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Neuroeconomics—From neural systems to economic behaviour

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Abstract

Neuroeconomics is a new and highly interdisciplinary field. Drawing from theories and methodologies employed in both economics and neuroscience, it aims at understanding the neural systems supporting and affecting economically relevant behaviour in real-life situations. Although incomplete, the evidence is beginning to clarify with the possibility that neuroeconomic methodology might eventually trace whole processes of economically relevant behaviour. This paper accompanies the author's ConNEcs 2004 keynote speech on applications of neuroeconomic research.

Keywords: Neuroeconomics; Magnetoencephalography; Choice making; Decision; Preference; Utility; Gender-related strategies

1. Introduction

Over the last few years, one has witnessed the formation of a new and potentially very powerful field of research: neuroeconomics. A perfect synergy it seems, as both economics and neuroscience provide strong methodologies complementing each other in some sense.

Economics may be seen as relatively 'macroscopic' in nature, where models are often based on concepts like partial versus general equilibrium of systems with many degrees of freedom, i.e. individuals, groups of individuals, or whole societies. In those models, the human mind – the driver of all economic action – is considered a 'black box', which is conceptualised in terms of abstract probabilities in order to describe the individual action in a given situation. Here, neuroscience could provide reliable measurements to uncover the relevant psychological forces operating within the black box.

On the contrary, neuroscience may be seen as relatively 'microscopic' in nature, where the focus tends to be on specific mechanisms, like the recognition of a face, leaving theories of large-scale interactions within the entire brain an uncharted territory. Here, approaches used in economics might help to better understand how the human neural system interacts as a whole and how it might utilise scarce resources such as metabolic energy, attention, or other processing capacities (for further introductory remarks on neuroeconomics, see e.g. [6,13]).

This paper will present some of the recent approaches in this new field, which aim at understanding the neural systems supporting and affecting economically relevant behaviour in real-life situations. These approaches highlight the synergy between economics and neuroscience, and illustrate the current state of affairs, where the validity and applicability of the methods are at the forefront of the debate.

2. Neuronal correlates of economic decisions in games

Game theory provides models, known as games, to study interactions with formalised incentive structures. Such games are of profound theoretical importance in economics (as well as many other fields) where one wishes to model processes in which the optimality and/or profitability of a course of (economic) action is affected by both the moves of the decision-maker and the actions of thinking competitors (e.g. [12]).

Gehring and Willoughby [11] have used electroencephalography (EEG) to study neuronal response in subjects performing a simple monetary gambling task, where partic-

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ipant's choices are followed by outcome stimuli that inform about gains and losses. The main finding in that study is an outcome-related evoked component, most likely generated in medial-frontal brain regions. Crucially, this component is greater in amplitude when a subject's choice results in a loss than when it results in a gain. Moreover, choices made after losses are riskier and are associated with stronger loss-related activity than choices made after gains. Those results suggest that neuronal processes in medial-frontal brain areas may relate to mental processes involved in economic decisions. Gehring and Willoughby's observations may also contribute to a better understanding of how individual choices deviate from normative behaviour, according to which the context in which a choice occurs – here the sequence of gains and losses – should not affect the choice.

The neural basis of economic decision-making in the ultimatum game has been investigated by Sanfey et al. [18] using functional magnetic resonance imaging (fMRI). The subjects act as responders in a game where they can either accept or reject an offer made by a proposer who decides how to split a given sum of money between the two. Standard utility theory (e.g. [10]) predicts that the responders accept any offer in this game, on the grounds that any monetary gain is better than none. However, Sanfey et al. observe that 'unfair' or low offers (around 20% of the total for the responder; 80% for the proposer) have a significant chance of being rejected (suboptimal economic behaviour), in particular when the proposer is a human being as opposed to a computer. The fMRI data obtained in that study suggest that unfair offers activate both anterior insula and dorsolateral prefrontal cortices associated with emotion and cognition, respectively. Moreover, activity in anterior insula is significantly increased for rejected unfair offers, suggesting a key role for emotion in choice and decision-making.

Smith et al. [23] have used positron emission tomography (PET) to study neuronal responses in subjects choosing between risky games (known payoffs with well-defined probabilities) and ambiguous games (known payoffs with undefined probabilities). The main finding in that study is a behavioural interaction effect between outcome structure (risk/ambiguity) and payoff structure (loss/gain). This effect maps onto two different neuronal pathways: a dorsomedial neocortical and a ventromedial system. Interestingly, the interaction effect observed in that study is contrary to standard economic reasoning, where one assumes the evaluations of outcomes and payoffs to be independent. Thus, the results obtained by Smith et al. may further contribute to a better understanding of how individual behaviour deviates from normative predictions.

McCabe et al. [16] have employed fMRI to study the neuronal mechanisms underlying cooperation in two-person reciprocal exchange. The observations made in that study suggest that in a game of trust and reciprocity, cooperative subjects exhibit significantly more activity in the frontal pole, in particular Brodmann area 10 than non-cooperative players. The same brain region is implicated in 'theory of mind' processes—our normal ability to understand and reason about the beliefs and intentions of others. Thus, the observations made by McCabe et al. could bear on studies of pervasive developmental disorders, such as autism, which may be associated with deficits in theory of mind processes [19,24].

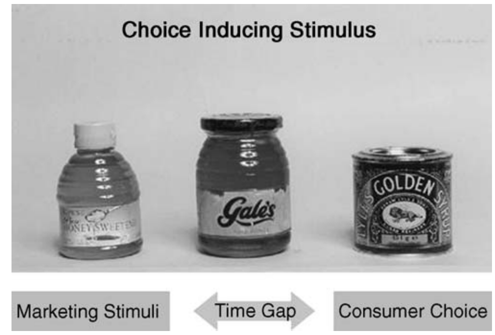

Fig. 1. Top: a choice inducing stimulus used by Braeutigam et al. [4,5] to model economically relevant behaviour (shopping choices) with real-life content. Bottom: a stylised view of consumer choice processes. Individual responses to marketing stimuli and actual choices interact in a time-separated fashion.

Evidently, game theory provides a rich theoretical background for neuroscientific investigations into a wide spectrum of economically relevant behaviour. However, it is debateable how the generalised incentive structures studied in such games map onto specific economic behaviour in a given real-life situation. Thus, researchers have recently begun to investigate the neuronal mechanisms underlying a more specific form of economically relevant behaviour, i.e. consumer choices concerning the selection and consumption of certain products. In this approach, one is interested in the relationship between marketing stimuli, most notably TV commercials, to which individuals are exposed; individual choices at the point-of-purchase (Fig. 1). Typically, there is a variable time gap between the two, making it very difficult to trace continuously the mechanisms underlying consumer choice behaviour.

Obviously, such behaviour is of immense importance. From an economic and/or marketing perspective, the aim is a better understanding of how mass consumer advertising of (established) brands affects brain systems. From a neuroscience perspective, the broad goal is a better understanding of both the neural mechanisms underlying the impact of affect and cognition on memory and the neural correlates of choice- and decision-making.

3. Neuronal responses to TV commercials

Ambler and Burne [1] have studied the impact of affect on memory of TV advertising, using behavioural measures to assess performance in tasks of image recognition and recall. The results obtained from that study suggest that under normal conditions, recognition and recall of affective TV material (using e.g. suspense, drama, humour) is superior to cognitive material (based on plain facts). Administration of propanolol reduces slightly recognition and recall of affective material, but increases substantially the recall of cognitive material. (Propanolol is a beta-adrenergic blocker drug used to treat anxiety, migraine, and heart irregularities. It is thought to interact with those brain regions, which mediate affect.) Ambler and Burne's results are broadly consistent with psychological models of affective primacy and mood congruency [9].

Assuming that memory processes are strongly involved in the connection between advertising inputs and behaviour, the findings obtained by Ambler and Burne can be placed somewhat between 'persuasive hierarchy' and (affective) 'reinforcement' models of advertising. The former see advertisements as providing information and reasons to buy and/or prefer the products advertised, assuming sequential mental processing according to learn first then feel and finally do. In contrast, reinforcement models view advertising as part of a continuing process where (initial) preferences are shaped, altered or reinforced by experience as well as rational and emotional aspects of marketing stimuli. The latter is in line with recent developments in neuroscience where emotion is considered to play an integral part in cognitive processes [7].

Ioannides et al. [14] have employed magnetoencephalography (MEG) to study the neuronal responses in subjects viewing the same TV advertisements as used by Ambler and Burne. Those MEG data suggest that cognitive advertisements activate predominately posterior parietal and superior prefrontal cortices, whereas affective material modulates activity in orbitofrontal cortices, the amygdala and the brainstem. The results seem to imply that cognitive rather than affective advertisements activate cortical centres associated with the executive control of working memory and maintenance of higher-order representations of complex visual material. Interestingly, neuronal responses to affective visual material seem to exhibit a greater inter-subject variability than responses to cognitive material.

Young [25] has used EEG to detect putative 'branding moments' within TV commercials. These moments comprise rather short periods within the advertisement, but are assumed to do much of the 'work' in actuating advertising performance measures. Young derives a rudimentary measure of (mental) engagement from fundamental α, β, and θ rhythms present in the EEG. He has found a high correlation between moments identified by brain waves and moments identified using a behavioural, attention-sensitive method of picture sorting. This may suggest that there are indeed moments of 'special' importance within a given TV commercial.

Using EEG, Silberstein et al. [20] and Rossiter et al. [17] have developed a technique to measure memory encoding of visual scenes presented in TV advertisements. The results obtained in those studies suggest that visual scenes (typically >1.5 s) that elicit the fastest brain activation in left frontal cortices are also better recognised. Those findings bear on theories of the transfer of visual information from short-term to long-term memory. In addition, those studies reinforce the notion that certain scenes within an advertisement are special in some sense.

4. Neuronal systems supporting consumer choice making

Arana et al. [2] have used PET to study neuronal responses in subjects choosing an item from a high-incentive food menu. The main results obtained in that study suggest that activation in the amygdala correlates with individual subjective ratings of incentive value, and that lateral orbitofrontal regions are instrumental in suppressing responses to alternative desirable items in order to select the most preferred one. Thus, Arana et al. provide some insight into the neuronal systems facilitating goal selection based on prospective incentive value of consumer items.

Erk et al. [8] have used fMRI to record neuronal responses in male subjects looking at pictures of cars and rating their attractiveness. That experiment does not involve actual choices. Instead it focuses on rewarding properties of cultural objects; such properties may influence choice making. Predictably, the subjects find sport cars more attractive than small cars or limousines. The fMRI data measured by Erk et al. reveals significantly more activity in orbitofrontal cortices, anterior cingulate regions, and occipital cortices for sport cars than for other cars. Those results corroborate the notion that strong social reinforcers activate reward-related brain regions.

In one still unpublished but widely discussed investigation, Montague et al. have used fMRI to study neuronal responses associated with preferences for soft drinks. During informed testing, as opposed to blind testing, subjects are more likely to prefer Coke over Pepsi, and this preference is reflected in increased neuronal activation in brain regions assumed to be involved in reward. The observations obtained by Montague et al. shed some light on the neuronal underpinnings of brand effects, which can strongly influence consumer choices.

Finally and reviewed in more detail here, Braeutigam et al. [4,5] have employed MEG to study the temporal interactions of the brain areas involved in consumer choice processes. A construct of choice predictability is used, which measures the relationship between the present, actual choice of an item and the relative frequency of choosing and using that particular item in the past (measured using a questionnaire). To some extent, choice predictability models the time gap between the individual's exposure to marketing stimuli and the actual choice. Behaviourally, predictable choices are faster than unpredictable choices, suggesting that the latter imply some form of difficulty in making a choice.

The main observation in those studies is a complex sequence of neural stages that manifest themselves as neurophysiological responses differentially sensitive to gender and predictability conditions (Fig. 2). Following choice inducing stimuli, a first neuronal stage (W) can be identified

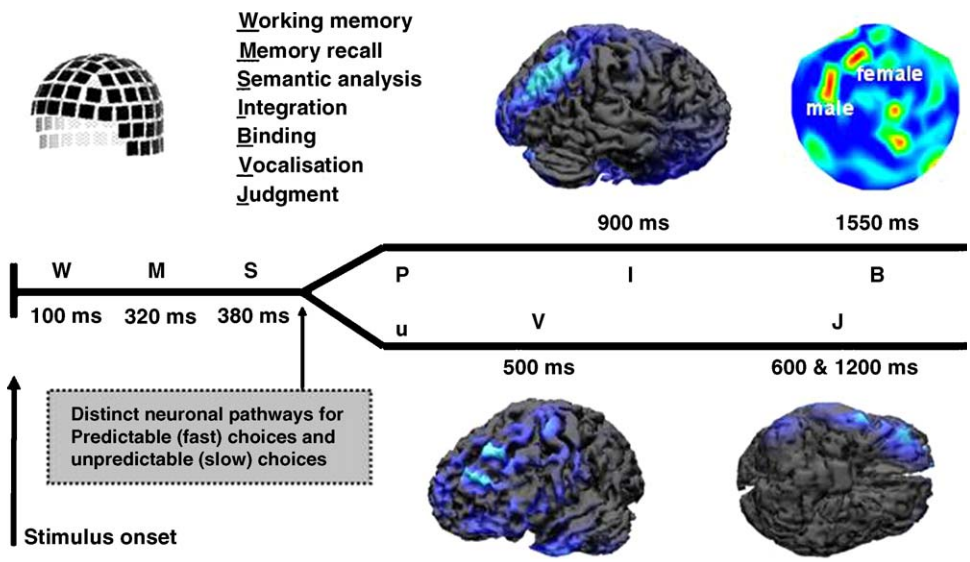

Fig. 2. Neural stages associated with choice making. Choice inducing stimuli elicit a complex sequence of neural stages that manifest themselves as neurophysiological responses differentially sensitive to gender and predictability conditions. Predictable choices are those where the item chosen is familiar and has been often bought or used in the past. Top left: the helmet-shaped array of MEG detectors used to record the dynamics of neuronal responses. Each of the 102 plates symbolises two, first-order gradiometers that are most sensitive to directly underlying neural currents. Top right: the map shows the distribution of coherent γ-band activity at long latency (blue: low; red: high). For the presentation of data, the detectors have been projected into two dimensions (right ear on the right, front at the top). Coherent γ-oscillations over left prefrontal cortices are gender-related. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

around 100 ms after stimulus onset over occipital cortices. The latency and topography of this activity are consistent with a variety of previous studies of visual processing, indicating that this neuronal stage is common to a wider class of processes. However, this stage (W) does differentiate between making a consumer choice and discriminating the height of consumer items, suggesting a higher working memory load when making a choice.

The sequence continues with two, partially interrelated neuronal stages (M and S) observed between about 280 and 400 ms after stimulus onset. At this time, selective attention is paid to the images as they are being identified, recognised and compared with data recalled from memories of the relevant brands and products. The memories may involve actual experience of using, purchasing or seeing advertisements for the specific brands.

At about the same latency, the evoked responses of women and men differ markedly: women show stronger neuronal activation in left posterior brain regions; whereas men exhibit stronger activation in right temporal brain areas. These gender-related differences hold for both choosing an item and discriminating its height. This observation suggests that, at this stage of processing, women tend to employ a strategy based on category-specific knowledge, whereas men tend to employ a strategy based on spatial memories (see [15] for a general discussion of gender-related differences in strategies). Reliance on default, task-independent strategies may explain to some extent why, in those studies, women choose faster, but discriminate height slower than men.

At latency greater than 500 ms, two distinct neuronal pathways can be identified according to the choice predictability condition. Predictable choices, i.e. those where the item chosen is familiar and has been often bought or used in the past, elicit strong neuronal activation in right parietal cortices around 900 after stimulus onset (I). At even longer latency, predictable choices elicit strong coherent γ-oscillations over left prefrontal cortices (B).

Parietal cortices receive input from many sources, making them available for second-order mapping, e.g. they are engaged in relating spatial to other representations. Also, lesions of the right parietal cortex may profoundly damage intentionality. This may suggest that predictable stimuli relate to choices where the outcome is consistent with some form of intention based on previous experience.

The late γ-oscillations (B) may indicate the binding of large-scale, functional neuronal assemblies [21] when familiarity or preference is high, thereby corroborating the notion that predictable choices relate to highly integrative, intention-based processes. The difference between women and men may reinforce the notion of differential strategies employed by the two groups.

In contrast to predictable choices, unpredictable choices, i.e. those where the item chosen is unfamiliar, elicit strong neuronal activation in right inferior frontal cortices (V) at around 500 ms, and in left orbital cortices (J) at around 600 and 1200 ms after stimulus onset. In the case of V, the responses are consistent with activity in Broca's area, which is involved in the expression of speech as well as in silent vocalisation occurring during the interpretation of visual pre-

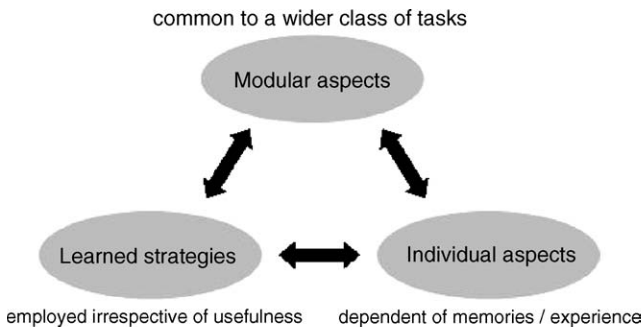

Fig. 3. Mental processes at the point-of-purchase. Making a brand choice has modular aspects, where the underlying processes are common to a wider class of tasks. It has aspects related to learned strategies. Moreover and crucially it has aspects specific to individual experience and the choice to be made.

sentations. Thus, the response at this latency may indicate an increased tendency to vocalise (silently and possibly unconsciously) as part of a strategy, which aids choice making when a choice is difficult or perceived as being difficult. Apparently, this putative vocalisation does not rely on obvious product attributes, such as colour or shape.

Regarding the activity in orbital cortices (J), one may assume that unpredictable choices require additional evaluation of reward values compared to predictable choices, where the reward may already be implied by the familiarity with the item. This follows from a variety of observations implying orbital cortices in decision-making based on reward values, and in gating affective information regarding decision options. In this context, the broader concept of proper judgement may also be relevant, as orbitofrontal lesions may entail poor judgement. Thus, proper judgement might of particular relevance when items are relatively unknown.

Taken together, these investigations are beginning to elucidate the complex distributed neuronal networks related to the highly integrative processes of consumer choice behaviour, where even seemingly simple choices may imply far from simple neuronal mechanisms (Fig. 3). This is consistent with recent views in psychology and consumer research [3,22]. Accordingly, choice making is considered a highly conditional form of information processing, sensitive to task complexity, perceived justification, anticipated regret, time pressure, framing, self-esteem, and a variety of other contextual factors.

5. Concluding remarks

Neuroeconomics is still in its infancy, but it has had an impressive start. Although incomplete, the evidence available to date is beginning to clarify with the possibility that neuroeconomic methodology might eventually trace whole processes of economically relevant behaviour.

For example, it might be possible to identify robust descriptors of intertemporal choice, i.e. the way in which consumers arrange their consumption over time, and how concerns about future consequences of their decision may influence present choices. Insight about the role of emotion in choice-making under conditions of risk and uncertainty, as obtained from approaches related to game theory, should permit to refine standard models of intertemporal choice as a rational trade-off of some form of utility between points separated in time.

It may also be possible to identify the individual stages between the point of perceiving an advertisement and the point of making a buying decision. Even, the broader concept of brand equity may become more accessible, as the existence of neuronal pathways specific to brand salience is suggested by evidence already accumulated.

Clearly, neuroeconomics will have some impact on fundamental research in a broader spectrum of scientific fields, either by providing new methodologies or by simply challenging scientists' intuitions. However, only time will tell whether neuroeconomics will eventually provide acceptable tools for commercial activities.

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