and his colleagues consider a series of relevant contexts that could validate their hypothesis: proper environmental changes in terms of temperature and pollution, but also, and closer to the focus of the present paper, what they term "bet-hedging", although the authors envision this concept in the context of sexual reproduction. But more generally, bet-hedging is a way of insuring oneself by cautious behavior against uncertainty and unpredictability in, precisely, changing environments. It has been noted by economists for a long-time that this is one of the main functions of money [Keynes 2018 (1936); and see Bourgeois-Gironde and Guille 2011, for a neuroeconomic point of view on this Keynesian issue]. It is then possible to imagine that money was the institutional and behavioral solution to hedge oneself against increased uncertainty due to the extension of transactions to communities of strangers. That practical solution may have coincided with a biological possibility. But the main point, for us, is that we do not need to feel theoretically impeded by the time scale under which those functional changes in the brains may have taken place, by necessarily relating them to the assumed temporal scales of genetic changes. As Rathkopf (2020) precisely points out, the reuse of neural structure is particularly observed at short task-relevant scales, which definitely corresponds to the categori-

[3] I thank the anonymous reviewers of a first version of this article to have directed my attention towards these counter-hypotheses.

zation task we have discussed above. It is different from an evolutionary time-scale and it is interesting to note with Rathkopf, especially when we try to relate our experimental observations with what it could have been for our ancestors to have reached a point in their evolution where monetary exchanges emerged, that neural re-use is a biological mechanism that "liberates [our] capacities from the ancestral tethers that might otherwise have constrained them". We could not express that better than this author has done.

But a second response is offered by the growing evidence of gene-culture interactions in recent human evolution (Laland *et al.* 2010) in support of the view that cultural processes can have affected human evolution – that is, including at a relatively short time-scale. Laland and colleagues provide convincing empirical evidence associated with survival activities. Yam cultivators in West Africa have developed a specific allele in accordance with their agricultural specialization; likewise, Polynesian navigators, given their long oceanic transhumances, developed a "thrifty metabolism". Allele selection, according to these authors, has been favored in relation to specialized cultural activities. We have of course no evidence to assert that gene-culture co-evolution took place during the emergence and generalization of monetary environments, but, again, we cannot exclude that the monetary cultural acceleration was not, therefore in principle, beyond the pace of biological adaptation to one's environment. Neural plasticity was enhanced by modern environments in the sense that typical genetic and neurobiological adaptive features, which had been selected on a long-term evolutionary basis, were certainly not cancelled out and started to perform novel functions. But it could also have been the case that genetic adaptations accompanied those behavioral and cultural innovations.

The stabilization and success of a given material culture may be strongly correlated with the same neurobiological processes (such as the convergence of cortical maps toward optimal recycling neuronal sites) undertaken by a close group of human brains, possibly over a few generations. Determining the speed and ease of cultural learning may then have anthropological and archeological implications. The study of past material cultures from a neurobiological point of view may, in particular, find a direct and challenging application in uncovering possible correlations between archeological typologies (Gosden 2008), indicating slow changes in artifacts over human generations, and the speed of convergence in early developmental stages of the brain toward a relevant cortical area that will eventually be selected to deal with a given artifact. We can think in particular of lithic cultures and of coinage: the time and resistance it took to introduce alternative monetary means, coins still remaining, even today, the prototypical mental representation of money (Snelders *et al.* 1992; Bourgeois-Gironde

2009). Money being a technological device, and requiring advanced technological capacities for its calibrated production, its adoption may also have been facilitated by an exaption of low-level motor neural mechansims – some of them requiring highly specialized neuronally wired functions. Crucially, tool-handling primarily taps into these low-level functions and, to the extent that there is a pre-established optimally relevant cortical map locally available, functional shift can be also hypothesized with respect to tools-manipulation, a hypothesis that we explore specifically in a previous article (Bourgeois-Gironde 2013).

Sahlins has envisioned the emergence of money as being contemporary with a significant shift in tribal and social organization. In his terms, when peripheral activities, for a given tribe, take some importance an artefactual mediator – a medium for exchange – regulates the distance between inner-group activities and outer-group exchanges with the less familiar. It is at this juncture which we might point to the birth of what we label "modern economic environments", when essential features that, we contend, money and monetary activities still encompass today, have taken shape, culturally and biologically. Not, of course, that there were no economic environments before the advent of money, but money defines what we can call a "modern economic environment", which we could make explicit by saying that it is one in which omnipresent face-to-face bargaining relationships become mediated by inert symbolic proxies. Like tools, money encompasses a very material level (not only if we consider the materialization of money, but also if we refer to the transfer of goods it facilitates) but also a highly abstract and symbolic one. It is interesting, as Sahlins does, to note that money presides over an increased abstraction of human relationships by means of a material artifact. This leads us to raise a final question. Is it this capacity of abstraction that made the development of money – and of expanded economic systems – a human phenomenon, not shared by other animal species?

De Petrillo and colleagues (De Petrillo *et al.* 2019) have implemented an experimental protocol aiming to show whether a group of capuchins could adopt an arbitrary token as a means of exchange that could encompass some proto-monetary attributes. That reinforcement can easily generate among monkeys some token-reward associations has been widely documented, but the goal of these authors' study was to see whether validity, independently of long experiential reinforcement – i.e. familiarity – could lead to the adoption of an arbitrary token in exchange situations. The idea of that experiment was then to transpose Tallon-Baudry *et al.* (2011)'s question to a behavioral setting involving non-human primates. They tested this ability in two stages. In the first experiment, they noted that the capuchins could categorize tokens as valid even though they had no prior

experience of exchange with respect to these tokens. Valid-familiar and valid-non-familiar tokens were chosen in preference to non-valid-unfamiliar and non-valid-familiar (tokens that had been used in previous experiments with the same group of monkeys for them to obtain food). In a second experiment, the authors tested whether the capuchins could "sell back" food they did not want to consume to obtain tokens in order to acquire some food that they preferred – the tastes of every participant being known in advance. In that case, the rate of success – that is, accuracy in the selection of non-familiar valid tokens – increased with the desirability of food. This suggests that non-human primates, even though they have not developed full-fledged monetary system, have the behavioral ability to adopt means for exchange sharing some fundamental features with human money and have the cognitive ability to make exchanges rely on such an abstract notion as monetary validity, a result that was confirmed by the same team in a sequel study (Quintiero *et al.* 2021). Leca and his co-researchers (Leca *et al.* 2021) have moreover documented that the transmission of the use of arbitrary tokens can give rise to a transgenerational cultural transmission in routinely bartering interactions with humans. The colony of long-tailed macaques around the Balinese Uluwatu temple may offer the first example of a proto-monetary economy in free-ranging animals, putting in question the genetic and cognitive boundaries between human and non-human primates as sufficient reasons for not envisioning emergence of a monetary economic systems, and giving more weight to cultural factors and especially trans-community cultural exchanges, as we initially understood Sahlins' main explanation of money-emergence.

Conclusion

A more substantial series of experiments in various cultural contexts and using different coins would be needed to definitively validate the interpretation we have given of our findings (Tallon-Baudry *et al.* 2011). This initial study, still speculatively pointing towards the plausibility of a cultural cortical recycling hypothesis in the case of monetary artifacts, needs to be extended in different directions. Among open questions we can mention the following:

– Is money the only conceptual category that can receive a fast, automatic, reinforcement-free treatment by the visual system? It is most unlikely that the neural pattern we observed stems from a module functionally dedicated to money. If any cortical recycling process has taken place in the case of money it is probable that it encompasses a more general or a more variegated symbolic category than just monetary validity.

– Another aspect which our results make salient is the fast and automatic processing of the validity of coins. Is there a connection between this observation that for an individual this processing is automatic and the possibility that the emergence of money among human communities could have been fast and that the use of this economic device quickly generalized? It is tempting to say so, but we lack this information, and let to anthropologists and archaeologists the possibility to extrapolate on this idea.
– Whichever pre-established mechanism money neural processing is rooted in, the fact that a conventionally socially defined object is treated so automatically, fluidly, and within circuits and mechanisms evolutionarily dedicated to ecological items such as faces or food, must have contributed its cultural emergence and success. Of course, there is a gap between this preliminary result and the more general hypothesis that cultural (artifacts, institutions, abilities, behaviors?) success in human history must be rooted in similar neurobiological recycling processes. What is clear, however, is that our data do not contradict, and rather support, the cultural grounding of money emergence in a joint neurobiological mechanism that allows for an efficient processing of valid unfamiliar vs. familiar objects and scenes and that is related to the perception of value itself. Moreover, the short temporal scale under which this neural exaption may have taken place is not incompatible with alternative hypotheses such as fast genetic adaptation following non-genetic inheritance of behavioral phenotypes and cultural traits or gene-culture interactions taking place on short-temporal scales in response to cultural and economic specializations of particular human communities.
– The emergence of money in humans, contrasted with its non-emergence in non-human primates, in spite of the latter's ability to perform token-mediated exchanges displaying some form of proto-monetary behavior, points more towards a cultural difference than a fundamentally biological, cognitive or behavioral one, as possibly testified by a series of recent experimental or field studies (De Petrillo *et al.* 2019; Quintiero *et al.* 2021, Leca *et al.* 2021). In our eyes, this reinforces the Sahlinsian hypothesis according to which out-of-group exchanges – an anthropological and cultural fact – have determined the appearance of money, our biological fabric flexibly adapting itself to this cultural change.

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