SELECTED READINGS IN
CONSUMER NEUROSCIENCE & NEUROMARKETING

2nd edition

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2014

OVERVIEW AND INTRODUCTION

Neuromarketing and Consumer Neuroscience are novel academic and commercial disciplines, but the topic has already been debated for many years. While many articles have focused on the coming neuromarketing trend, only today we see the actual realization of the use of neuroscience tools in consumer insights and marketing.

We should distinguish between *neuromarketing*, which is a commercial use of neuroscience tools to improve consumer insights and marketing effects; and *consumer neuroscience*, which is more an academic exercise, where the aim is to use neuroscience to better understand consumer psychology and behavior.

A central overview paper is Plassmann, Ramsøy & Milosavljevic (2012). This paper both reviews the field as a whole, but also suggests a consumer/branding model that can be used as a map when reading other materials.

Neuromarketing: Who Decides What You Buy?

Vicky Phan

People who have found themselves indulging in clothing trends, jiving to mainstream music, or frequenting the local Starbucks can see that companies spend billions a year researching how to perpetuate such conformity. What people may not know is that the advertising itself is becoming far more scientifically advanced. Neuromarketing is an emerging branch of neuroscience in which researchers use medical technology to determine consumer reactions to particular brands, slogans, and advertisements. By observing brain activity, researchers in lab-coats can predict whether you prefer Pepsi or Coke more accurately than you can. Critics have already begun to denounce the idea for its intrusiveness; however, though the field is already highly controversial, there is no doubt that its continuing development will ultimately have a profound impact on consumerism and the overall study of human behavior.

In America's capitalist society, advertisements drive our everyday lives. While the idea of actual 'mind control' may seem far-fetched and unrealistic, the fact remains that the marketing industry has had a firm grasp over the American perception of everything from smoking to sex education. Our current concept of marketing, with its image-based ads, department store window displays, and catchy TV jingles, actually did not exist before the mid-1900s. Starting in the 1950s, fast food industries teamed up with processed food companies to shape the concept of what we now understand to be McDonald's and Burger King 'cuisine' [1]. In the 1980s, the invention of cable TV, VCRs, and remote controls revolutionized the advertising world, as it allowed the media to become much more easily accessible to average families [2]. These developments soon allowed advertising executives to cater to the public's general interests and subconscious desires.

Malls are a prime example of where plenty of Neuromarketing takes place, such as here in Plaza Blok M. Mall in Jakarta, Indonesia. Reproduced from [8].

> "Advertising is becoming more scientifically advanced"

Over time, the marketing industry has learned to exploit our responses to a wide variety of images and concepts. It is not difficult, however, to recognize and understand the methodology behind these marketing campaigns. The strategic placement of Victoria's Secret models into Super Bowl halftime commercials has an obvious sexual appeal. Celebrities are paid to endorse particular products, since their personal testimonies make any company just seem better. Even the catchiness of a jingle makes us more likely to pause when we see a bag of Kit Kats or Goldfish crackers. But somehow, despite the almost laughably obvious marketing methods, we still respond positively to popular brands and catchy slogans—tools crafted purposely by marketing executives to catch our attention. This tendency to gravitate toward familiar symbols and phrases is the driving force behind the concept of neuromarketing. Scientists are focusing on these natural inclinations, using brain imaging techniques to gauge consumer reactions and expand upon more common, traditional methods, such as surveys and focus groups [3].

There are multiple types of brain-imaging technologies used in current neuromarketing studies: fMRI (functional magnetic resonance imaging), QEEG (quantitative electroencephalography), and MEG (magnetoencephalography). However, the fMRI method is currently the most popular amongst marketing companies, since it utilizes mainstream technology to produce clear images of real-time brain activity [4]. As an imaging technique, the process also translates results more easily into layman's terms: rather than presenting data in strings of incomprehensible numbers, fMRI technology gives people the opportunity to actually visualize the activity patterns in their brains [5].

fMRI works by gauging amounts of hemoglobin, the oxygen-carrier on red blood cells, in certain parts of the body.

An example of a functional MRI Scanner: UC Berkeley's Varian 4T. Reproduced from [9].

For mental imaging, the machine "measures the amount of oxygenated blood throughout the brain and can pinpoint an area as small as one millimeter" [6]. The harder a specific area of the brain is working, the more oxygen it requires; so when the fMRI machine scans the brain, it picks up on the areas with concentrated amounts of hemoglobin and displays them as regions of high mental activity on the computer screen. These computer images are what researchers use to identify the parts of the brain being utilized.

> "Researchers can predict whether you prefer Pepsi or Coke"

For neuromarketing, scientists use fMRI to observe areas of the brain that respond to consumer-based stimuli, such as particular brands, price ranges, and even taste preferences [4]. The researchers have found that the regions in the brain corresponding to the prediction of gain and loss (the nucleus accumbens and the insula, respectively) are indicators of behavior and reaction to finances and economics [3]. In other words, we make our decisions based on cursory judgments of whether we will gain or lose money when purchasing a product.

Though fMRI technology was first used for marketing purposes in the late 1990s, the actual term "neuromarketing" was only just coined by Erasmus University's Professor Ale Smidts in 2002, and the general premise of the research was not widely recognized until the first neuromarketing conference in 2004. However, the potential results and subsequent discoveries about human responses to the media are causing this infant branch of science to rapidly gain popularity [4].

The infamous "Pepsi vs. Coca-Cola" experiment, in which scientists studied the motivation behind brand preferences, was what first put early neuromarketing in the spotlight. The researchers observed that although Pepsi and Coke are essentially identical, people often favor one over the other. They subsequently sought to investigate how cultural messages work to guide our perception of products as simple as everyday beverages [7].

The experiment was simple: there were two taste tests—one blind and one in which subjects knew which beverage was which—and the researchers observed the corresponding brain activity. When volunteers were unaware of which brand they were drinking, the fMRI showed activation in the ventromedial prefrontal cortex, a basic "reward center," when they drank Pepsi. However, when the subjects knew which soda was which, the scans showed brain activity in the hippocampus, midbrain, and dorsolateral prefrontal cortex (which are centers for memory and emotion), in favor of Coke. So essentially, people actually liked the taste of Pepsi, but they were more inclined to believe that they preferred Coke, based off of nostalgia and emotional connections. From these results, the researchers determined that "a preference for Coke is more influenced by the brand image than by the taste itself" [4].

The outcome of these studies is intriguing and even a bit entertaining; however, upon a second glance, it can also be alarming. The fact that a series of ads could actually cause your brain to believe something that contradicts what the rest of your body thinks is unnerving, to say the least. Because of this, there is a growing amount of controversy surrounding the subject of neuromarketing.

> **"The amount of research we have today is still minimal"**

One of the more paranoid views on this subject is that people may eventually fall victim to an uncontrollable force compelling them to think or act a certain way. While it is still too early for anyone to make definitive legal restrictions on the technology, people are already anxious about its subliminal undermining of free will. Commercial Alert, an organization protesting the development of neuromarketing, has expressed concern over the use of medical technology for advertising purposes, claiming that brain scans "subjugate the mind and use it for commercial gain" [6]. The group has argued that any power-hungry neuroscientist could use these studies to manipulate the public's desire for specific products, or that the research could be used in the realm of politics and propaganda, dragging us down a slippery slope toward totalitarianism and war [6].

On the other hand, more optimistic observers contend that the studies could in fact be beneficial for our society. For example, neuromarketing has the potential to be a great boon to public service industries by helping them understand how to improve anti-drug or anti-smoking campaigns [3]. By utilizing these new advancements in neuroscience, we could educate the public more effectively; we would know how to better present information to inattentive children, how to best impact teenagers having unprotected sex, and how to inform the public about conserving energy. The road toward understanding consumer responses opens paths to understanding human behavior in general, which could be invaluable to the development of our global community.

Despite the ongoing debate about the ethics of neuromarketing, the amount of research we have today is still minimal, and the results are leading researchers to believe that nobody currently has the power to fully alter our personal opinions and preferences. Most professionals are presently under the impression that this field is underdeveloped and that researchers are hyping it up using neuroscience, a current 'hot topic,' to elicit extra funding [3]. However, though there isn't much evidence so far to prove that the imaging studies will have a drastic effect on consumers, researchers agree that even a slight edge in the competition to win the public's attention would be worth the cost for many advertisers.

Do you really prefer the taste of Coke over Pepsi, or do you just prefer the brand? Reproduced from [10].

Like all new scientific advancements, neuromarketing is thus far merely a research tool. Marketing expert Martin Lindstrom views the area of study as "simply an instrument used to help us decode what we as consumers are already thinking about when we're confronted with a product or a brand" [6]. In either case, the studies would reveal more intimate details about human thought-processing and decision-making on a broader scale.

So the question remains: Is neuromarketing a step forward in understanding the human mind, or is it an invasive marketing ploy geared toward demolishing privacy and personal opinion? As of right now, nobody seems to be sure. Though there is always the possibility that this technology could be exploited for immoral purposes, one could say that any scientific discovery has the same potential for misuse in the wrong hands. The best way to limit the media's influence is to educate ourselves about the science and to be more deliberate with our decisions; a well-educated consumer is less likely to make rash judgments based on unfounded claims. Still, knowing that companies have people researching how our minds work probably won't stop most of us from pining after all of the latest products —we will always have commercialism to thank for that. ■

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'Neuromarketing': can science predict what we'll buy?

Advertisers have long used science to peer into consumers' brains; today 'neuromarketing' has given them the power to delve into our subconscious, finds Alex Hannaford

Neuromarketing Illustration Photo: NEIL WEBB

By Alex Hannaford

7:00AM BST 13 Apr 2013

In 2008, a team of scientists in Germany published a study showing how the brain unconsciously prepares our decisions: that several seconds before we consciously decide what we're going to do, its outcome can be predicted by looking at unconscious activity in our grey matter.

The researchers, from the Max Planck Institute in Leipzig, told participants in the study that they could freely decide if they wanted to press a button with their left or right hands, whenever they wanted, but they had to remember at which time they felt they had made up their mind. They found that it was possible to predict from their brain signals which option they would choose seven seconds before they consciously made their decision.

"It's all very Minority Report," Steve Sands says, referring to the Tom Cruise film in which a special police department known as "PreCrime" tracks down criminals based on knowledge provided by psychics. "But we're not too far from that now."

In fact, it's incredible how close Sands is. For the past 20 years, from his lab in El Paso, Texas, he's been using technology to look inside our heads and show what consumers really feel, as opposed to what marketers think we feel. Using EEG tests (essentially a plastic swimming cap complete with electrodes to measure brain signals), functional magnetic resonance imaging (fMRI, which measures brain activity by looking at changes in blood flow), and eye-tracking technology, neuromarketing, as it's known, has completely revolutionised the worlds of advertising and marketing.

Sands sits opposite me, looking relaxed in a white shirt and jeans. In his office there's a framed 1995 cover of Newsweek on the wall with the headline: "The new science of the brain: why men and women think differently".

“That’s the first cap I made,” he says of the EEG-outfitted woman on the cover. Sands used to work with rhesus monkeys in the psychology department at the University of Texas. When his lab closed down he started Neuroscan, which became one of the world’s largest suppliers of EEG equipment to research scientists. After selling Neuroscan, Sands and his team started to use the same machines to look at the brain’s response to advertising.

He recently finished a one-and-a-half year project for POPAI, an international trade association, for which Sands’s researchers used eye-tracking and EEG technology to gain insight into shopper habits. The results were fascinating. Forget scrawled shopping lists on the back of an envelope: Sands found that the vast majority (76 per cent) of US grocery shoppers make their purchase decisions in-store, and that shoppers using non-cash payment methods are most likely to make impulse purchases. So shelf-placement and in-store marketing are more crucial than ever.

Sands's team would pop a pair of eye-tracking glasses on their volunteers (which were in turn wired up to a MacBook Air, carried in a rucksack), then send them off around the store to do their shopping. The researchers then waded through three terabytes of data and analysed 80,000 eye movements from the shoppers that agreed to take part in the study. Sands says a single eye movement takes just 200 milliseconds, the time a product in store gets to persuade a shopper to buy it. "And it only takes one eye movement to change their behaviour," he says.

The researchers noted what Sands calls "approach-avoidance" taking place in the sweets and chocolate aisle, and that the eyes sought out the shopper's favourite sweets, even though they may have decided not to succumb to buying them. "Twenty per cent of eye movements relate to what you're going to buy. The rest are alternatives," Sands says. "We'd watch them pick up a packet of doughnuts, put them back, then walk away. Some came back later and put them in their shopping cart."

Sands says one interesting observation was that while the fizzy drinks aisle was the most organised in the entire supermarket, the sweets and chocolate aisle was the least: what Sands describes as "a potpourri of different sizes, shapes and brands that makes a lot of noise".

"Our brain is looking for something simple, and it's happiest when it finds what it's looking for," he says. "Candy is unusually noisy. The industry doesn't organise itself as well as the canned drinks one does. Visual clutter really does matter. All you're doing is frustrating the brain."

The neuromarketing industry isn't just interested in what makes shoppers choose the products they do in the supermarket. Much of their work is done before they've even walked through the door.

Each year, Sands Research screens the commercials that have aired during the Super Bowl, the FA Cup of American football, to a test group of around 30 people. As in other tests, his team wires each person up to an EEG machine to monitor their brain signals, and each wears a pair of eye-tracking glasses so the Sands researchers can see what, specifically, they're focusing on.

Super Bowl ads are the most sought-after and expensive slots in the industry. In 2011, among the companies vying for hearts, minds, and cold, hard cash, were Coca-Cola and Volkswagen, both of which came out with brilliant spots. Coca-Cola's featured two border guards in different military uniforms at some godforsaken desert outpost, who bond over a bottle of Coke.

As for Volkswagen, their ad for the VW Passat saw a pint-size Darth Vader walking down the hallway of his suburban home, attempting to use "The Force" on his parents' exercise bike, the washing machine — even the family dog. When his father arrived home in his Passat, the boy was almost ready to admit defeat: he ran outside and tried one last time to use his powers on the car, while inside the house his dad saw what he was trying to do and started the car's ignition with the remote control. The boy turned around, astonished that The Force worked.

Of all the ads Sands has ever tested, The Force was, to use the American vernacular, off the charts, achieving the highest "neuro-engagement score" ever. Adweek named it 2011's best commercial; it won two Gold Lions at Cannes. Before the game even began it had attracted 12 million YouTube views. At the time of writing it's had almost 58 million.

The man behind the advert was Deutsch LA's Doug Van Praet. He says Sands's research demonstrated that The Force ad had an inordinate capacity to engage the brain. “It galvanised our attention, our engagement and our emotion, and it turned out to be a very powerful predictor of end-market performance.” As he writes in his book Unconscious Branding: How Neuroscience Can Empower (and Inspire) Marketing, “it drove significant increases in purchase consideration, upped traffic to the VW website by half, and contributed to a hugely successful sales year for the brand.”

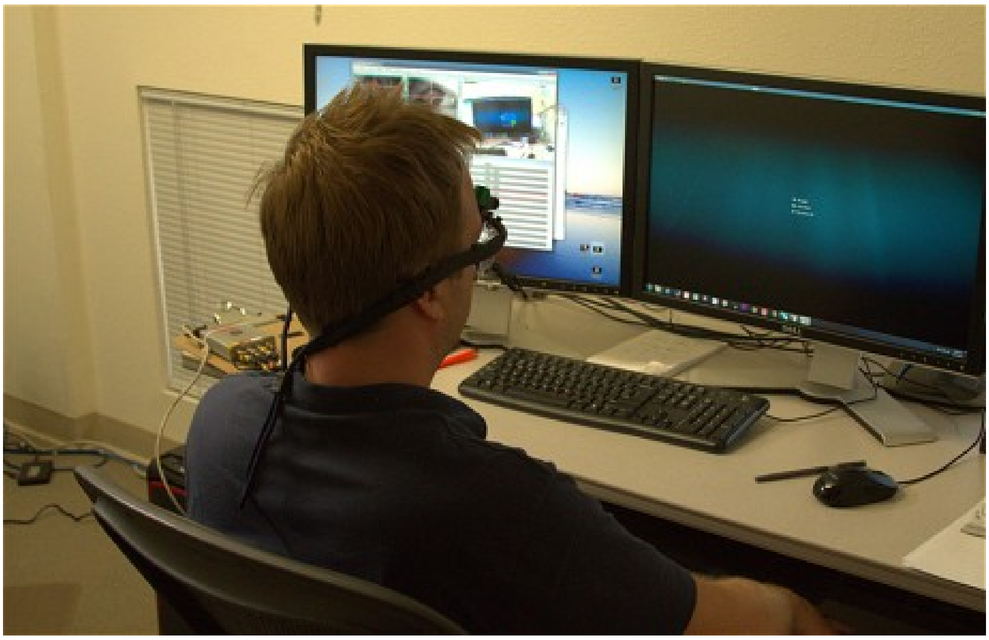
Amazingly, it’s taken big business 20-plus years to realise how effective neuromarketing can be. British psychologist Dr David Lewis-Hodgson founded one of the earliest firms, Mindlab International, in the UK in 1988. One of his early “products” was Mindscan, a piece of software which measured the brain’s responses to marketing messages, working on the premise: “What can’t speak, can’t lie.”

Hollywood’s interest was piqued by a 2012 study by Innerscope Research. They showed 40 film trailers to more than 1,000 people, measuring their heart rate, breathing, how much they sweat and motion responses – as well as what they focused on using eye-tracking technology.

Using the results, they found they could predict box office hits. According to Fast Company magazine, “If a film’s trailer fails to reach a specific emotional engagement threshold (65), it will very likely generate less than $10 million in revenue on opening weekend.” But a film whose trailer exceeds an engagement threshold of 80 “will very likely earn more than $20 million the first weekend”. Studios such as Fox and Paramount have now started taking neuromarketing very seriously.

And in January, the research agency Millward Brown announced its clients Unilever and Coca-Cola would be using facial coding technology – where emotions are tracked in facial expressions – in all their advertising testing in 2013. According to the company, this would “automatically interpret viewers’ emotional and cognitive states, moment by moment”.

As well as gauging an audience’s reaction to Super Bowl commercials and tracking shoppers in supermarkets, Sands Research also tests ads before they’ve aired, letting agencies know what works and what doesn’t. “By looking at the EEG readout we can tell whether they’re disengaged or engaged,” Sands says. “And we’ve found that storyline wins every time. If you want to lose someone’s attention, have several storylines in your commercial.”



In a small office adjoining his, Sands sits me in front of two computer monitors and hooks me up to a pair of eye-tracking glasses. On the left-hand screen I can see my eyes, with a target indicating where my pupils are as they flit from left to right; on the right-hand screen is an ad for the Hyundai Sonata hybrid. The places on the screen where my eyes land are denoted by a frenetic green dot that jumps around at incredible speeds. When we play back the recording of my viewing session, I seem to have focused on exactly what the advertisers intended: initially the various characters in the commercial, but by far the longest spell is devoted to eyeing up the car itself.

Only when he places an EEG cap on the head of his test subjects, however, can Sands really tell whether they like what they're seeing. He says he once looked at an ad for a telecoms company and the panel he showed it to had such a negative reaction he had to tell the agency to think again. "There were two competing storylines," he says. "Young creatives think they're multitaskers, and this influences how they design things. And it doesn't work. Simplicity wins every time."

Using EEG, Sands records the electrical activity of the brain along the scalp. In ads that really engage an audience, a large portion of the cerebral cortex, the part of the brain that plays a role in memory, attention, awareness and thought, is activated. Sands says that during portions of an ad that "work", the frontal lobe, which deals with emotion and processes information, lights up. On the computer screen, Sands sees a line, much the same as you see on a heart monitor, which shows the exact moments during the commercial that different parts of the brain are engaged.

Sands's company has also been using EEG technology to gauge taste and smell. "From our experience, people usually tell market researchers what they think they want to hear. We're social animals and we don't want to offend anyone." But by looking at the brain's response to scents, Sands can tell exactly which fragrance you prefer.

Van Praet acknowledges that neuromarketing is not without its pitfalls; that in studying the human brain, we have to be comfortable with paradox and contradictions. For example, he says you can like an ad and it can create a positive emotion, but if it doesn't leave you with an appropriate and corresponding set of associations and emotions for that product, it's no use to the company trying to sell it. He gives an example: Quiznos, the US sandwich chain that now has some locations in the UK. "They ran an ad that featured cartoonlike rodents, and it was funny as heck," Van Praet says. "It was very likeable and engaging and people remembered it. But there's a bad association between rats and food. It wasn't very successful."

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Neuromarketing: Tapping Into the 'Pleasure Center' of Consumers

It's easy for businesses to keep track of what we buy, but harder to figure out why. Enter a nascent field called neuromarketing, which uses the tools of neuroscience to determine why we prefer some products over others. Harvard Business School marketing professor Uma R. Karmarkar explains how raw brain data is helping researchers unlock the mysteries of consumer choice in this article by Carmen Nobel, which first appeared on the HBS Working Knowledge website.

In the early 1950s, two scientists at McGill University inadvertently discovered an area of the rodent brain dubbed "the pleasure center," located deep in the nucleus accumbens. When a group of lab rats had the opportunity to stimulate their own pleasure centers via a lever-activated electrical current, they pressed the lever over and over again, hundreds of times per hour, forgoing food or sleep, until many of them dropped dead from exhaustion. Further research found pleasure centers exist in human brains, too.


(Photo credit: Wikipedia)

Most humans are a little more complicated than rats, of course. But we are largely motivated by what makes us feel good, especially when it comes to our purchasing decisions. To that end, many major corporations have begun to take special interest in how understanding the human brain can help them better understand consumers. Enter a nascent but fast-growing field called neuromarketing, which uses brain-tracking tools to determine why we prefer some products over others.

"People are fairly good at expressing what they want, what they like, or even how much they will pay for an item," says Uma R. Karmarkar, an assistant professor at Harvard Business School who sports PhDs in both marketing and neuroscience. "But they aren't very good at accessing where that value comes from, or how and when it is influenced by factors like store displays or brands. [Neuroscience] can help us understand those hidden elements of the decision process."

To be sure, there is a clear difference between the goals of academia and the goals of a corporation in utilizing neuroscience. For Karmarkar, her work falls into the category of decision neuroscience, which is the study of what our brains do as we make choices. She harbors no motive other than to understand that process and its implications for behavior, and draws on concepts and techniques from neuroscience to inform her research in marketing.

For corporations, on the other hand, the science is a means to an end goal of selling more stuff. But the tools, once restricted to biomedical research, are largely the same. And Karmarkar expects brain data to play a key role in future research on consumer choice.

(In a recent HBS industry background note on neuromarketing, she discusses the techniques that have helped researchers decode secrets such as why people love artificially colored snack food and how to predict whether a pop song will be a hit or a flop.)

Tricks of the trade

When tracking brain functions, neuroscientists generally use either electroencephalography (EEG) or functional magnetic resonance imaging (fMRI) technology. EEG measures fluctuations in the electrical activity directly below the scalp, which occurs as a result of neural activity. By attaching electrodes to subjects' heads and evaluating the electrical patterns of their brain waves, researchers can track the intensity of visceral responses such as anger, lust, disgust, and excitement.

Karmarkar cites the example of junk-food giant Frito-Lay, which in 2008 hired a neuromarketing firm to look into how consumers respond to Cheetos, the top-selling brand of cheese puffs in the United States. Using EEG technology on a group of willing subjects, the firm determined that consumers respond strongly to the fact that eating Cheetos turns their fingers orange with residual cheese dust. In her background note, Karmarkar cites an article in the August 2011 issue of *Fast Company*, which describes how the EEG patterns indicated "a sense of giddy subversion that consumers enjoy over the messiness of the product."

That data in hand, Frito-Lay moved ahead with an ad campaign called "The Orange Underground," featuring a series of 30-second TV spots in which the Cheetos mascot, Chester Cheetah, encourages consumers to commit subversive acts with Cheetos. (In one commercial, an airline passenger quietly sticks Cheetos up the nostrils of a snoring seatmate. Problem solved.) The campaign garnered Frito-Lay a 2009 Grand Ogilvy Award from the Advertising Research Foundation.

EEG vs. fMRI

Karmarkar notes that EEG and fMRI have different strengths and weaknesses, and that EEG has some limitations in its reach. "The cap of electrodes sits on the surface of your head, so you're never going to get to the deep areas of the brain with EEG," Karmarkar explains.

The fMRI uses a giant magnet, often 3 Teslas strong, to track the blood flow throughout the brain as test subjects respond to visual, audio, or even taste cues. The technology has its own logistical limitations. Running an fMRI scanner costs researchers up to $1,000 per hour, and studies often use 20-30 subjects, Karmarkar says. And while EEG lets subjects move around during testing, fMRI requires them to lie very still inside a machine that can be intimidating.

"This is a sophisticated piece of medical equipment that exerts a very strong magnetic field at all times, and it's important to be very careful around it," Karmarkar says. "For example, you cannot take metal into a magnet room!"

But fMRI is invaluable to neuroscience and neuromarketing in that it gives researchers a view into the aforementioned pleasure center. "The more desirable something is, the more significant the changes in blood flow in that part of the brain," Karmarkar says. "Studies have shown activity in that brain area can predict the future popularity of a product or experience."

In her note, Karmarkar discusses research by Emory University's Gregory Berns and Sara Moore, who connected the dots between neural activity and success in the music industry. In a seminal lab experiment, teenagers listened to a series of new, relatively unknown songs while lying inside an fMRI machine. The researchers found that the activity within the adolescents' pleasure centers correlated with whether a song achieved eventual commercial success. The OneRepublic song Apologize performed especially well in both the brain scans and the market.

"Importantly, Berns and Moore also asked their original study participants how much they liked the songs they heard, but those responses were not able to predict sales," Karmarker's note states, illustrating the marketing value of subconscious cerebral data.

Neuromarketing can provide important but complex data to companies that target a global audience. While product testing may provide similar neural responses in American and Asian subjects, for instance, the marketing implications may be very different.

"Expressions of happiness in some Eastern cultures are expressed as a sense of calm or peace, whereas in some Western cultures, happiness means jumping around with joy and excitement," Karmarkar explains. "So you might get two totally different fMRI results that actually mean the same thing—or you may have two totally different stimuli create the desired effect of profound happiness, but for different reasons. If you get an excited effect in an Eastern market, it may not be a good outcome, even though that was the effect you wanted in a Western market. On the other hand, a sense of peace might be misconstrued as a failure."

Valid concerns

For businesses looking to enlist the services of a neuromarketing company, she advises watching out for consultanting firms that claim to offer such services but don't really have the technology or expertise to back up the claim. Rather, look for a company whose employees have a healthy, skeptical respect for neuroscience.

"The rubric for picking a good [firm] is making sure it was started by a scientist, or has a good science advisory board," Karmarkar says. "This is a field where scientists are very, very skeptical, and we should be. It's easy to feel like you've discovered some big, important truth when you see that the brain has done something that correlates with behavior. And it's just as easy to overstate our conclusions."

For consumers, the idea of giving advertisers additional insight into the subconscious mind might prompt privacy concerns. But Karmarkar says that the research is more about understanding brain waves, not controlling them.

"It's similar to the concerns about genetics," she explains. "People wonder, now that we can map the genome, are we going to manipulate the genome? I think it's a valid and important question to ask. But I don't think it's the direction that companies should take or that academics are taking."

She adds, though, that we need to keep in mind that advertisers have been successfully controlling our brains, to some extent, since long before the existence of EEG or fMRI technology.

"Imagine Angelina Jolie biting into an apple," she says. "It's the juiciest apple ever. She's licking her lips. There's juice running down her chin. Now if I spend some time setting up that scenario and then follow up by asking you to tell me how much you like Mac computers, I *promise* you that you'll rate them more highly than you would have if I hadn't just talked about how great that apple was for Angelina Jolie. So, yes, I just used your brain to manipulate you. Sex sells, and it has since the dawn of time. It sells because it engages that pleasurable reward center of your brain. As academics, neuroscience just helps us to understand how."

WK

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This article is available online at:
http://www.forbes.com/sites/hbsworkingknowledge/2013/02/01/neuromarketing-tapping-into-the-pleasure-center-of-consumers/

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Journal of Consumer Psychology 22 (2012) 18 – 36

Journal of CONSUMER PSYCHOLOGY

Branding the brain: A critical review and outlook

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Received 2 February 2011; received in revised form 28 November 2011; accepted 30 November 2011
Available online 21 January 2012

Abstract

The application of neuroscience to marketing, and in particular to the consumer psychology of brands, has gained popularity over the past decade in the academic and the corporate world. In this paper, we provide an overview of the current and previous research in this area and explain why researchers and practitioners alike are excited about applying neuroscience to the consumer psychology of brands. We identify critical issues of past research and discuss how to address these issues in future research. We conclude with our vision of the future potential of research at the intersection of neuroscience and consumer psychology.

Keywords: Consumer neuroscience; Neuromarketing; Branding; Attention; Memory; Value

Introduction

The application of neuroscience to consumer psychology, and in particular to branding, has gained popularity over the past decade in academic research and business practice: in the last decade the number of publications in top marketing journals and Google references around this topic has grown exponentially and the same holds for the number of neuromarketing companies founded (see Fig. 1).

The birth of the field of consumer neuroscience has generated wide-ranging, ongoing debates of whether this hybrid field benefits its parent disciplines (consumer psychology and neuroscience) and, within them, what forms these benefits might take (Ariely & Berns, 2010; Kenning & Plassmann, 2008; Lee, Broderick, & Chamberlain, 2007; Plassmann, Ambler, Braeutigam, & Kenning, 2007). The goal of consumer neuroscience is to adapt methods and theories from neuroscience—combined with behavioral theories, models, and tested experimental designs from consumer psychology and related disciplines such as behavioral decision sciences—to develop a neuropsychologically sound theory to understand consumer behavior.

To appreciate the value of combining neuroscience with consumer psychology, it is important to understand the broad range of insights available from neuroscience. Neuroscience is the study of the nervous system that seeks to understand the biological basis of behavior. This range of insights is too broad for the study of consumer psychology, which is why in the following paragraphs we briefly clarify which areas within neuroscience are the most relevant for consumer neuroscience.

Neuroscience research ranges from studying single cells (cellular neuroscience) to studying how different brain areas or complex brain systems, such as the visual system, interact (systems neuroscience). Because of the complexity of consumer behavior,

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1057-7408/$ -see front matter
doi:10.1016/j.jcps.2011.11.010

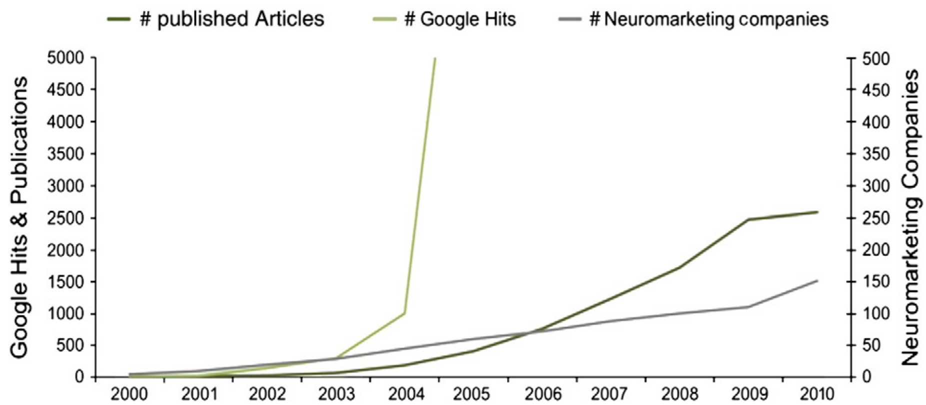

Fig. 1. Growth of research applying neuroscience to marketing over time.

insights from systems neuroscience are crucial for consumer neuroscience, whereas those from cellular neuroscience currently are limited.

Neuroscientists study species ranging from the primitive (such as sea snails, fruit flies, and leeches) to the complex (such as mammals and primates). Most consumer neuroscience studies investigate mental processes in human subjects, but a few selected studies also use non-human primates or small animals such as monkeys as subject populations. [1]

Another important distinction is between clinical and non-clinical research in neuroscience. Clinical research, known as neurology, studies how nervous system disorders, trauma, tumors and injuries affect cognition, emotion, and behavior in patients as compared to healthy subject populations. In general, consumer neuroscience studies consumer responses in healthy subject populations. [2]

A last critical distinction is between consumer neuroscience, which refers to academic research at the intersection of neuroscience and consumer psychology, and neuromarketing, which refers to practitioner and commercial interest in neurophysiological tools, such as eye tracking, skin conductance, electroencephalography (EEG), and functional magnetic resonance imaging (fMRI), to conduct company-specific market research. Neuromarketing has received considerable attention in the corporate world, and the growth of neuromarketing companies over the last decade has been impressive (see Fig. 1).

The goal of this paper is to shed light on what neuroscience can bring to the table to advance our understanding of the consumer psychology of brands. In particular, we aim to provide an overview of the current state of research in this area, identify critical issues of past research and discuss how to address these issues in future research. We conclude with our vision of the future potential of research at the intersection of neuroscience and consumer psychology.

What is currently done: toward an interdisciplinary understanding of consumer decision making

In this section, we review previous work in neuroscience pertinent to understanding underlying processes involved with brand decisions. We structure the review using a simple consumer decision-making framework based on prior work in consumer psychology (Fig. 2; Kahneman & Snell, 1992; Kahneman, Wakker, & Sarin, 1997; Rangel, Camerer, & Montague, 2008; Wirtz, Kruger, Scollon, & Diener, 2003). We also use this framework to integrate previous consumer neuroscience studies that are directly related to branding questions and to point the way for future applications in consumer research.

The framework divides the stages that are required for brand preference formation over time into four basic components: (1) representation and attention, (2) predicted value, (3) experienced value, and (4) remembered value and learning. Below we explain these basic components and review previous findings on the underlying neuropsychological processes of each of those components. The main brain areas involved with each component of the model are shown in Fig. 3.

Representation and attention

The amount of information consumers are exposed to is enormous, yet our processing capacity is limited. Each second we are exposed to an estimated 11 million bits of information that reach us through all our senses, yet humans are capable of processing only around 50 bits of that information, letting most of the input go by unnoticed (Wilson, 2002). How consumers represent, attend to, and perceive incoming information may have a profound influence on their behavior. In the current section, we discuss representation (i.e., brand identification) and attention.

[1] There are at least two major reasons to study non-human subjects in consumer neuroscience. First, studying animals allows consumer neuroscientists to make causal links between brain areas and specific behaviors. Animal work allows the application of more invasive methods to brain systems that animals and humans have in common. Second, if consumer neuroscience researchers are using evolutionary theories to explain phenomena in consumer behavior such as behavioral biases, using an animal model allows evolutionary inferences (i.e., going back in the evolutionary chain).

[2] However, there are several reasons to use patient populations in consumer neuroscience. The most prominent one is to use patients with brain lesions to establish causal relationship between brain regions and consumption behavior. At the end of this paper, we will discuss some of these aspects as potential future developments.

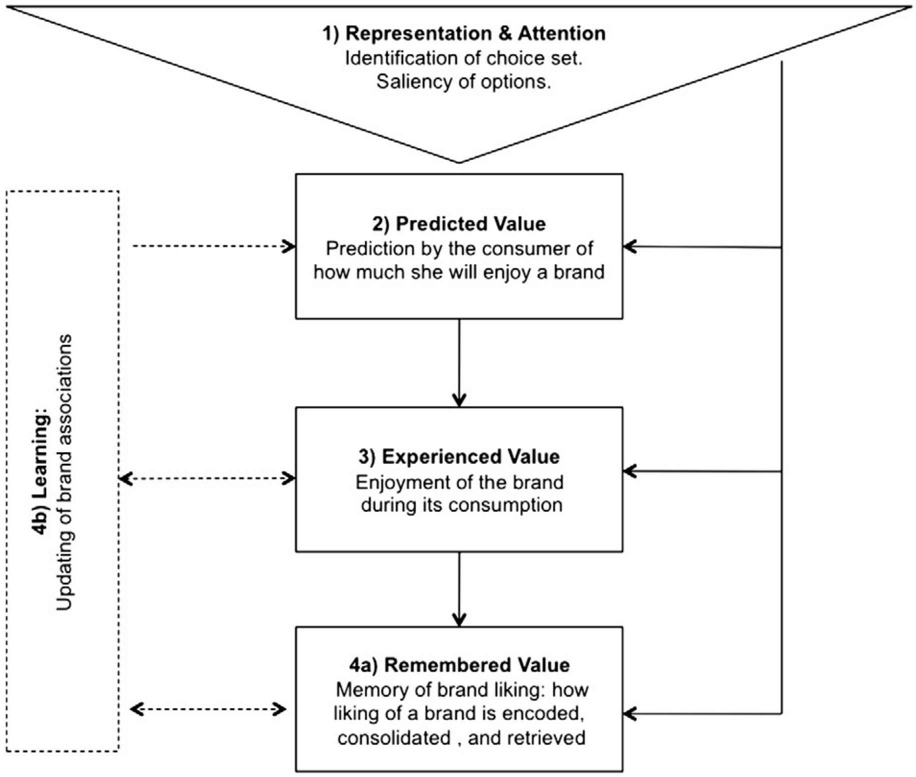

Fig. 2. Value signals important for brand decisions.

Representation The first process in brand decisions involves forming the representation of the choice alternatives—that is, brand identification. This entails processing the incoming information, so that different options for choice are identified (e.g., different beer brands). At the same time, the consumer needs to integrate information on internal states (e.g., thirst level) and external states (e.g., location, social context) that drive attention. For example, when faced with a choice between drinking Heineken or Beck's beer (an incoming information) a consumer's choice is likely to depend on her own level of thirst (an internal state) and what her friend chooses to drink (an external state).

Humans are predominately visual creatures, and most of the incoming information we receive is visual (Koch, 2004). Our visual system contains two cortical routes that are involved with visual processing (see Fig. 3). The dorsal visual pathway is involved with the spatial deployment of attention (the "where/how" pathway) and proceeds from the primary visual cortex V1 in the occipital lobe, through the posterior parietal cortex, to the dorsolateral prefrontal cortex (dlPFC). The ventral visual pathway is responsible for object recognition (the "what" pathway) and originates in V1, then continues to the inferotemporal cortex, and to the ventrolateral PFC.

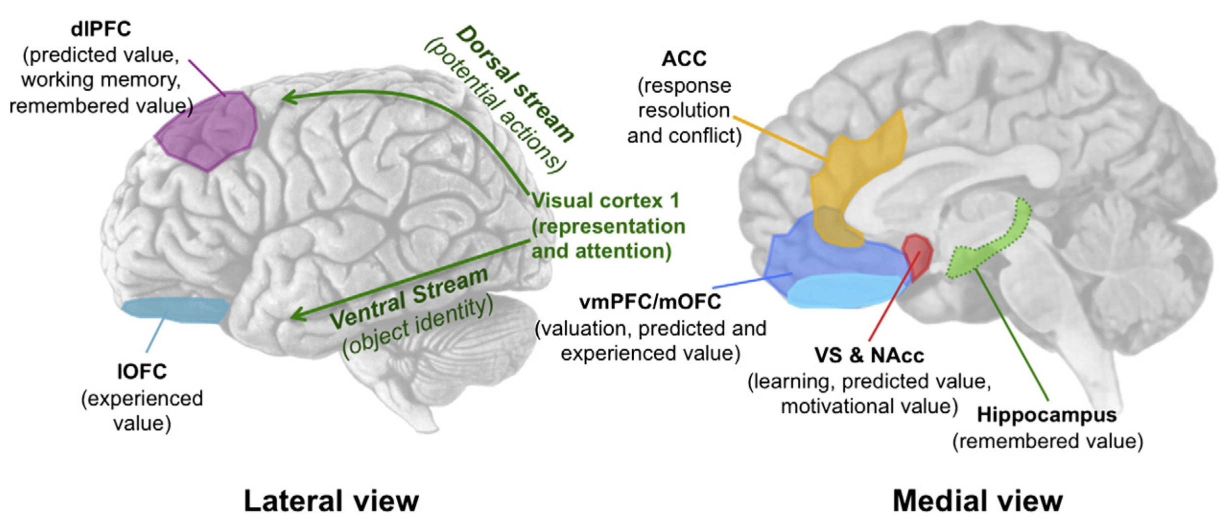

Fig. 3. Overview of prominent brain areas involved in brand decisions.Abbreviations used: ACC = anterior cingulate cortex; dlPFC = dorsolateral prefrontal cortex; lOFC = lateral orbitofrontal cortex; mOFC = medial orbitofrontal cortex; NAcc = nucleus accumbens; vmPFC = ventromedial prefrontal cortex; VS = ventral striatum.

The visual system allows for rapid brand and product identification. A recent magnetoencephalography (MEG) study showed that female participants viewing shoes (compared to motorcycles) had stronger activity in occipitotemporal regions between 130 and 180 ms after image presentation (Junghoefer et al., 2010). Similarly, Milosavljevic, Koch, and Rangel (2011) showed that consumers can identify two different food brands and make up their mind about which one they prefer in as little as 313 ms. Furthermore, processes involved in the representation stage need not even be conscious, as recent studies have demonstrated that unconscious processes also shape how we represent our decision-making situations (Chartrand, Huber, Shiv, & Tanner, 2008). One of the key questions at this stage, discussed next, is what consumers pay attention to (i.e., focus on) once they are exposed to a number of rapidly identified choice alternatives (i.e., brands).

Attention Attention is the mechanism responsible for selecting the information that gains preferential status above other available information. Recent review of attention in neuroscience indicates that four conceptual components are fundamental to attention: bottom-up or saliency filters, top-down control, competitive visual selection, and working memory (Knudsen, 2007). We will focus on the first three components and discuss their relevance for research on branding.

Bottom-up or saliency filters automatically select the most important information from all available information. This selection is based on the low-level features of the visual input: colors, luminance, orientation, size, shape, movement, etc. (Itti, Koch, & Niebur, 1998; Wolfe & Horowitz, 2004). Such bottom-up factors have a strong effect on the initial eye movements when consumers are exposed to marketing information: the first four eye-movements are made within the initial 2.5 s of exposure (Leven, 1991). Some higher-level factors are also capable of gaining automatic, preferential access to attention. These include faces, text, novelty, and one's own name.

All of these features are combined in the brain, and preattentional scan paths are created, making a saliency map of the regions in the visual field that are most important and thus most likely to be further processed.

Thus, at the outset of early attention, the decision maker is biased toward salient stimuli (van Zoest, Donk, & Theeuwes, 2004). The salient stimuli will attract the initial eye movements of consumers, and thus may have a profound effect on related consumer behavior.

For example, Pieters and Wedel (2007) showed that ensuring that consumers pay attention to the brand displayed in a print ad is the most effective way to ensure that they will transfer their attention to other elements of the print ad. Further, Milosavljevic and colleagues showed that salient features (i.e., the brightness of the food packaging) influence real food choices (Milosavljevic, Navalpakkam, Koch, & Rangel, 2011). Namely, at fast decision speeds a significant number of food choices were biased toward the food items with brighter packaging, even when subjects preferred the taste of alternative food options.

There are other automatic biases known to influence what people pay attention to (Glaholt, Wu, & Reingold, 2010). For example, people tend to look toward the upper visual field (Durgin, Doyle, & Egan, 2008) and the right visual field (Efron & Yund, 1996), which may be of importance in the consumer behavior context (e.g., at the point of purchase). In a famous experiment, when five identical stockings were displayed horizontally, subjects were biased toward choosing stockings on the outmost right (Nissbet & Wilson, 1977). Chandon and colleagues showed that only the top-shelf positions carry through to brand evaluation (Chandon, Hutchinson, Bradlow, & Young, 2009). Clearly, products can be placed in locations that are known to attract more attention and will thus be more likely to be chosen by a buyer (Pieters & Warlop, 1999).

Strong location effects were also found when consumers browse websites (Dreze & Hussherr, 2003). The influence of bottom-up factors may be especially strong online, as consumers engage in fast web surfing and often spend very little time on any given page. Systematically manipulating low-level visual features to "guide" viewers' eyes to a webpage's regions of interest is possible by utilizing insights from visual neuroscience. Milosavljevic (2009) used a computer simulation of visual attention to optimize banner ads, and the rest of a website, to make certain brands/banner ads visually salient. This manipulation resulted in an increased liking for the target banner ad, perhaps due to mere exposure effects (Milosavljevic & Cerf, 2008). Recently, a strong bias of looking toward the center of the viewing area (e.g., the center of the computer screen) has been reported (Tatler, 2007). Reutskaya and colleagues showed that an item in the center of the screen was almost 60% more likely to be chosen by a decision maker than similar items displayed at other locations (Reutskaya, Nagel, Camerer, & Rangel, 2011).

Top-down control depends on internal and external states, goals, and expectations. Hence, looking for a can of Coke will enhance processing of red areas in visual input by increasing the neuronal sensitivity for that particular color (Theeuwes, 2010; Treisman & Gelade, 1980; Van der Lans, Pieters, & Wedel, 2008). Expectation can modulate what consumers pay attention to via brain structures that include the dorsolateral cortex (Egidi, Nusbaum, & Cacioppo, 2008). The information that is relevant for goal attainment will be attended to more than irrelevant information. For example, when we are thirsty, we pay more attention to drinks than to other items (Aarts, Dijksterhuis, & De Vries, 2001; Dijksterhuis & Aarts, 2010).

Goals also exert a strong influence on eye-movements and can result in different eye-movement patterns when subjects are exposed to the same visual input (Glaholt et al., 2010; Pieters & Wedel, 2007; Yarbus, 1967). Rosbergen, Pieters, and Wedel (1997) identifed tendencies in how individuals scan marketing materials, such as print ads or store shelves. Their work was based on a well-established idea of visual scan paths, that is, the patterns of saccades and fixations across some visual input (Norton & Stark, 1971). They found three types of eye movements that are characteristic of people examining the ads: scanning (eyes move to headline and pictorial), initial (eyes move to headline, pictorial, and brand), and sustained (eyes move to headline, pictorial, brand, and text). As one might expect, the time spent viewing the ad, the level of involvement, brand attitude, and recall all improved from the first to the third type of viewing. Further, Pieters and Wedel (2007) showed that the informativeness of ads is contingent on the goals consumers pursue while viewing them. For example, in comparison with free viewing of the same ads, consumers spend more time on the text when asked to evaluate the brand, and less time on pictorial elements when asked to learn about the brand.

Visual selection occurs when the most important information from all the areas that are identified as potentially important in preattentive scans (based on the bottom-up input) is chosen. This means that attention is given to a particular location in space. It is believed that as the number of choice options increases, the decision maker becomes more selective in what information he or she encodes, that is, which locations in the scene he or she processes (Payne, Bettman, & Johnson, 1993).

Glaholt et al. (2010) showed that when asked to choose the most expensive of six items (6-alternative-forced-choice, or 6-AFC), subjects were more selective in the processing of stimulus information (i.e., they achieved greater differentiation between individual stimuli via more fixations, longer duration of total fixations, etc.) than when they were asked to choose which of the two sets of three items (2-AFC) was more expensive. Thus, gaze selectivity increases as the number of alternatives increases (Glaholt et al., 2010). Reutskaya et al. (2011) showed that time pressure induced people to shorten the duration of their fixations and to search somewhat longer so as to increase the number of options that are considered before making a choice.

Visual selection and eye movement enhance the quality of incoming information. Gaze bias shows that people spend longer time examining (i.e., fixating on) options that they eventually choose (Glaholt & Reingold, 2009; Krajbich, Armel, & Rangel, 2010; Pieters & Warlop, 1999; Shimojo, Simion, Shimojo, & Scheier, 2003). For example, consumers spent 54% more time looking at the ads of businesses (in a phone directory) that they ended up choosing (Lohse, 1997). It is especially interesting to note that externally manipulating what people look at—for example, by displaying choice options one at a time while manipulating the exposure duration—biases the resulting choices toward the options subjects are exposed to longer (Armel, Beaumel, & Rangel, 2008).

Further, eye movements may be useful in evaluating the effectiveness of brand extensions. Stewart, Pickering, and Sturt (2004) showed that consumers spend 200 ms longer examining implausible brand extensions (they cause immediate disruption of visual processing) compared to plausible brand extensions. The authors propose eye-tracking as a useful tool for determining the extent to which consumers find different brand extensions plausible.

In sum, representation and attention are complex processes that influence all subsequent steps in our brand decisions framework. Theoretical and methodological insights from neuroscience can prove especially useful in allowing consumer researchers to better understand attention and its effects on branding-related behavior. However, research in this area has received little attention in consumer neuroscience, which offers a lot of potential for future research.

Predicted value

The predicted value of each brand that is available for choice (e.g., Heineken vs. Beck's) represents the consumer's belief about the experienced value of that brand at some time in the future. In other words, the predicted value involves the consumer's evaluation of how much enjoyment she will derive from consuming a Heineken or a Beck's beer.

Previous studies suggest that at least three brain structures might be of particular importance when consumers evaluate predicted values: the striatum, the ventral medial prefrontal cortex (vmPFC), and the dorsolateral prefrontal cortex (dlPFC; see Fig. 3). In the next sections, we first review these previous studies and then review studies that have investigated how branding influences predicted value signals in each respective brain region. For the latter we use Keller's customer-based brand equity framework to categorize the different studies (Keller, 1993). Applying Keller's framework, we distinguish between studies investigating how favorableness, type, and uniqueness of brand associations alter the neural signatures of predicted value (see Table 1). Fig. 4 visualizes the results of the studies listed in Table 1 and shows which brain areas are involved in representing Keller's framework in the brain.

Predicted value signals in the striatum Several studies have used functional magnetic resonance imaging to investigate the predicted value of products or other types of desirable objects such as money. Pioneering work by Knutson and colleagues showed that a structure within the ventral striatum (VS), the nucleus accumbens (NAcc), is involved in encoding anticipated rewards of monetary payoffs (Ballard & Knutson, 2009; Knutson, Adams, Fong, & Hommer, 2001; Knutson & Cooper, 2005; Talmi, Dayan, Kiebel, Frith, & Dolan, 2009) and branded products (Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Knutson et al., 2008).

Two studies investigated how favorableness of brand associations affects predicted value signals in the striatum. In the first one, Schaefer and Rotte (2007a) found that imagining a pleasant experience, such as driving a car of a brand that is linked to favorable brand associations, correlates with activity changes in that brain area. However, it remains unclear what exactly consumers were imagining and whether activity in the striatum is based on the difference in pleasantness of the predicted experience per se or the difference in brand information. This weakness of the study is further confounded by the fact that the more attractive car brands are also more expensive, and driving an expensive car might be a pleasurable experience by itself.

One problem with using a given brain activation (the striatum) to infer a mental process (a pleasurable experience) is the proposed one-to-one relationship between the brain activity and the mental process of interest. Such a "reversed inference" is problematic because one brain area is usually involved in more than one mental process (for a detailed discussion of the "reverse

Table 1
Overview of consumer neuroscience studies directly related to branding.

Branding area	Author	Main question	Method	Main results
Favorability of brand associations	Deppe, Schwindt, Kugel, Plassmann, and Kenning (2005)	What brain areas correlate with brand preference?	fMRI	When choosing between one's favorite brand as compared to a second or lower ranked brand increased activity in the vmPFC and reduced with activity in dlPFC/IFG and visual cortex (cuneus/precuneus) are triggered.
	Deppe, Schwindt, Kramer, et al. (2005)	What are the underlying neural processes of how brand information bias semantic product judgments?	fMRI	Activity in the ACC predicted whether a person is biased by the brand name of a newspaper while evaluating the credibility of a headline.
	Deppe et al. (2007)	What are the underlying neural processes of how brand information bias visual product judgments?	fMRI	Activity in the ACC predicted whether a person is biased by the brand name of a newspaper while evaluating the attractiveness of print advertisements.
	Schaefer and Rotte (2007a)	What are the neural correlates of brand preferences during (imagined) consumption?	fMRI	Imagining driving a car from one's favorite brand correlates with activity changes in the ventral striatum. Activity in this area also correlates with perceived luxury and sportiness of the car.
	Koenigs and Tranel (2008)	What is the role of the vmPFC for how brand information biases preference judgments?	Lesion-study	Patients with damage in the vmPFC were not biased by brand information during blind vs. open tasting of Coke and Pepsi.
	Plassmann et al. (2008)	Does uncertainty modulate the neural signatures of brand preference?	fMRI	Interaction of brand preference with uncertainty of the decision amplifies the neural correlate of brand preference in the vmPFC.
Different types of brand associations	Erk et al. (2002)	What are the neural correlates of preferences for product types that are vs. low in social status signaling?	fMRI	Sports cars vs. limousines induced increased activity changes in the brain areas involved in reward processing (striatum, vmPFC/mOFC and ACC).
	Schaefer and Rotte (2007b)	Does high social status signaled by brands trigger the same responses than low social status signals?	fMRI	• Car brands signaling high social status activated regions in the MPFC and precuneus. • Car brands signaling low social status activated the left superior frontal gyrus and ACC
	McClure et al. (2004)	What are the underlying brain processes of how brand information alters brand evaluations during consumption?	fMRI	Stated preferences for Coke vs. Pepsi did not correlate with revealed preferences in blind tastings Revealed preference correlated with activity changes in the vmPFC/mOFC Knowing you drink Coke vs. not knowing what you drink correlated with activity changes in memory/association areas (hippocampus, dlPFC/SFG). No such difference could be found for the case of Pepsi
	Yoon et al. (2006)	Do brand judgments recruit the same neural networks as judgments about people?	fMRI	Brain areas involved in making judgments about human traits for people do not overlap with brain areas involved in making judgments about human traits for brands.
Brand recall and memories	Schaefer et al. (2006)	What are the neural correlates of brand familiarity?	fMRI	Activity changes in the MFG correlate with familiar vs. unfamiliar brands
	Klucharev et al. (2008)	How does the expertise of an endorser affect brand memory and attitude?	fMRI	Increased brand recall for expert endorsement was related to stronger activation during encoding of memory structures of the left hemisphere, the dlPFC and medial temporal lobe structures, and accompanied by stronger engagement of the bilateral striatum.
	Esch et al. (2012)	What are the neural correlates of brand familiarity and brand "strength"	fMRI	Unfamiliar brand logos vs. "strong" brands induce activity changes in the IFG "strong" vs. unfamiliar brands induce activity changes in the hippocampus and lingual gyrus "strong" vs. "weak" brands induce activity changes in the dlPFC/MFG
Brand loyalty	Plassman, Kenning, and Ahlert (2007)	Do loyal customers recruit other brain areas than disloyal customers during brand choice?	fMRI	Activity in the striatum correlates with brand loyalty to retail brands.

Note: The table includes studies that uncover brain areas involved in different topics related to branding that allow making inferences about locations in the brain. We did not include studies investigating temporal dynamics, such as techniques with a high temporal resolution such as EEG/MEG.
Abbreviations used: ACC = anterior cingulate cortex; dlPFC = dorsolateral prefrontal cortex; IFG = inferior frontal gyrus; mOFC = medial orbitofrontal cortex; vmPFC = ventromedial prefrontal cortex.

inference problem" in consumer neuroscience studies see below). A potentially interesting direction for further studies in this area is to manipulate the expected pleasantness of the consumption experience (e.g., a road trip vs. commuting in heavy traffic) and investigate how this is altered by brand information while controlling for price levels.

The second study, by Plassmann, Kenning, and Ahlert (2007), found that when choosing between buying identical

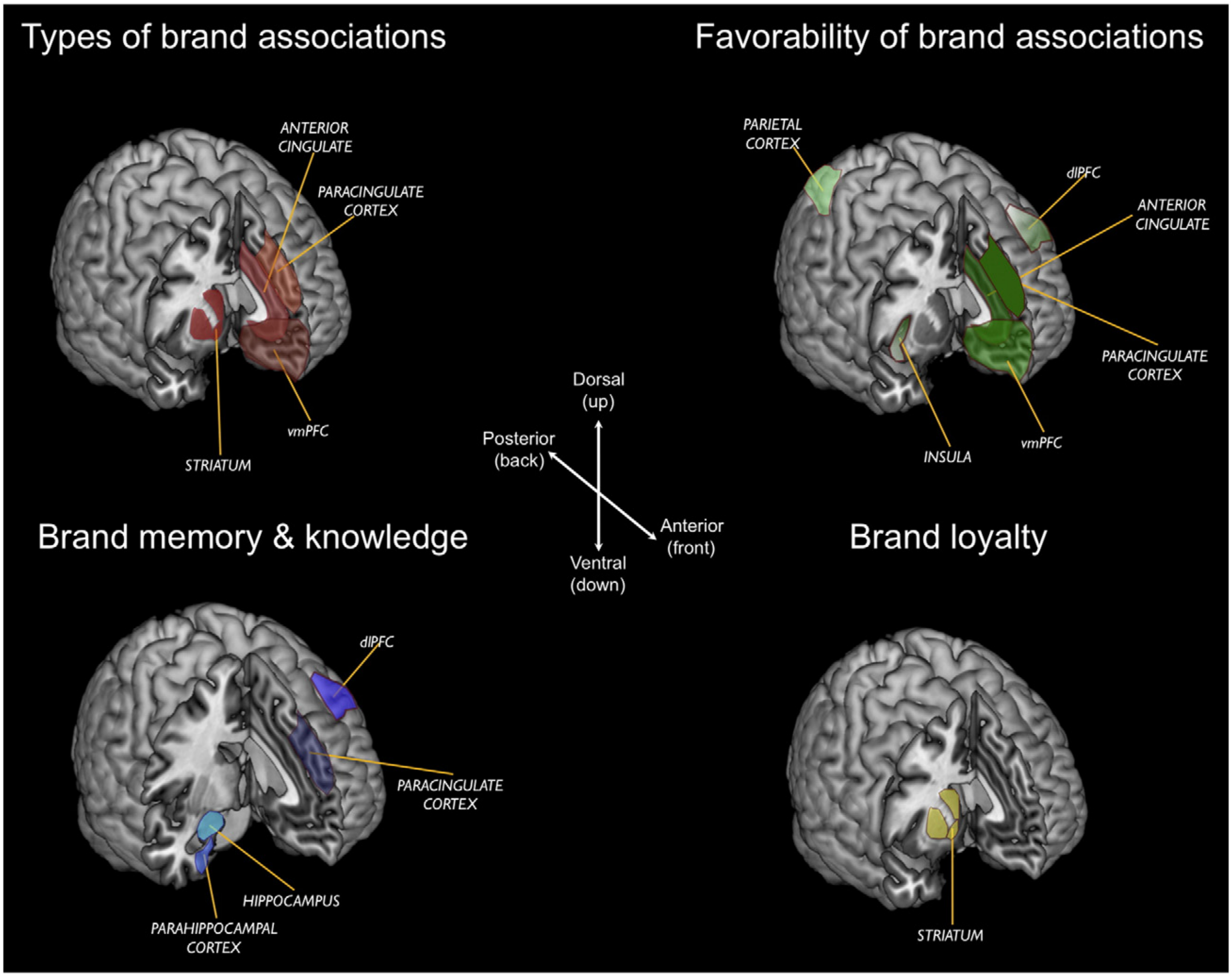

Fig. 4. Overview brain systems involved in the psychology of brands.Note: this figure shows a three-dimensional view of the brain and it is important to note that the front (anterior) to back (posterior) slice view shown differs between the different parts of the figure, i.e. a view showing the hippocampus is more posterior than views showing the striatum; Abbreviations used: dlPFC = dorsolateral prefrontal cortex; vmPFC = ventromedial prefrontal cortex.

clothes at different retail stores (e.g., H&M vs. Zara), customers who are loyal to a store as measured by real purchasing behavior (i.e., amount spent, frequency and recency of purchases based on loyalty card data) show more activation in the striatum compared to customers who are less loyal. Although this study provides an interesting and methodologically valuable link between real-life purchasing behavior outside the lab (i.e., based on scanner data at the point of sale) and brain activation by inviting loyalty card holders to the brain imaging lab, one potential confound of this study is the passive choice paradigm applied in the study. In the passive choice paradigm test persons were not required to respond, i.e. make choices inside the scanner. Instead, behavioral measures were taken outside the scanner. The lack of these response measures results in missing important manipulation checks. This is further linked to the above-mentioned problematic reliance on reverse inference.

To the best of our knowledge, no study to date has investigated the impact of the different types of brand associations or uniqueness of brand associations on predicted value signals in the striatum. This calls for further research in this area.

Predicted value signals in the ventromedial prefrontal cortex (vmPFC) and the dorsolateral prefrontal cortex (dlPFC) Another series of human fMRI studies has studied predicted values using real choices and has found that neural activity in the vmPFC correlates with behavioral measures of consumers' positive and negative predicted values for a range of different branded products (Chib, Rangel, Shimojo, & O'Doherty, 2009; Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008; Plassmann, O'Doherty, & Rangel, 2007; Plassmann, O'Doherty, & Rangel, 2010) and also in a social context when making decisions about charitable donations (Hare, Camerer, Knoepfle, & Rangel, 2010).

Most of the abovementioned studies found that a brain system consisting of the vmPFC and the dlPFC encodes behavioral preferences (Camus et al., 2009; Plassmann et al., 2007; Plassmann et al., 2010; Wallis & Miller, 2003). Importantly, in Camus et al.'s (2009) study, test subjects were "virtually lesioned" in the dlPFC using transcranial magnetic stimulation (TMS) and showed a change in behavioral measures of predicted values.

Several consumer neuroscience studies have investigated how brand associations alter predicted value signals in the vmPFC and dlPFC as well as in related brain areas. Some of these studies investigated how brand favorableness influences neural signatures of predicted value signals; other studies compared how different types of brand associations alter those signals.

A series of studies by Deppe and colleagues investigated how favorableness of brand associations influences predicted value signals in the brain. In the first study, the authors found increased neural activity in the vmPFC when the choice set contained the consumer's favorite brand compared to choice sets containing two less preferred brands. They also found that the part of the dlPFC involved in working memory and the part of the visual system involved in object recognition were less active when the choice set contained the consumer's favorite brand compared to a set containing two non-preferred brands (Deppe, Schwindt, Kugel, Plassmann, & Kenning, 2005). A potential confound of this first study is the passive choice design that did not allow the recording of choices and reaction times. In other words, no actual behavioral choices were recorded, but preference rankings were sampled at the end of the experiment outside the scanner. These measures could have served as important manipulation checks and would have avoided having the results rely on reversed inference, discussed below.

In two follow-up studies the authors applied an active choice task and replicated their finding that the vmPFC correlated with favorableness of brand associations (Deppe et al., 2005; Deppe et al., 2007). Interestingly, in these follow-up studies, the authors showed that the degree to which a brain area involved in selective attention and conflict monitoring (the anterior cingulate cortex, ACC; see Fig. 3) is correlated with the degree of how much consumers' judgments are biased by brand associations (Deppe, Schwindt, Kramer, et al., 2005; Deppe et al., 2007). In other words, these two studies suggest that ACC activity predicts individual differences of how much brand associations influence consumers' judgments.

A more recent study by Esch et al. (2012) also investigated how favorableness of brand associations influences brain activity during brand decisions. They found that the part of the dlPFC involved in predicted value encoding is more active when consumers are exposed to "strong" vs. "weak" brands. They also found that exposure to "weak" vs. "strong" brands leads to more activity in the insula, the brain area previously found to encode disgusting, painful, or more generally intense and arousing emotional experiences. However, because the reported results are based on a very low statistical threshold not corrected for multiple comparisons (i.e., .005) or for cluster levels (i.e., small volume corrections or region of interest analysis) that are typically not reported as core findings in neuroscience journals, the study by Esch et al. awaits further empirical validation.

Several studies have investigated how different types of brand associations influence predicted value signals in the vmPFC, dlPFC, and related areas. Most of the studies look at brand associations linked to cultural influences and social status. Studies by Erk, Spitzer, Wunderlich, Galley, and Walter (2002) and Schaefer and Rotte (2007a) found that exposure to branded products associated with high social status induces activity changes in the vmPFC, ACC, PFC and striatum. For both studies it remains unclear whether the type of brand association (i.e., high vs. low social status) or how much people like the brand (i.e., favorableness of brand association) is driving the results because the experimental design does not allow these two factors to be dissociated. As a result, both studies also rely on reverse inference.

A study by Yoon, Gutchess, Feinberg, and Polk (2006) investigated brand personality associations. The authors compared whether judgments about personality attributes of people are represented in the same neural system as judgments about personality attributes of brands and whether this differs when these judgments refer to the self or others. They found that brain areas involved in making judgments about human traits for people do not overlap with brain areas involved in making judgments about human traits for brands. These first findings challenge the view that we associate brands with personalities and are able to form relationships with brands the same way we form relationships with people (Aaker, 1997; Aaker & Fournier, 1995; Aggarwal, 2004; Fournier, 1997; Swaminathan, Page, & Gurhan-Canli, 2007) and call for further research.

To the best of our knowledge, no study has looked at the impact of the uniqueness of brand associations on predicted value signals in the vmPFC and dlPFC to date. This calls for further research in this area.

Experienced value

Experienced value is based on the pleasure derived from consuming a brand. According to early notions of utility or value, experienced value is the "true value" that should matter the most for value-based decision making (Kahneman et al., 1997). Experienced value consists of the (a) valence and (b) intensity of the consumption experience. In this section, we first review general and branding-related neuroscientific research investigating valence and intensity of experienced values and then review the neural basis of a concept that connects brain systems involved in representing predicted and experienced value, namely motivational value.

Valence The neural bases of computations made by the evaluation system during the consumption experience are beginning to be understood. Human fMRI studies have shown that activity in the orbitofrontal cortex (OFC), in particular its medial parts (see Fig. 3), at the time a reward is being enjoyed correlates with subjective reports about the pleasantness or valence of the experience. This has been shown for olfactory experiences (Anderson et al., 2003; Kringelbach, O'Doherty, Rolls, & Andrews, 2003; McClure et al., 2004; Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001; Small et al., 2003), musical rewards (Blood & Zatorre, 2001), visual rewards (Aharon et al., 2001; Kirk, Skov, Hulme, Christensen, & Zeki, 2009), pleasantness of touch (McCabe, Rolls, Bilderbeck, & McGlone, 2008), and even secondary rewards such as money (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001; Knutson, Fong, Adams, Varner, & Hommer, 2001; Knutson, Fong, Bennett, Adams, & Hommer, 2003). Moreover, the activity in the OFC is reduced when consumers are fed to satiety on a specific food (O'Doherty et al., 2000).

Taken together, these findings suggest that the medial OFC might be an area where positive experienced values are computed. Other studies have found that brain areas that receive inputs from the OFC areas, such as the ventral striatum and the pregenual cingulate cortex (Grabenhorst, Rolls, & Bilderbeck, 2008; McCabe et al., 2008; Rolls, Grabenhorst, & Franco, 2009; Rolls & McCabe, 2007), are also correlated with sensory pleasantness.

An interesting open question is which neural systems encode negative experiences. Several studies have found that unpleasantness of taste might be correlated with brain activity in the lateral OFC and left dorsal anterior insula/operculum (Small et al., 2001; Small et al., 2003). O'Doherty and colleagues found that the size of abstract punishments (i.e., losing money) activated lateral parts of the OFC (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001). One problem in investigating negative experience is to dissociate it from intensity. This problem arises due to the negativity bias of intensity: negative experiences are usually also perceived to be more intense and thus are often confounded (Small et al., 2003), in particular for visual stimuli such as facial or object attractiveness.

Using a different methodological approach to investigate positive vs. negative emotional experiences, neuromarketing studies are based on the idea that there is a left–right asymmetry of the frontal electroencephalography (EEG) signals (Davidson, Ekman, Saron, Senulis, & Friesen, 1990). These and related studies suggest that relatively greater activity in the left frontal region is associated with either positive emotional experience or the motivational drive to approach an object (Harmon-Jones, 2003). Although there are strong correlations between frontal EEG asymmetry and personality traits, the degree to which the asymmetry changes from one moment to another is questionable. Some studies have applied this approach to measure moment-to-moment fluctuations in emotional responses to advertisements without accounting for autocorrelations in time or multiple statistical comparisons (Ohme, Reykowska, Wiener, & Choromanska, 2009). However, the validity of such approaches is unclear, as hemispheric asymmetry is also an index of working memory load (Habib, Nyberg, & Tulving, 2003; Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). Further research to investigate the neural representation of positive vs. negative experienced values is needed.

Several recent human fMRI experiments have provided novel insights into how marketing actions such as branding might alter the properties of the experienced value signals. For example, one study showed that activity in the medial OFC in response to an odor depended on whether subjects believed that they smelled cheddar cheese or body odor (de Araujo, Rolls, Velazco, Margot, & Cayeux, 2005). In another study, activity in the medial OFC in response to the consumption of wine depended on quality beliefs about its price (Plassmann, O'Doherty, Shiv, & Rangel, 2008). Yet another study found that experienced values of works of art, and accompanying engagement of the medial OFC, depended on whether the subjects believed they were created by an expert (i.e., an artist) or by a non-expert (i.e., the experimenter; Kirk et al., 2009). Together, these findings suggest that the experienced valuation system is modulated by higher cognitive processes that determine expectancies and beliefs—a phenomenon recently referred to as the "placebo effects of marketing" actions (Shiv, Carmon, & Ariely, 2005; Waber, Shiv, Carmon, & Ariely, 2008) or "expectation bias" (Plassmann & Niessing, 2010).

To date there is only one study that has investigated how favorable brand associations alter experienced value signals. McClure et al. (2004) investigated differences in brain activity during consumption of sodas when the subjects knew they were drinking Coke or Pepsi vs. when they did not know which brand they were consuming. Unbeknownst to the subjects, they were consuming Coke and Pepsi in both conditions (brand-cued and non-brand-cued trials). The study showed that the experienced value signals depended on brand associations. In particular, the authors found that subjects' knowing they were drinking Coke vs. not knowing what they were drinking correlated with activity changes in their memory/association areas (hippocampus, dlPFC/SFG). No such difference could be found for Pepsi.

An interesting follow-up of this experiment would be to have four different types of trials. In two types of trials Coke would be administered, once cued with a Coke logo and once cued with a Pepsi logo. In the other two types of trials Pepsi would be administered, once cued with a Pepsi logo and once cued with a Coke logo. This would help to dissociate the role of brand information for preference encoding from memory functions linked to retrieving the brand associations.

A similar version of the above-suggested experiment has been done using a different methodological approach, namely using patients with brain damage or lesions in a specific brain area, here the vmPFC. Koenigs and Tranel (2008) investigated how preferences for Coke vs. Pepsi in patients with damage in the vmPFC changed during blind vs. open tasting of both sodas. They found that brand associations in the open tasting did not influence the lesion patients, only the control patients. In other words, patients with a lesioned vmPFC did not reverse their preferences when they knew what brand of soda they were consuming. To better understand the roles of the regions reported by McClure et al. (2004), similar studies should be conducted on patients with injury to the dorsolateral PFC and hippocampus. The advantage of using lesion patients as compared to fMRI is that causal and not "only" correlational links between mental processes and brain functioning can be established.

Intensity Another, much smaller stream of research has investigated the intensity of emotional and sensory experiences: In humans, subjective reports of pain intensity correlated with activity in the insula and the ACC (Davis, Taylor, Crawley, Wood, & Mikulis, 1997; Peyron et al., 1999). Recent studies in the chemosensory domain found that amygdala activity increased with the intensity of negative and positive chemosensory stimuli (Anderson et al., 2003; Small et al., 2003). Several studies by Berns and colleagues suggest that the saliency or intensity of objects such as sound and money correlate with neural activity in the dorsal and ventral striatum (Zink, Pagnoni, Chappelow, Martin-Skurski, & Berns, 2006; Zink, Pagnoni, Martin, Dhamala, & Berns, 2003; Zink, Pagnoni, Martin-Skurski, Chappelow, & Berns, 2004). Similar results have been found for the neural correlates of flavor intensity vs. flavor pleasantness (Small et al., 2003). To the best of our knowledge no studies to date have investigated how brand associations influence the intensity of experienced value signals. In turn, there are a lot of questions open for future research in this area.

Motivational value A concept that is related to how predicted and experienced values interact is the motivational value or incentive salience of an option. Over the past two decades, pioneering work by Berridge and colleagues has contributed to a better understanding of value processing in the brain by distinguishing between "wanting" and "liking" responses to stimuli (Berridge, 2007, 2009a, 2009b; Berridge & Kringelbach, 2008; Berridge & Robinson, 1998). "Wanting" refers to a person's (or animal's) motivation to obtain a given reward, as observed by increased effort, longer viewing times, and stronger grip strength (e.g., Pessiglione et al., 2007). "Liking" refers to the experienced value. This line of research has found an important role of the dopaminergic system for wanting, but not necessarily for liking (Berridge & Kringelbach, 2008; Berridge & Robinson, 1998).

A study by Litt, Plassmann, Shiv, and Rangel (2011) showed that the predicted value signals encoded in the mOFC/vmPFC are not confounded with related saliency signals of the options for choice.

More recently, the distinction between "wanting" and "liking" has also received more attention in consumer behavior research (Brendl, Markman, & Messner, 2003; Litt, Khan, & Shiv, 2010; Morewedge, Huh, & Vosgerau, 2010; Xianchi, Brendl, & Ariely, 2010). However, to date there is no behavioral or neuroscientific research trying to understand how different types of brand associations, and how favorable or unique they are, affect wanting and liking for brands.

Remembered value and learning

Consider again our example of choosing between Heineken and Beck's. An important predictor of your choice is your memory of previous exposures to the two brands. If you remember that Heineken had a bitter taste and Beck's had a distinct whiff of something sweet, these experiences may influence your decision. You may remember a recent entertaining Heineken commercial, but you have no such memory of a Beck's commercial. Brands "work their magic" by associating themselves with experiences, which in turn influence subsequent retrieval and recognition. It is important to note that these can be personal experiences or those of other people—shown in commercials or told by friends through word of mouth.

Remembered value refers to how different brand associations are encoded, consolidated, and retrieved in the consumer's memory. Recent research suggests that parts of these processes happen on an unconscious level. Similar models have been seen in consumer psychology. For example, Van Osselaer and Janiszewski (2001) distinguished between the Human Associative Memory model, a process that was a general and unfocused incidental (or unconscious) associative learning, and an adaptive learning mechanism focusing on feature-benefit associations for future rewards.

Hence, the remembered value consists of both explicit memory and implicit memory of prior consumption experience. In this section, we first review the neuroscientific literature of explicit and implicit memory and learning processes relevant to branding. Following this, we briefly review recent studies on the dynamic nature of brand memories, that is, how explicit and implicit memory changes over time and how external factors such as marketing actions might affect remembered value.

Explicit brand memory Studies have demonstrated that explicit memories—also known as declarative memories—rely on specific brain regions such as the hippocampus and surrounding medial temporal lobe (MTL) region, in synchrony with other brain regions such as the dlPFC (Squire & Zola, 1996a, 1996b, 1998). Indeed, the distinction between declarative and non-declarative memories remains a dominant model for our understanding of memory function (Ramsøy et al., 2009; but see Henke, 2010, for a recent alternative account). Several studies have reported a strong link between memory and preference. In a seminal paper by McClure et al. (2004), it was reported that an increase in preference for the beverage labeled as Coca-Cola, but not the one labeled Pepsi Cola, was paralleled by an activation increase in the hippocampus and the dlPFC. In other words, the brand-induced change in preference was mediated by regions implicated in declarative memory.

Similar activations of the PFC were reported in the aforementioned study by Schaefer, Berens, Heinze, and Rotte (2006) in which subjects were asked to visually imagine driving a car of a well-known car manufacturer (e.g., BMW) or an unknown generic car brand in the German car market at the time the study was conducted (e.g., Acura). That is, while the act of imagining driving a car was equal between the two conditions, imagining driving a well-known car led to a stronger engagement of the superior frontal gyrus of the PFC, which has also been implicated in memory function.

In a recent study by Klucharev, Smidts, and Fernandez (2008) the link between memory and preference was further strengthened by studying how "expert power" influences this link. In the study, products that were presented simultaneously with an expert person were associated with improved recall at a subsequent memory test on a different day. Notably, by using fMRI during expert object presentations, the researchers found activation changes related to successful encoding and subsequent recall. Expert conditions were associated with increased activity in the striatum (both caudate and likely the ventral striatum/NAcc) and, interestingly, with memory-related activity in the dlPFC, hippocampus, and parahippocampal cortex. Probing the relationship between favorable attitude toward experts and memory performance, the researchers also demonstrated a more direct coactivation of the bilateral caudate nuclei, hippocampus, and parahippocampal cortex. Thus, the link between preference and memory seems to be based on a synergic coactivation of the reward system and memory-related structures such as the dlPFC, hippocampus, and parahippocampal cortex. In another study, Schaefer and Rotte (2007b) demonstrated that brand names or logos engaged the neural reward system, further suggesting that a brand can work as a secondary reinforcer and act on the valuation systems of the brain.

Nevertheless, much is still unknown about the relationship between explicit memory and preference formation, and studies have shown inconsistencies. In another study by Schaefer and Rotte (2007a) it was found that when subjects viewed their most beloved brands, there was a decrease in the activation of both the dlPFC and the hippocampus and an increase in activation in reward regions such as the striatum. Thus, this study may seem at odds with previous suggestions of a positive relationship between memory engagement and preference formation. However, one may contend that the increased activation of memory-related regions found by Schaefer et al. (2006) can be explained by the greater visualization richness when imagining driving a well-known car brand compared to an unknown, generic car. Thus, this complicating factor may be related to differences in study design and other factors, but nevertheless highlights that the neural bases and the basic mechanisms of branding are still poorly understood.

Implicit brand memory As shown by several recent reports during the past few decades, the search for unconscious processes and implicit measures of branding is an active field of inquiry in consumer psychology (Baker, 2003; Bargh, 2002; Brasel and Gips, 2011; Chartrand et al., 2008; Claudi, Dimofte and Yalch, 2011; Friese, Wänke, & Plessner, 2006; Janiszewski, 1993; Moore, 1988; Nevid, 2010; Pratkanis & Greenwald, 1988; Saegert, 1987; Shapiro, 1999; Synodinos, 1988; Theus, 1994; Zajonc & Markus, 1985; Zaltman, 2000). For example Chartrand et al. (2008) demonstrated that subliminally presented retail brand names had an influence on goal pursuit. This suggests that the motivational effect of brands has an unconscious basis.

Although some scholars suggest a more cautious take on the power of the unconscious in the consumer research domain (see Simonson, 2005), recent insights from both behavioral approaches and neuroimaging make it inescapable that brands can be triggered unconsciously or, even when presented overtly, can affect consumer behavior without the person being privy to such effects.

An ongoing debate in cognitive neuroscience concerns the degree to which unconscious stimuli can affect processing in the brain and influence behaviors (Kouider & Dehaene, 2007). Most accounts postulate that low-level computations (e.g., motor reflexes and sensory processing) are driven by unconscious mechanisms, while high-level executive functions such as decision making require consciousness. Yet an increasing body of evidence suggests that higher processing levels can be engaged unconsciously.

Recent studies have demonstrated that the prefrontal cortex, associated with conscious executive functions, can be engaged by subliminal task-switching cues (Lau & Passingham, 2007). For example, Pessiglione et al. (2007) reported that subliminal high-value rewards increased the strength with which subjects deployed effort on a hand grip task relative to low-value rewards. This was related to activation of the ventral striatum (VS), a subcortical reward structure.

Similar findings were made for abstract icons as primes, showing that reward-related activation and learning mechanisms of the VS could operate unconsciously (Pessiglione et al., 2008), and such findings suggest a role for unconscious learning processes in guiding motivated behaviors. From early studies of primates and mammals (Hollerman & Schultz, 1998; Schultz, 1998, 2001; Schultz & Dickinson, 2000) to more recent neuroimaging studies (Brown & Braver, 2007; D'Ardenne, McClure, Nystrom, & Cohen, 2008), value-based learning is now thought to include sub-cortical, low-level brain regions such as the ventral tegmental area, striatum, anterior cingulate cortex, and hippocampus.

Taken together, the implicit brand memories seem to engage both the deeper basic structures of the brain and memory regions previously thought to be dedicated solely to explicit memories. By using new and sophisticated analysis tools on neuroimaging data, it is possible to track neural processes that precede and even predict conscious choice. Such advances not only improve our understanding of implicit brand memory but provide a whole new avenue for studying the consumer psychology of branding.

The dynamic nature of memories Different models of memory retrieval have seen memories as being "replayed," contributing to the popular notion that (episodic) memories are stored as hard copies in the brain. In this view, remembering is the process of retrieving factual and true information about the experiences we have had. While memories have been thought of as labile during encoding, information that is consolidated in memory has been thought to be retrieved as more stable "information packages." Neurobiological studies have recently challenged this notion (Nader, Schafe, & LeDoux, 2000; Schafe, Nader, Blair, & LeDoux, 2001), showing that even powerful memories such as fear conditioning can be altered or eradicated by inhibiting the neural mechanisms (protein synthesis in the amygdala) during retrieval. This suggests that the retrieval stage is an active and dynamic relearning process rather than the mere replay of previously acquired information.

The idea of false memories has been paralleled by research in consumer psychology and behavior. A study by Braun-Latour and Zaltman (2006) demonstrated that advertising can unconsciously alter consumers' beliefs as reflected by a change in how they recalled their earlier reporting of these beliefs following exposure to advertising. A related study by Cowley (2007) also showed that affective reactions derived from post-experience information (i.e., advertising) may interfere with the retrieval of experience-based reactions: The results of three experiments showed that when post-experience affective reactions interfere with the retrieval of an experience-based reaction, consumers use post-experience behavior as a proxy for their liking of the experience. In a recent study making use of the dynamic nature of memory, Rajagopal and Montgomery (2011) demonstrated that exposure to an imagery-evoking ad led to a false memory of prior product exposure, further causing alterations in product attitude. Future studies should connect the consumer psychology and neuroscience literatures, and focus on the role and neural bases of dynamic memory in the formation, sustaining, and alteration of brand preferences.

Taken together, this review of "what has been done" shows that interdisciplinary effort in understanding how decision making is represented in the brain has taken off and that these findings can be applied to extend our understanding of the psychology of branding. Our review also points out directions for future research in this area. Two critical issues are important to note:

First, most of the studies reviewed above are mostly exploratory in nature, but have already succeeded in challenging our notions of how branding works. We encourage researchers to go beyond a mere correlation approach, i.e., localizing the neural bases of brand familiarity or brand preference. This type of research is important but contributes mostly to our understanding of the brain while providing fewer novel insights into the psychology of brands. To advance the psychology of branding, we suggest that future work focus more on establishing meaningful brain-behavior relationships that go beyond correlational findings, by combining the neuroscientific tool kit with traditional methods. We make suggestions to address this point in the last section of this paper.

Second, the review in this section pointed out several methodological issues with previous consumer neuroscience studies related to branding that have been published in academic journals. Many additional issues can be raised for unpublished work in the form of commercial applications of neuroscience to the psychology of branding, which has become a business with almost exponential growth. In the next section of the paper we detail the major issues and make suggestions for how to overcome them.

What should not be done: the need of standards for neuroscience work published in marketing journals

How can neuroimaging be a valuable tool for branding researchers? The promise of having a method for opening the "black box" of consumers' brains may seem like a dream come true for any academic or practitioner interested in branding and other areas of consumer behavior. However, as seen in the review above, one can identify at least one major issue that needs the attention of researchers applying neuroscience tools for branding questions and of reviewers of such work: how to overcome the problem of reverse inference.

One practice that has become common in consumer neuroscience studies in general, and those related to branding in particular, is reverse inference, by which the engagement of a particular mental process is inferred from the activation of a particular brain region (Poldrack, 2006). We believe the deductive validity of such inferences is limited.

The inference that is usually drawn from neuroimaging data, according to current scientific standards, is of the form "if cognitive process X (e.g., willingness-to-pay computation) is engaged, then brain area Z (e.g., mOFC) is active." However, previous consumer neuroscience and commercial neuromarketing studies reverse this reasoning, as follows:

- In the current study, when task comparison A was presented (e.g., imagining driving a car branded by a familiar vs. an unfamiliar logo seen on the screen), brain area Z (e.g., the medial prefrontal cortex) was active.
- In other studies, when cognitive process X (e.g., self-reflection and self-relevant thoughts) was putatively engaged, brain area Z (e.g., the medial prefrontal cortex) was active.
- Thus, the activity of area Z (e.g., the medial prefrontal cortex) in the current study demonstrates engagement of cognitive process X (e.g., self-reflection and self-relevant thoughts) by task A (e.g., imagining driving a car branded by a familiar vs. an unfamiliar logo seen on the screen).

This has been referred to as a reverse inference, since it reasons backwards from the presence of brain activation to the engagement of a particular mental process (Poldrack, 2006). The fact that reverse inference is problematic is partly due to the fact that functional brain imaging research is still relatively new, and as a consequence, we do not have a detailed map of the brain to date. More important is the fact that a single brain area can multitask, and that the brain has a built-in redundancy. In other words, one particular brain area could be involved in encoding both brand personality associations and brand familiarity. If a study finds this brain area Z to be involved in brand decisions without implementing a design that allows dissociating between the two, the inference that activity in this area means that one brand is more familiar is of only limited validity.

In many cases the use of reverse inference is informal; the presence of unexpected activation in a particular region is explained by reference to other studies that found activation in the same region. The issue of reverse inference becomes much more problematic when the central findings and contributions of the paper are built on reverse inference. As our review of consumer neuroscience studies related to branding revealed, several of the previous studies in this area (these authors' included) use reverse inference as a central feature to discuss their findings. There are several ways to address the problem of reverse inference in neuroimaging studies.

The first and most straightforward way is to implement an experimental design and data analysis that allow capturing the neural signature of the mental process of interest directly. For example, a recent study investigated how changing the price of wine affects taste processing in the brain (Plassmann et al., 2008). The study found that when subjects consumed the same wine in two experimental conditions, once cued with a high price and once with a low price, brain activity in the mOFC was affected. Other studies found that this brain area encoded taste pleasantness. The design of the study allowed the authors to run a different data model to check which brain area in their data encoded taste pleasantness. They found that in their data also the mOFC encoded taste pleasantness irrespective of the changes in the price of the wine. Their design and data analysis procedure allowed the authors to control for relying on reverse inference.

The second way to address the reverse inference problem is to find a measure of the degree to which the region of interest is selectively activated by the mental process of interest (Ariely & Berns, 2010; Poldrack, 2006). If, on one hand, a region is activated by a large number of mental processes, then activation in that region provides relatively weak evidence of the engagement of the mental process. If, on the other hand, the region is activated relatively selectively by the specific mental process of interest, then one can infer with substantial confidence that the process is engaged given activation in the region. The idea is to compute a selectivity factor that determines the posterior probability for the reverse inference using Bayesian statistics based on previous findings (see Poldrack, 2006 for details).

However, there are at least two important concerns. First, although Poldrack's procedure to compute a selectivity factor is meaningful in a statistical sense, the assumptions behind such a calculation are rather liberal and may suffer from a publication bias for positive results. Second, the mental process of interest needs to be specified very precisely for an application of this idea to consumer neuroscience. "Reward processing" seems rather general, and the question remains whether this refers to the prediction or the experience of reward. In other words, different and imprecise definitions of "reward" are problematic.

Taken together, the application of such a selectivity factor for judging whether reverse inference is possible needs to be done with caution. Given the limited power of reverse inference from single-region brain activations, more sophisticated multivariate methods for interpreting brain imaging data have been at the forefront of analysis techniques. The idea behind these techniques and how consumer neuroscience research related to branding may benefit from those is detailed in the next section of this paper.

What could be done: conclusions and suggestions for future directions

In this last section of the paper we lay out our vision of future consumer neuroscience research and why we think academics and practitioners alike could and should be excited about this new field. Since we have already provided concrete future directions for branding research in our review of what is currently done, we conclude with a broader view on the new directions the field of consumer neuroscience could take to make a substantial contribution to consumer research and the psychology of branding.

The application of neuroscience to consumer psychology, specifically to the psychology of branding, has an interesting potential for at least two reasons. First, it can be viewed as a new methodological tool, as a "magnifying glass" to observe mental processes without asking consumers directly for their thoughts, memories, evaluations, or decision-making strategies, and thus can provide access to otherwise hidden information (Ariely & Berns, 2010; Plassmann et al., in press). Second, neuroscience can be viewed as a source of theory generation, supplementing traditional theories from psychology, marketing, and economics (Plassmann et al., in press). We explain both ideas in the following section.

Neuroscience as a tool

Neuroscience's potential as a tool stems from at least two ways it can contribute to a better understanding of the psychology underlying brands. First, combining advanced statistical models from computer science with neuroscience data makes it possible to predict behavior in a more accurate way than relying on traditional measures such as self-reports. Second, by combining different tools from the neuroscientific tool kit we can establish brain–behavior relationships that are meaningful for understanding the psychology underlying consumer choices.

Predicting consumer choices Empirical studies in consumer neuroscience and neuromarketing employ neuroimaging tools as biomarkers to assess responses to marketing stimuli such as brands, advertisements, packaging and to predict consumer choices.

For example, in a study by Knutson et al. (2007), subjects, while being scanned using fMRI, first saw the product (4 s), then were shown the price of the product (4 s), and finally made their choice (4 s). Subjects reported making their decision consciously only at the very end of each run (i.e., the last 4 s), yet analysis of the fMRI data showed the neural predictors of purchase at earlier time points. Notably, these activation changes could be traced from 8 to 12 s before the decision was made, and before subjects reported having made up their minds. However, the neural predictors did not demonstrate better predictive power than self-reports (pseudo-R^2 was 0.528 when only self-reports were included and changed to 0.533 when neural predictors were added; note that pseudo-R^2 was 0.105 based on neural predictors alone). Taken together, Knutson and colleagues could extract neural predictors at a time when subjects had not made up their minds yet, but these predictors were not fundamentally better at predicting purchase behavior than simply asking the subjects about their preferences.

Another example is a recent study by Berns and Moore (2012) that used a small group of subjects' neural responses to music to predict subsequent market level impact in form of commercial success of the songs (using sales data for a period of three years after the experiment). Interestingly, subjective liking ratings of songs did not correlate with future sales data, but the neural response did (i.e., brain activation within the nucleus accumbens).

New developments in neural pattern classification techniques and multivariate decoding analysis of fMRI data (Haynes & Rees, 2006) are very promising to increase the predictive power of neuroscientific tools in the years to come. A first study in the context of consumer behavior was done by Tusche, Bode, and Haynes (2010). In their study subjects were presented with images of different cars, and asked either to rate their liking of each car (high-attention group) or perform a visual fixation task (low-attention group). After the task, subjects rated their willingness to buy each car. Crucially, subjects were scanned using fMRI during the task, allowing the researchers to test whether neural activation could predict subsequent car choice. The fMRI data were analyzed using a multivariate analysis approach, in which data were fed into the analysis, showing brain regions between the high- and low-attention groups that predicted subsequent purchase intentions.

The idea behind these techniques is as follows. Whole-brain neuroimaging data acquisition, such as fMRI, generates time series data from thousands of data points across the brain. While standard analyses of neuroimaging data employ large-scale univariate analyses by contrasting different experimental conditions, multivariate pattern classification techniques take advantage of information contained in multiple voxels distributed across space. They allow investigation of whether spatial patterns of brain activation contain stable information about different experimental conditions (e.g., purchase vs. no purchase).

These approaches promise better predictions of decision-making behavior across domains, such as neural, physiological, and behavioral predictors of in-store purchase, unhealthy behaviors, and overspending. We believe that decoding of brain patterns using such sophisticated algorithms will be a turning point for consumer neuroscience research.

Establishing brain–behavior relationships that are meaningful for consumer psychology Another potential way to apply methodologies from neuroscience to consumer behavior is to observe consumers' mental processes in real time. As discussed earlier, this is of particular importance when the underlying processes are difficult to investigate because they are below consumers' awareness or are difficult to verbalize and/or manipulate in a traditional experimental setting or survey. One example was provided by a recent study (Plassmann et al., 2008) that investigated whether marketing actions (i.e., changing the price of a wine) does alter taste processing (i.e., the wine actually tastes better) or cognitive processing because of rationalizing (i.e., the consumer thinks the wine tastes better). It is very difficult for consumers to verbalize whether the price changes how much they think they like the wine or how much they actually like the wine, although this difference is very important from a consumer psychology perspective. The authors could show that changing the price of an identical wine does actually change taste processing and more specifically that part of taste processing that encodes the pleasantness of the taste. This finding provides neuropsychological evidence for a placebo effect of marketing actions on positive experiences similar to placebo effects in the pain domain.

Another approach is to use neuroscientific measures to validate behavioral measures. An example of this approach is a recent study (Dietvorst et al., 2009) that aimed at developing a sales force–specific Theory-of-Mind (ToM) scale in two steps. First, they developed a personality scale measuring salespeople's interpersonal-mentalizing skills, based on questionnaires. Second, they validated the questionnaire-based scale by comparing high- and low-scoring salespeople on the scale when they worked on interpersonal-mentalizing and control tasks while having their brains scanned using fMRI. Interestingly, they found that salespeople who scored high on their sales force-specific ToM scale also showed more activation in brain areas involved in ToM during the interpersonal-mentalizing tasks but not during the control tasks.

It is important to note that the next level of research in this area needs to go beyond merely establishing associations between brain activity and a specific behavior. A review by Kable (2011) showed that 60% to 70% of empirical studies applying neuroscience to behavioral decision-making theories use only one method: fMRI. To establish a deeper understanding of the relationships between neuropsychological processes and behavior that can profoundly advance our understanding of consumer psychology, consumer neuroscientists need to expand the neuroscientific tool kit. The idea behind this is to show that (a) brain mechanisms are necessary for a specific consumer behavior (i.e., when brain activity is interrupted, behavior is impaired) and (b) brain mechanisms are sufficient for a specific consumer behavior (i.e., when brain activity is induced, behavioral effects occur; see Kable, 2011, for a more detailed discussion).

Methods to test necessity include using patients who have a lesion in a specific brain area of interest, such as the vmPFC, and testing their behavior as compared to control populations. For example, it has been shown that focal brain lesions in this area make patients outperform healthy controls in financial performance tasks (Shiv, Loewenstein, & Bechara, 2005). Another way to study necessity is the application of techniques that "virtually lesion" healthy subjects by temporarily interrupting electromagnetic activity (Transcranial Magnetic Stimulation (TMS) or cathodal Transcranial Direct Current Stimulation (TDCS)). A recent study by Camus et al. (2009) showed that the application of inhibitory TMS to subjects' dlPFC decreased subjects' predicted values in an economic auction.

The toolkit to test sufficiency is much more limited and includes primarily a reversed version of transcranial direct current stimulation (anodal TDCS). For example, a study by Fregni et al. (2008) showed that stimulation of the lateral prefrontal cortex reduced craving in smokers.

Beyond testing relationships between brain systems and behavior, another novel and exciting approach is to go one level deeper and test the relationships between specific neurotransmitters and behavior. Recent advances in our understanding of the role of neurotransmitters, and how they relate to processes underlying decision making, may lead to improved understanding of consumer psychology. Few studies, if any, have approached this from a consumer behavior perspective, but insights from studying decision-making on a neurotransmitter-level might serve as a source to generate new research ideas (see Ramsøy & Skov, 2010, for a review). Applying the same idea described above, the neuroscientific tool kit allows us to test associations, necessity, and sufficiency of neurotransmitters and specific consumer behavior (see Kable, 2011, for a more detailed discussion).

Specific brain imaging techniques that allow tracking of changes in neurotransmitters (forms of Positron Emission Tomography (PET)) and the study of genetics allow researchers to make associations between neurotransmitters such as dopamine and a specific behavior such as gambling or other impulsive behaviors.

Administration of pharmacological antagonists or depletion of a specific neurotransmitter (e.g., through dietary restrictions) allows researchers to test necessity. For example, a study by Crockett, Clark, Tabibnia, Lieberman, and Robbins (2008) found that serotonin depletion increased rejection of unfair offers in an ultimatum game.

Along those lines, administration of pharmacological agonist or depletion of a specific neurotransmitter allows researchers to test *specificity*. For example, Kosfeld, Heinrichs, Zak, Fischbacher, and Fehr (2005) demonstrated that administration of oxytocin increased trust during economic exchange. Another example is a study by Schweighofer et al. (2008), who tested the effect of serotonin loading and depletion on reward discounting.

Taken together, studies in consumer psychology can benefit from new tools that allow the testing of association, necessity, and sufficiency of neuropsychological processes and consumer behavior. By expanding the toolbox in consumer neuroscience, advances can be made in our understanding of both basic mechanisms and individual differences in consumer decision making.

Neuroscience as basis for theory generation

Although most of the hype around the potential of consumer neuroscience and neuromarketing evolves around using neuroscientific tools, in this review we would like to suggest neuroscientific findings as a novel source of understanding the mechanisms underlying consumer psychology, as pioneered by Wadhwa, Shiv, and Nowlis (2008) and others (e.g., Lee, Amir, & Ariely, 2009; Van Den Bergh, Dewitte, & Warlop, 2008).

Wadhwa and colleagues investigated the effect of product sampling at the point of sale on subsequent consumption behavior (Wadhwa et al., 2008). The authors compared different hypotheses about whether product sampling would increase subsequent consumption behavior, and if so, whether the effects would be specific to the product sampled, to its product category, or to anything perceived as pleasurable. These predictions were based on different theories from psychology, physiology, and neurophysiology of taste and reward. In a series of experiments, the authors found support for the prediction that our general motivation system in the brain is at work when we sample products, leading to an increased subsequent reward-seeking behavior for any other type of reward. Similarly, a study from Van Den Bergh et al. (2008) found impatience in intertemporal choice to be linked to the activation of the general motivation system in the brain.

Another example is a recent study by Ramsøy, Loving, Skov, and Clement (2011) in which women were studied during different phases of their ovarian cycle. It is well known that this cycle has significant effects on female thinking and behavior, including changes in memory, sexual behavior, and mate selection (Jones et al., 2008; Pillsworth, Haselton, & Buss, 2004; Rupp & Wallen, 2007; Vranić & Hromatko, 2008; Zhu et al., 2010). In particular, recent studies have demonstrated changes in consumer behavior, including the increased likelihood of purchasing and wearing sexually suggestive clothing at peak fertility (Durante, Li, & Haselton, 2008; Durante et al., 2010), although Saad and Stenstrom (2012), interestingly, did not find evidence linking menstrual cycle to attitudes towards brand-related information. Little is known about the exact mechanisms underlying such effects and to what extent menstrual cycle affects the processing of different kinds of brands or advertisements. By using eye tracking to assess visual attention, Ramsøy et al. (2011) found that at peak fertility, women tended to show faster and more frequent fixations and longer total viewing time toward sexual elements in ads. Such effects were not at the cost of visual attention toward brand information and did not have an impact on preference or long-term memory scores. Nevertheless, these findings demonstrate how a known biological factor may influence consumer psychology.

These studies are examples of how scholars in consumer psychology can integrate findings and concepts from neuroscience without actually applying neuroscientific methods. This approach is of great potential for developing an interdisciplinary understanding of how consumers make decisions and may provide significant improvements in our understanding of preference formation and decision making. We hope this review will help researchers as a starting point for generating hypotheses based on an interdisciplinary framework to advance existing theories in consumer psychology.

To conclude, in this last section of this critical review, we have pointed out two major new directions in which neuroscience might advance consumer psychology. These new directions extend first findings in the nascent field of consumer neuroscience related to branding and, more important, help to address the issues of previous work reviewed in this paper. We hope this review provides researchers with exciting new perspectives and ideas for their future work in consumer neuroscience to advance our understanding of the psychology of branding.

Acknowledgments

The authors would like to thank Beth Pavlicek, Anupama Deepa Kumar, and the participants of the INSEAD course “Decision-Making and the Human Brain” for their comments on previous versions of this paper. We thank the participants of the tutorial “Decision Neuroscience” at the University of California at San Diego and University of Southern California for their insightful comments on aspects addressed in this paper. We also thank the editors and the two anonymous reviewers for their valuable feedback and comments.

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A framework for studying the neurobiology of value-based decision making

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Abstract | Neuroeconomics is the study of the neurobiological and computational basis of value-based decision making. Its goal is to provide a biologically based account of human behaviour that can be applied in both the natural and the social sciences. This Review proposes a framework to investigate different aspects of the neurobiology of decision making. The framework allows us to bring together recent findings in the field, highlight some of the most important outstanding problems, define a common lexicon that bridges the different disciplines that inform neuroeconomics, and point the way to future applications.

Value-based decision making is pervasive in nature. It occurs whenever an animal makes a choice from several alternatives on the basis of a subjective value that it places on them. Examples include basic animal behaviours, such as bee foraging, and complicated human decisions, such as trading in the stock market. Neuroeconomics is a relatively new discipline that studies the computations that the brain carries out in order to make value-based decisions, as well as the neural implementation of those computations. It seeks to build a biologically sound theory of how humans make decisions that can be applied in both the natural and the social sciences.

The field brings together models, tools and techniques from several disciplines. Economics provides a rich class of choice paradigms, formal models of the subjective variables that the brain needs to compute to make decisions, and some experimental protocols for how to measure these variables. Psychology provides a wealth of behavioural data that shows how animals learn and choose under different conditions, as well as theories about the nature of those processes. Neuroscience provides the knowledge of the brain and the tools to study the neural events that attend decision making. Finally, computer science provides computational models of machine learning and decision making. Ultimately, it is the computations that are central to uniting these disparate levels of description, as computational models identify the kinds of signals and signal dynamics that are required by different value-dependent learning and decision problems. However, a full understanding of choice will require a description at all these levels.

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doi:10.1038/nrn2357
Published online 11 June 2008

In this Review we propose a framework for thinking about decision making. It has three components: first, it divides decision-making computations into five types; second, it shows that there are multiple types of valuation systems; and third, it incorporates modulating variables that affect the different valuation processes. This framework will allow us to bring together recent findings in the field, highlight some of the most important outstanding problems, define a common lexicon that bridges the different disciplines that inform neuroeconomics, and point the way to future applications. The development of a common lexicon is important because a lot of confusion has been introduced into the literature on the neurobiology of decision making by the use of the unqualified terms 'reward' and 'value'; as shown in the Review, these terms could apply to very different computations.

Computations involved in decision making

The first part of the framework divides the computations that are required for value-based decision making into five basic processes (FIG. 1). The categorization that we propose is based on existing theoretical models of decision making in economics, psychology and computer science[1–3]. Most models in these disciplines assume, sometimes implicitly, that all of these processes are carried out every time an animal makes a value-based decision.

The first process in decision making involves the computation of a representation of the decision problem. This entails identifying internal states (for example, hunger level), external states (for example, threat level)

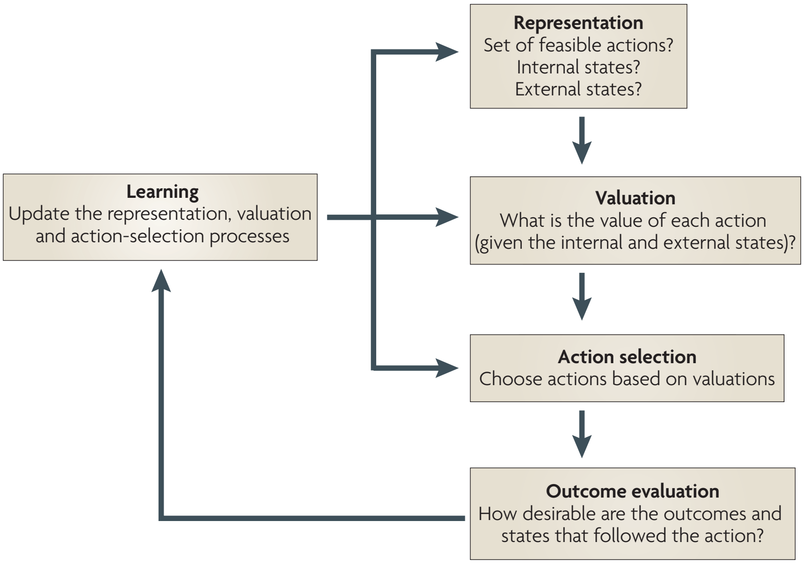


Figure 1 | **Basic computations involved in making a choice.** Value-based decision making can be broken down into five basic processes: first, the construction of a representation of the decision problem, which entails identifying internal and external states as well as potential courses of action; second, the valuation of the different actions under consideration; third, the selection of one of the actions on the basis of their valuations; fourth, after implementing the decision the brain needs to measure the desirability of the outcomes that follow; and finally, the outcome evaluation is used to update the other processes to improve the quality of future decisions.

and potential courses of action (for example, pursue prey). In the second process, the different actions that are under consideration need to be assigned a value (valuation). In order to make appropriate decisions, these values have to be reliable predictors of the benefits that are likely to result from each action. Third, the different values need to be compared for the animal to be able to make a choice (action selection). Fourth, after implementing the decision, the brain needs to measure the desirability of the outcomes. Finally, these feedback measures are used to update the other processes to improve the quality of future decisions (learning).

The five categories are not rigid, and many questions remain about how well they match the computations that are made by the brain. For example, it is not known whether valuation (step 2 in our model) must occur before action selection (step 3), or whether both computations are performed in parallel. Nevertheless, the taxonomy is conceptually useful because it breaks down the decision-making process into testable constituent processes, it organizes the neuroeconomics literature in terms of the computations that are being studied, and it makes predictions about the neurobiology of decision making, such as the hypothesis that the brain must encode distinct value signals at the decision and outcome stages, and the hypothesis that the brain computes a value signal for every course of action under consideration.

Representation

The representation process plays an essential part in decision making by identifying the potential courses of action that need to be evaluated, as well as the internal and external states that inform those valuations. For example, the valuation that a predator assigns to the action 'chasing prey' is likely to depend on its level of hunger (an internal state) as well as the conditions of the terrain (an external variable). Unfortunately, little is known about the computational and neurobiological basis of this step. Basic open questions include: how does the brain determine which actions to assign values to, and thus consider in the decision-making process, and which actions to ignore? Is there a limit to the number of actions that animals can consider at a time? How are internal and external states computed? How are the states passed to the valuation mechanisms described below?

Valuation at the time of choice

On the basis of a sizable body of animal and human behavioural evidence, several groups have proposed the existence of three different types of valuation systems: Pavlovian, habitual and goal-directed systems[4–6] (BOX. 1). These systems are sometimes in agreement but often in conflict (see section on action selection). It is important to emphasize that the precise neural basis of these three distinct valuation systems is yet to fully be established. Although the evidence described below points to neural dissociations between some of the components of the three hypothetical systems, it is possible that they do not map directly onto completely separate neural systems[6–9]. In fact, it is likely that they share common elements. Moreover, even the exact nature and number of valuation systems is still being debated. Nevertheless, conceptually the three systems provide a useful operational division of the valuation problem according to the style of the computations that are performed by each.

Pavlovian systems. Pavlovian systems assign values to a small set of behaviours that are evolutionarily appropriate responses to particular environmental stimuli. Typical examples include preparatory behaviours (such as approaching cues that predict the delivery of food) and consummatory responses to a reward (such as pecking at a food magazine). Analogously, cues that predict a punishment or the presence of an aversive stimulus can lead to avoidance behaviours. We refer to these types of behaviours as Pavlovian behaviours, and to the systems that assign value to them as the Pavlovian valuation systems.

Many Pavlovian behaviours are innate, or 'hardwired', responses to specific predetermined stimuli. However, with sufficient training animals can also learn to deploy them in response to other stimuli. For example, rats and pigeons learn to approach lights that predict the delivery of food. An important difference between Pavlovian systems and the other two systems is that Pavlovian systems assign value to only a small set of 'prepared' behaviours and thus have a limited behavioural repertoire. Nonetheless, a wide range of human behaviours that have important economic consequences might be controlled by Pavlovian systems, such as overeating in the presence of food, behaviours displayed in people with obsessive–compulsive disorders (OCDs) and, perhaps, harvesting immediate smaller rewards at the expense of delayed larger rewards[5,9].

Box 1 | **Examples of behaviours driven by different valuation systems**

Valuation system	Valence	
	Appetitive (rewards)	**Avoidance (punishments)**
Pavlovian	Eat all food on plate	Cross street upon seeing dangerous person
	Reward obtained: food	Punishment avoided: potential harm
Habitual	Morning cup of coffee	Drive usual route to work
	Reward obtained: stimulant	Punishment avoided:traffic
Goal-directed	Movie selection	Go for a run
	Reward obtained: entertainment	Punishment avoided: obesity

Behaviour can be driven by different valuation systems. These systems can operate in the domain of rewards (that is, appetitive outcomes) and punishments (that is, aversive outcomes). Although the exact number of valuation systems and their scope remain to be determined, it is known that behaviour can be influenced by Pavlovian, habitual and goal-directed evaluators. The table contains examples of behaviours that are characteristic of each system. Consummatory actions, such as eating food that is within reach, are assigned a high value by the Pavlovian system regardless of the state of hunger. Routine actions, such as having a cup of coffee in the morning, are assigned a high value by the habitual system regardless of that morning's particular needs. Choices that are made infrequently, such as which movie to see, are assigned values by the goal-directed system.

At first glance, Pavlovian behaviours look like automatic, stimulus-triggered responses, and not like instances of value-based choice. However, as Pavlovian responses can be interrupted by other brain systems, they must be assigned something akin to a 'value' so that they can compete with the actions that are favoured by the other valuation systems.

Characterizing the computational and neural basis of Pavlovian systems has so far proven difficult. This is due in part to the fact that there might be multiple Pavlovian controllers, some of which might be responsible for triggering outcome-specific responses (for example, pecking at food or licking at water) whereas others might be responsible for triggering more general valence-dependent responses (for example, approaching for positive outcomes or withdrawing from negative ones).

The neural bases of active and passive Pavlovian responses to negative stimuli seem to have specific and spatial organizations along an axis of the dorsal periaqueductal grey[10]. With respect to valence-dependent responses, studies that used various species and methods suggested that a network that includes the basolateral amygdala, the ventral striatum and the orbitofrontal cortex (OFC) underlies the learning processes through which neutral stimuli become predictive of the value of outcomes[11,12]. In particular, the amygdala has been shown to play a crucial part in influencing some Pavlovian responses[8,13–15]. Specifically, the central nucleus of the amygdala, through its connections to the brainstem nuclei and the core of the nucleus accumbens, seems to be involved in nonspecific preparatory responses, whereas the basolateral complex of the amygdala seems to be involved in more specific responses through its connections to the hypothalamus and the periaqueductal grey.

Valence
The appetitive or aversive nature of a stimulus.

It is not currently known how many Pavlovian systems exist or how they interact with each other. Other important questions are whether there is a common carrier of Pavlovian value and, if so, how it is encoded; whether learning is possible within these systems; and how Pavlovian systems interact with the other valuation systems — for example, in phenomena such as Pavlovian-instrumental transfer[4].

Habit systems. In contrast to Pavlovian systems, which value only a small set of responses, habit systems can learn, through repeated training, to assign values to a large number of actions. Habit-valuation systems have a number of key characteristics. First, they learn to assign values to stimulus–response associations (which indicate the action that should be taken in a particular state of the world), on the basis of previous experience, through a process of trial-and-error (see the learning section below). Second, subject to some technical qualifications, habit systems learn to assign a value to actions that is commensurate with the expected reward that these actions generate, as long as sufficient practice is provided and the environment is sufficiently stable[3,6,16]. Third, because values are learned by trial-and-error, habit systems are believed to learn relatively slowly. As a consequence, they might forecast the value of actions incorrectly immediately after a change in the action–reward contingencies. Finally, these systems rely on 'generalization' when assigning action values in novel situations. For example, a rat that has learned to lever-press for liquids in response to a sound cue might respond with a similar behaviour when first exposed to a light cue. We refer to the actions that are controlled by these systems as 'habits' and the values that they compute as 'habit values'. Examples of habits include a smoker's desire to have a cigarette at particular times of day (for example, after a meal) and a rat's tendency to forage in a cue-dependent location after sufficient training.

Studies using several species and methods suggest that the dorsolateral striatum might play a crucial part in the control of habits[17,18]. As discussed below, the projections of dopamine neurons into this area are believed to be important for learning the value of actions. Furthermore, it has been suggested that stimulus–response representations might be encoded in cortico-thalamic loops[18]. Lesion studies in rats have shown that the infralimbic cortex is necessary for the establishment and deployment of habits[19,20].

There are many open questions regarding habit systems. Are there multiple habit systems? How do habitual systems value delayed rewards? What are the limits on the complexity of the environments in which the habit system can learn to compute adequate action values? How does the system incorporate risk and uncertainty? How much generalization is there from one state to another in this system (for example, from hunger to thirst)?

Goal-directed systems. In contrast to the habit system, the goal-directed system assigns values to actions by computing action–outcome associations and then evaluating the rewards that are associated with the different outcomes.

Under ideal conditions, the value that is assigned to an action equals the average reward to which it might lead. We refer to values computed by this system as 'goal values' and to the actions that it controls as 'goal-directed behaviours'. An example of a goal-directed behaviour is the decision of what to eat at a new restaurant.

Note that an important difference between habitual and goal-directed systems has to do with how they respond to changes in the environment. Consider, for example, the valuations made by a rat that has learned to press a lever to obtain food, after it is fed to satiation. The goal-directed system has learned to associate the action 'lever-press' with the outcome 'food' and thus assigns a value to the lever-press that is equal to the current value of food — which in this example is low because the animal has been fed to satiation. By contrast, the habit system assigns a high value to the lever-press because this is the value that it learned during the pre-satiation training. Thus, the goal-directed system updates the value of an action as soon as the value of its outcome changes, whereas the habit system does not.

To carry out the necessary computations, the goal-directed system needs to store action–outcome and outcome–value associations. Unfortunately, relatively little is known about the neural basis of these processes. Several rat lesion studies suggest that the dorsomedial striatum has a role in the learning and expression of action–outcome associations[21], whereas the OFC might be responsible for encoding outcome–value associations. Consistent with this, monkey electrophysiology studies have found appetitive goal-value signals in the OFC and in the dorsolateral prefrontal cortex (DLPFC)[22–25]. Electrophysiology experiments in rats point to the same conclusion[26]. In a further convergence of findings across methods and species, human functional MRI (fMRI) studies have shown that blood-oxygen-level-dependent (BOLD) activity in the medial OFC[27–31] and the DLPFC[28] correlates with behavioural measures of appetitive goal values, and individuals with damage to the medial OFC have problems making consistent appetitive choices[32]. Several lines of evidence from these various methods also point to an involvement of the basolateral amygdala and the mediodorsal thalamus (which, in combination with the DLPFC, form a network that Balleine has called the "associative cortico-basal-ganglia loop" (REF. 17)).

Several questions regarding this system remain unanswered. Are there specialized goal-directed systems for reward and punishment, and for different types of goals? How are action–outcome associations learned? How does the goal-directed system assign value to familiar and unfamiliar outcomes? How are action–outcome associations activated at the time that a choice has to be made?

For complex economic choices (such as choosing among detailed health-care plans), we speculate that, in humans, propositional logic systems have a role in constructing associations that are subsequently evaluated by the goal-directed system. For example, individuals might use a propositional system to try to forecast the consequences of a particular action, which are then evaluated by the goal-directed system. This highlights a limitation of the goal-directed system: the quality of its valuations is limited by the quality of the action–outcome associations that it uses.

Propositional logic system
A cognitive system that makes predictions about the world on the basis of known pieces of information.

Outstanding issues. Some general, important questions regarding the different valuation systems remain unanswered. First, are there multiple Pavlovian, habitual and goal-directed valuation systems, with each system specializing in particular classes of actions (in the case of the Pavlovian and habit systems) or outcomes (in the case of the goal-directed system)? For example, consider a dieter who is offered a tasty dessert at a party. If this is a novel situation, it is likely to be evaluated by the goal-directed system. The dieter is likely to experience conflict between going for the taste of the dessert and sticking to his health goals. This might entail a conflict between two goal-directed systems, one that is focused on the evaluation of immediate taste rewards and one that is focused on the evaluation of long-term outcomes. Second, are there more than three valuation systems? Lengyel and Dayan[5,33] have proposed the existence of an additional, 'episodic' system. At this point it is unclear how such a system differs both conceptually and neurally from the goal-directed system. Third, how does the brain implement the valuation computations of the different systems? Finally, how do long-term goals, cultural norms and moral considerations get incorporated into the valuation process? One possibility is that the habit and goal-directed systems treat violations of these goals and cultural and moral rules as aversive outcomes, and that compliance with them is treated as a rewarding outcome[34]. However, this can be the case only if the brain has developed the capacity to incorporate social and moral considerations into its standard valuation circuitry. Another possibility is that there are separate valuation systems for these types of considerations that are yet to be discovered.

Modulators of the valuation systems

Several factors can affect the values that the Pavlovian, habitual and goal-directed systems assign to actions. For example, the value that is assigned to an action might depend on the riskiness of its associated payoffs, the delay which with those payoffs occur and the social context. We refer to these types of variables as value modulators. Importantly, modulators might have different effects in each of the valuation systems. In this section we focus on the impact of risk and delay on the goal-directed valuation system, as most of the existing evidence pertains to this system. For reviews on social modulators, see REFS 35,36.

Risk and uncertainty. All decisions involve some degree of risk, in the sense that action–outcome associations are probabilistic (BOX 2). We refer to an action that has uncertain rewards as a 'prospect'. In order to make good decisions, the goal-directed system needs to take into account the likelihood of the different outcomes. Two hotly debated questions are: first, what are the computations that the goal-directed system uses to incorporate

Statistical moments
Properties of a distribution, such as mean and variance.

risks into its valuations; and second, how does the brain implement such computations[37]?

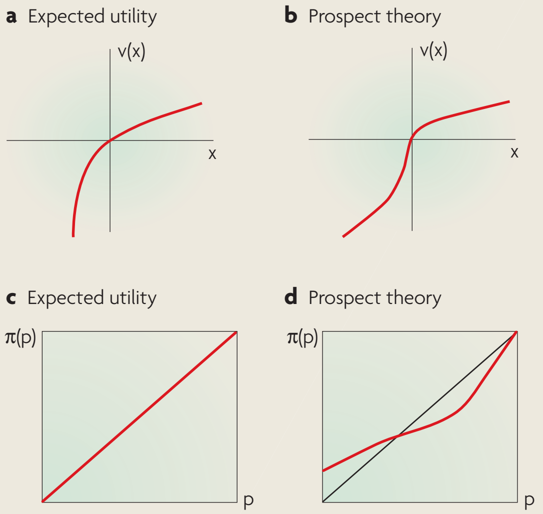
Early human neuroimaging studies in this topic identified some of the areas that are involved in making risky decisions, but were not able to characterize the nature of the computations made by these systems[38–41]. Currently, two main competing views regarding the nature of such computations are being tested. The first view, which is widely used in financial economics and behavioural ecology, asserts that the brain assigns value to prospects by first computing its statistical moments (such as its expected magnitude, its variance or coefficient of variation, and its skewness) and then aggregating them into a value signal[42,43]. The second view, which is widely used in other areas of economics and in psychology, asserts that the value is computed using either expected-utility theory (EU) or prospect theory (PT) (BOX 2). In this case the brain needs to compute a utility value for each potential outcome, which is then weighted by a function of the probabilities.

Decisions that result from an EU or PT valuation function can be approximated by a weighted sum of the prospects' statistical moments (and vice versa). This makes it difficult to distinguish the two views on the basis of behavioural data alone. Neuroimaging studies can provide important insights, although the debate between the two views has not yet been settled. In agreement with the first view, a number of recent human fMRI studies have found activity that is consistent with the presence of expected value signals in the striatum[44,45] and the medial OFC[46], and activity that is consistent with risk signals (as measured by the mathematical variance of the prospects) in the striatum[44,47], the insula[46,48] and the lateral OFC[45]. Similar risk and expected-value signals have been found in the midbrain dopamine system in electrophysiology studies in non-human primates[49]. Expected-value signals (BOX 2) have also been found in the lateral intraparietal cortex in non-human primate electrophysiology experiments[50]. Consistent with the second view, a recent human fMRI study found evidence for a PT-like value signal in a network that includes the ventral and dorsal striatum, the ventromedial and ventrolateral prefrontal cortex, the anterior cingulate cortex (ACC) and some midbrain dopaminergic regions[27]. The existence of evidence that is consistent with both views presents an apparent puzzle. A potential resolution that should be explored in future studies is that the striatal-prefrontal network might integrate the statistical moments that are encoded elsewhere into a value signal that exhibits EU- or PT-like properties.

In many circumstances, decision makers have incomplete knowledge of the risk parameters — a situation known as ambiguity that is different from the pure risk case in which the probabilities are known. Human behavioural studies have shown that people generally have an aversion to choices that are ambiguous[51], which suggests that a parameter that measures the amount of ambiguity might be encoded in the brain and might be used to modulate the value signal. Some preliminary human fMRI evidence points to the amygdala, the OFC[52] and the anterior insula[53] as areas where such a parameter might be encoded.

Some issues regarding risk and valuation are still unclear. First, little is known about how risk affects the computation of value in Pavlovian and habitual systems. For example, most reinforcement learning models (see below) assume that the habit learning system encodes a value signal that incorporates expected values but not risks. This assumption, however, has not been thoroughly tested. Second, little is known about how the brain learns the risk parameters. For example, some behavioural

Box 2 | Risk modulators of value in the goal-directed system



Many decisions involve the valuation of rewards and costs that occur probabilistically, often called 'prospects'. There are two dominant theories in economics about how valuation systems incorporate probability in the assignment of value. In expected-utility theory (EU), the value of a prospect equals the sum of the value of the individual outcomes, *v(x)*, weighted by their objective probability, *p(x)*, which is given by $\sum_x p(x)v(x)$. Under some special assumptions on the function *v(.)*, which are popular in the study of financial markets, the EU formula boils down to a weighted sum of the expected value and the variance of the prospect[42]. The appeal of EU comes from the fact that it is consistent with plausible normative axioms for decision making, from its mathematical tractability and from its success in explaining some aspects of market behaviour. An alternative approach, called prospect theory (PT), states that the value of a prospect equals $\sum_x \pi(p(x))v(x-r)$, where the values of the outcomes now depend on a reference point, r, and are weighted by a nonlinear function, $\pi(.)$, of the objective probabilities[122,123]. Reference-dependence can create framing effects (analogous to figure–ground switches in vision), in which different values are assigned to the same prospect depending on which reference point is cognitively prominent. The figure illustrates the usual assumptions that are imposed in the value and probability functions by the two theories. As shown in parts **a** and **c**, in EU the value function, *v(.)*, is a concave function of outcomes, and the probability function is the identity function. Note that a special case that is often used in the experimental neuroeconomics literature is $v(x) = x$, which makes the EU function reduce to the expected value of the prospect. The properties of PT are illustrated in parts **b** and **d**. The value function is usually revealed by choices to be concave for gains but convex for losses. This assumption is justified by the psychologically plausible assumption of diminished marginal sensitivity to both gains and losses starting from the reference point. PT also assumes that $v(x) < -v(-x)$ for $x > 0$, a property called 'loss-aversion', which leads to a kink in the value function. Part **d** illustrates the version of PT in which small probabilities are overweighted and large probabilities are underweighted. PT has been successful in explaining some behaviour that was inconsistent with EU theory in behavioural experiments with humans[123] and monkeys[124], as well as economic field evidence[125].

Neuroeconomists make a distinction between prospects that involve risk and those that involve ambiguity. Risk refers to a situation in which all of the probabilities are known. Ambiguity refers to a situation in which some of the probabilities are unknown. The EU and PT models described above apply to valuation under risk, but not under ambiguity. Several models of valuation under ambiguity have been proposed, but none of them has received strong empirical support[51,126,127].

Expected-utility theory
A theory that states that the value of a prospect (or of random rewards) equals the sum of the value of the potential outcomes weighted by their probability.

Prospect theory
An alternative to the expected utility theory that also pertains to how to evaluate prospects.

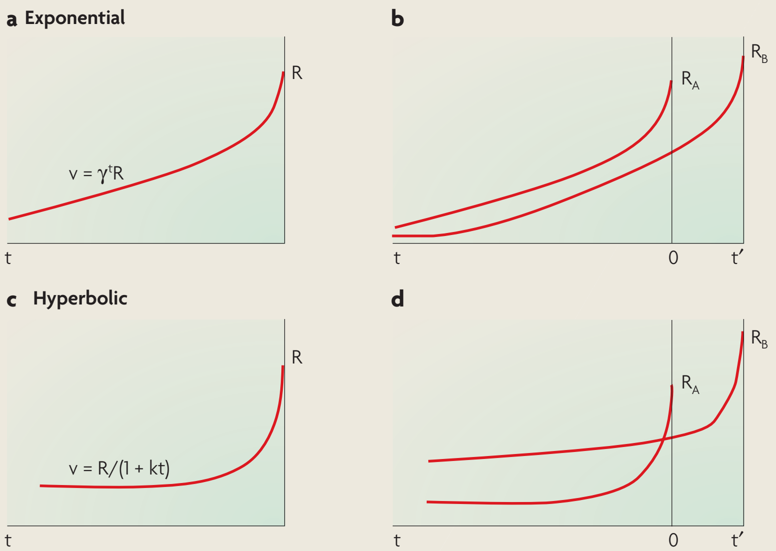
evidence suggests that habit and goal-directed systems learn about probabilities in different ways and that this leads to different probability weighting by the two systems[54]. Finally, more work is required to better characterize the nature of the computations that are made by the amygdala and the insula in decision making under uncertainty. Preliminary insights suggest that the amygdala might have an asymmetric role in the evaluation of gains and losses. For example, humans with amygdala damage made poor decisions if the decisions involved potential gains, but not if they involved losses[55], and a related study showed that the amygdala is differentially activated when subjects decide to take risks for large gains and when they decide to accept a sure loss[56].

Time discounting. In all real-world situations there is a time lag between decisions and outcomes. From a range of behavioural experiments it is well-established that the goal-directed and habitual systems assign lower values to delayed rewards than to immediate ones; this phenomenon is known as time discounting[57]. The role of time discounting in the Pavlovian system is not as well-understood. As before, we focus on the impact of temporal discounting on the goal-directed system, as this is where most of the studies so far have focused.

The current understanding of time discounting parallels that for risk: two competing views have been proposed and are being tested using a combination of human-behavioural and neuroimaging experiments. One camp interprets the human fMRI evidence using the perspective of dual-process psychological models and has argued that discounting results from the interaction of at least two different neural valuation systems (BOX 3), one with a low discount rate and one with a high discount rate[58–60]. In this view, the patience that is exhibited by any given individual when making decisions depends on the relative activation of these two systems. In sharp contrast, the other camp has presented human fMRI evidence that suggests that there is a single valuation system that discounts future rewards either exponentially or hyperbolically[61] (BOX 3). As with the situation for risk valuation, this presents an apparent puzzle. A potential reconciliation is that the striatal-prefrontal network might integrate information that is encoded elsewhere in the brain into a single value signal, but that immediate and delayed outcomes might activate different types of information that are used to compute the value. For example, immediate rewards might activate 'immediacy markers' that increase the valuation signals in the striatal-prefrontal network. An understanding of these issues is also important from the perspective of brain development. When do value signals get computed in their 'adult' form and how do they contribute to choices made by children and adolescents? These and other related questions show that the economic framing of decision making will continue to provide new ways to probe the development and function of choice mechanisms in humans.

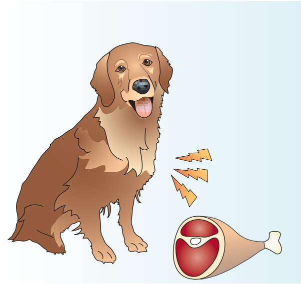
Time discounting remains a fruitful topic of investigation. First, the discounting properties of Pavlovian and habitual systems in humans have not been systematically explored. Second, the inputs to the valuation network are unknown, as is the reason why the aggregation of those inputs produces a hyperbolic-like signal in valuation areas such as the ventral striatum and the medial OFC. Third, the behavioural evidence suggests that discount factors are highly dependent on contextual variables. For example, subjects' willingness to delay gratification depends on whether the choice is phrased as a "delay" or as a "choice between two points in time" (REF. 62), on how they are instructed to think about the rewards[63] and on the subjects' arousal level[64]. The mechanisms through which such variables affect the valuation process

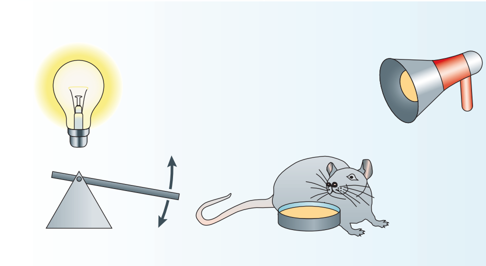
Box 3 | **Temporal modulators of value in the goal-directed system**

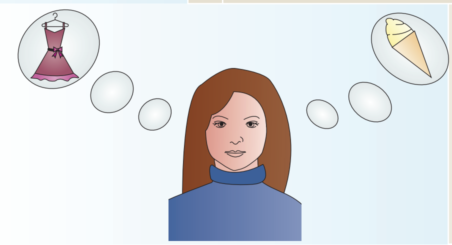


Many decisions involve the evaluation of rewards and costs that arrive with different delays. Thus, the valuation systems require a mechanism for incorporating the timing of rewards into their computations. Two prominent models of discounting have been proposed in psychology and economics. In the first model, known as hyperbolic discounting, rewards and costs that arrive t units of time in the future are discounted by a factor $1/(1+kt)$. Note that the discount factor is a hyperbolic function of time and that a smaller k is associated with less discounting (that is, more patience). In the second model, known as exponential discounting, the corresponding discount factor is γ^t. Note that a value of γ closer to one is associated with more patience. An important distinction between the two models is illustrated in parts **a** and **c** of the figure, which depict the value of a reward of size R t units of time before it arrives. Note that whereas every additional delay is discounted at the same rate (γ) in the exponential case, in hyperbolic discounting initial delays are discounted at a much higher rate and the discount curve flattens out for additional delays.

In most comparative behavioural studies of goal-directed behaviour with adequate statistical power, hyperbolic discount functions always fit the observed behaviour better than exponential functions[57]. Nevertheless, economists and computer scientists find the exponential function appealing because it is the only discount function that satisfies the normative principle of dynamic consistency, which greatly simplifies modelling. This property requires that if a reward, A, is assigned a higher value than another reward, B, at time t, then the same reward is also assigned a higher value when evaluated at any time $t–k$. Under hyperbolic discounting, by contrast, the relative valuation between the two actions depends on when the choice is made. This is known as dynamic inconsistency. Parts **b** and **d** of the figure illustrate this difference. They depict the comparative value of a reward, R_A, received at time 0 with a reward, R_B, received at time t' as a function of the time when the rewards are being evaluated. Note that in the exponential case the relative desirability of the two rewards is constant, whereas for the hyperbolic case it depends on the time of evaluation.







	Pavlovian	Habitual	Goal-directed
Pavlovian	Example: hungry animal presented with food and electric shock simultaneously Appetitive Pavlovian system: high value for food, low value for escape behaviours Avoidance Pavlovian system: high value for escape behaviours, low value for food	Example: animal rewarded for running away from food Appetitive Pavlovian system: high value for running towards food Avoidance habitual system: high value for running away from food	Example: individual considering taking an extra bite after feeling full Appetitive Pavlovian system: high value for food Health goal-directed system: low value for food
Habitual		Example: an animal trained to run towards a lever in response to a sound and away from a lever in response to a light being presented with both stimuli Approach habitual system: high value for lever approach Avoidance habitual system: high value for lever avoidance	Example: alcoholic considering having a drink at a bar Appetitive habitual system: high value for drink Avoidance goal-directed system: low value for drink
Goal-directed			Example: dieter considering having ice-cream Appetitive goal-directed system: high value for ice-cream Avoidance goal-directed system: low value for ice-cream

Figure 2 | **Conflict between the valuation systems.** The different valuation systems are often in agreement. For example, when an individual is hungry at meal time, the Pavlovian, habitual and goal-directed systems assign high value to the consumption of food. However, conflicts between the systems are also common and might lead to poor decision making. This figure provides examples of conflict among the different valuation systems and of conflict among different value signals of the same type.

are unknown. Fourth, several studies have shown that the anticipation of future rewards and punishments can affect subjects' behavioural discount rates[65,66]. The mechanisms through which anticipation affects valuation are also unknown. Finally, animals make very myopic choices that are consistent with large hyperbolic discount rates[67–70]. How do humans and animals differ in the way in which they incorporate temporal delays into the valuation process?

Action selection

Even for choices that involve only one of the valuation systems discussed above, options with different values need to be compared in order to make a decision. Little is known about how the brain does this. The only available theoretical models come from the literature on perceptual decision making, which has modelled binary perceptual choices as a race-to-barrier diffusion process[71–76]. However, it is unclear whether this class of model also applies to value-based decision making and, if so, how the models might be extended to cases of multi-action choice.

Another issue is the competition that arises among the different valuation systems when an animal has to make a choice between several potential actions that are assigned conflicting values (FIG. 2). Some preliminary theoretical proposals have been made, but the experimental evidence is scarce. Daw *et al.*[77] have suggested that the brain arbitrates between the habit and goal-directed valuation systems by assigning control to the system that at any given time has the less uncertain estimate of the true value of the actions. As the quality of the estimates that are made by the habit system increases with experience, this means in practice that the habit system should gradually take over from the goal-directed system[34]. Frank has proposed a neural-network model for choice between appetitive and aversive habitual valuations[78,79].

Understanding how the 'control assignment' problem is resolved is important for several reasons. First, as illustrated in FIG. 2 and as emphasized by Dayan *et al.*[9], many apparently puzzling behaviours are likely to arise as a result of the conflict between the different valuation systems. Second, in most circumstances the quality of decision making depends on the brain's ability to assign control to the valuation system that makes the best value forecasts. For example, it is probably optimal to assign control to the habit system in familiar circumstances, but not in rapidly changing environments. Third, some decision-making pathologies (for example, OCD and overeating) might be due to an inability to assign control to the appropriate system.

Dual-process models
A class of psychological models in which two processes with different properties compete to determine the outcome of a computation.

Race-to-barrier diffusion process
A stochastic process that terminates when the variable of interest reaches a certain threshold value.

There are many important open questions in the domain of action selection. First, in the case of goal-directed decisions, does the brain make decisions by comparing the value of outcomes, of the actions that are necessary to achieve those outcomes, or both? Second, what is the neural basis of the action-selection processes in the Pavlovian, habitual and goal-directed systems? Third, what are the neural mechanisms that are used to arbitrate between the different controllers, and is there a hierarchy of controllers so that some (for example, Pavlovian systems) tend to take precedence over others (for example, goal-directed systems)? Fourth, are there any neural markers that can be reliably used to identify goal-directed or habitual behavioural control?

Outcome evaluation

In order to learn how to make good decisions the brain needs to compute a separate value signal that measures the desirability of the outcomes that were generated by its previous decisions. For example, it is useful for an animal to know whether the last food that it consumed led to illness so that it can know whether it ought to avoid that food in the future.

The computations that are made by the outcome-evaluation system, as well as the neural basis of these computations, are slowly beginning to be understood. The existing evidence comes from several different methods and species. Human fMRI studies have shown that activity in the medial OFC at the time that a reward is being enjoyed correlates with subjective reports about the quality of the experience — this has been shown for olfactory[80–83], gustatory[84–86] and even musical rewards[87]. Moreover, the activity in the medial OFC parallels the reduction in outcome value that one would expect after a subject is fed to satiation[88,89]. This suggests that the medial OFC might be an area where positive outcome valuations are computed. Interestingly, other human fMRI studies have found positive responses in the medial OFC to the receipt of secondary reinforcers, such as monetary payoffs[90–92]. Analogous results have been found for negative experiences: in humans, subjective reports of pain intensity correlated with activity in the insula and the ACC[93,94].

Animal studies have also provided insight into the neural basis of the outcome-value signal. A recent electrophysiology experiment in monkeys found outcome-value signals in the dorsal ACC[95]. In addition, a series of provocative rat studies showed that it is possible to increase outward manifestations of 'liking' in rats (for example, tongue protrusions) by activating the nucleus accumbens and subsets of the ventral pallidum using opioid agonists[85,96–98]. Interestingly, and consistent with the hypothesis that outcome-evaluation signals play a part in learning, rats that received opioid agonists subsequently consumed more of the reward that was paired with the agonist.

Some recent human fMRI experiments have also provided novel insights into the computational properties of the outcome-value signal. For example, one study showed that activity in the medial OFC in response to an odour depended on whether subjects believed that they were smelling cheddar cheese or a sweaty sock[83]. In another study[99], activity in the medial OFC in response to the consumption of wine depended on beliefs about its price, and a third study[84] showed that the outcome-valuation signal after consumption of soda depended on beliefs about its brand. Together, these findings suggest that the outcome-valuation system is modulated by higher cognitive processes that determine expectancies and beliefs.

Much remains to be understood about the outcome-valuation system. What network is responsible for computing positive and negative outcome values in different types of domains? How are positive and negative outcome-valuation signals integrated? How are these signals passed to the learning processes described in the next section? Can they be modulated by variables such as long-term goals, social norms and moral considerations?

Learning

Although some Pavlovian behaviours are innate responses to environmental stimuli, most forms of behaviour involve some form of learning. In fact, in order to make good choices animals need to learn how to deploy the appropriate computations during the different stages of decision making. First, the brain must learn to activate representations of the most advantageous behaviours in every state. This is a non-trivial learning problem given that animals and humans have limited computational power, and yet they can deploy a large number of behavioural responses. Second, the valuation systems must learn to assign to actions values that match their anticipated rewards. Finally, the action-selection processes need to learn how to best allocate control among the different valuation systems.

Of all of these processes, the one that is best-understood is the learning of action values by the habit system. In this area there has been a productive interplay between theoretical models from computer science (BOX 4) and experiments using electrophysiology in rats and monkeys and fMRI in humans. In particular, various reinforcement learning models have been proposed to describe the computations that are made by the habit system[3,100]. The basic idea behind these models is that a prediction-error signal is computed after observing the outcome generated by every choice. The signal is called a prediction error because it measures the quality of the forecast that was implicit in the previous valuation (BOX 4). Every time a learning event occurs, the value of the actions is changed by an amount that is proportional to the prediction error. Over time, and under the appropriate technical conditions, the animal learns to assign the correct value to actions.

The existence of prediction-error-like signals in the brain is one of the best-documented facts in neuroeconomics. Schultz and colleagues initially observed such signals in electrophysiology studies performed in midbrain dopamine neurons of monkeys[101–106]. The connection between these signals and reinforcement-learning models was made in a series of papers by Montague and colleagues that were published in the 1990s[103,107]. Since then, several fMRI studies have

Box 4 | Reinforcement learning models action-value learning in the habitual system

Several models from computer science have proved to be useful in modelling how the habitual system learns to assign values to actions. All of these models have the following structure, which is known as a Markovian decision problem: first, the animal can be in a finite set of states and can take a finite set of actions; second, there is a transition function, $T(s,a,s')$, that specifies the probability that state s and action a at one time-step will result in the state s' at the next time-step; and third, at every time-step the animal obtains an action and a state-contingent reward, $r(a,s)$. A behavioural rule in this world (called a policy and denoted by $\pi(s)$) specifies the action that the animal takes in every state. In this world the habitual system needs to solve two problems. First, given a policy, it needs to compute the value of taking every action a in every state s. This is given by

$$Q^{\pi}(s, a) = E[r_t + \gamma r_{t+1} + \gamma^2 r_{t+2} + \gamma^3 r_{t+3} + \ldots \mid s_t = s, a_t = a, a_{t+1} = \pi(s_{t+1}), \ldots]; \quad (1)$$

where r_{t+k} denotes the reward that is received at time $t + k$ and where $\gamma > 0$ is the discount rate. Second, it needs to identify the policy that generates the largest sum of exponentially discounted rewards (see BOX 3) in every state.

How could the habitual system learn $Q^{\pi}(s,a)$? Let $Q^{\pi}(s, a)$ denote the estimate that the system has at any point in time. Equation 1 can be rewritten in recursive form as

$$Q^{\pi}(s, a) = R(s) + \gamma \sum_{s' \in S} T(s, a, s')\, Q^{\pi}(s', \pi(s')) \quad (2)$$

Consider an estimator, $\hat{Q}(s, a)$, of $Q^{\pi}(s, a)$. Note that if $\hat{Q}(s, a)$ does not satisfy this expression, then it is not a good estimate of the value function. Define a prediction error

$$\delta_t = r_t + \gamma\, max_{a'} [\hat{Q}(s_{t+1}, a')] - \hat{Q}(s_t, a_t) \quad (3)$$

that is a sample measure of how close the estimate is to satisfying equation 2. If $\delta_t > 0$ the value of the action is overestimated; if $\delta_t < 0$ the value is underestimated. One can then use the prediction error to update the estimates of the action values as follows:

$$\hat{Q}(s_t, a_t) \leftarrow Q(\hat{s_t}, a_t) + \eta\delta_t \quad (4)$$

where η is a number between 0 and 1 that determines the speed of learning. This model is known as Q-learning and it satisfies one important property: subject to some technical conditions, the estimated action values converge to those that are generated by the optimal policy. It then follows that the animal can learn the optimal policy simply by following this algorithm and, at every step of the learning process, selecting the actions with the largest values. Two other variants of this model have been proposed as descriptions of how the habitual system learns. They are known as SARSA and the actor–critic model. They differ from Q-learning on the exact specification of the prediction error and the update rule, but they are based on essentially the same idea. Note that neither SARSA nor the actor–critic model is guaranteed to converge to the optimal policy.

It is worth emphasizing several properties of these learning models. First, they are model-free in the sense that the animal is not assumed to know anything about the transition function or the reward function. Second, they explain a wide range of conditioning behaviours that are associated with the habitual system, such as blocking, overshadowing and inhibitory conditioning. Finally, they are computationally simple in the sense that they do not require the animal to keep track of long sequences of rewards to learn the value of actions.

The reinforcement-learning models described here are often used to describe the process of action-value learning in the habitual system. The algorithms that the Pavlovian and goal-directed systems use to update their values based on feedback from the environment are currently unknown.

shown that, in humans, the BOLD signal in the ventral striatum (an important target of midbrain dopamine neurons) correlates with prediction errors in a wide range of tasks[29,90,108–113].

Although the existing evidence suggests that there is a remarkable match between the computational models and the activity of the dopamine system, recent experiments have demonstrated that much remains to be understood. First, a monkey electrophysiology study[114] suggested that the phasic firing rates of midbrain dopamine neurons might only encode the positive component of the prediction error (henceforth the 'positive prediction error'). This raises the question of which brain areas and neurotransmitter systems encode the negative component (henceforth the 'negative prediction error'), which is also essential for learning. Several possibilities have been proposed. A secondary analysis[115] of the monkey electrophysiology experiment[114] suggested that the magnitude of the negative prediction errors might be encoded in the timing of the fire-and-pause patterns of the dopamine cells[115]. Some human fMRI studies have found a BOLD signal in the amygdala that resembles a negative prediction error[108], but others have failed to replicate this finding and have instead found evidence for both types of prediction error in different parts of the striatum[116]. In turn, Daw and Dayan[117] proposed that the two prediction-error signals are encoded by the phasic responses of two neurotransmitter systems: dopamine for positive prediction errors and serotonin for negative prediction errors. Second, it was shown that midbrain dopamine neurons adjust their firing rates to changes in the magnitude of reward in a way that is inconsistent with the standard interpretation of prediction errors[49]. The exact nature of these adjustments remains an open

Box 5 | From neuroeconomics to computational psychiatry

Sometimes the brain's decision-making processes function so differently from societal norms that we label the ensuing behaviours and perceptions a psychiatric disease. The medical community recognizes and categorizes them according to well-accepted diagnostic criteria that, so far, have relied mostly on collections of behavioural features. Neuroscientists have accumulated a substantial amount of neurobiological data that impinges directly on these illnesses[128]. For example, there are now animal models for nicotine addiction, anxiety, depression and schizophrenia that have produced a veritable flood of data on neurotransmitter systems, receptors and gene expression[129,130]. Thus, there is a substantial body of biological data and detailed descriptions of the behavioural outcomes, but little is known about what connects them. This situation presents an opportunity for neuroeconomics and other computationally oriented sciences to connect the growing body of biological knowledge to the behavioural end points.

Computational models of reinforcement learning provide a new language for understanding mental illness and a starting point for connecting detailed neural substrates to behavioural outcomes. For example, reinforcement-learning models predict the existence of valuation malfunctions, in which a drug, a disease or a developmental event perturbs the brain's capacity to assign appropriate value to behavioural acts or mental states[34,131–133].

Disorders of decision making can also arise at the action-selection stage, especially when there are conflicts among the valuation systems. This presents the possibility of generating a new quantifiable taxonomy of mental-disease states. Interestingly, this set of issues is closely related to the problem of how to think about the 'will' and has applications to addiction, obsessive–compulsive disorder and obesity. These issues relate directly to the idea of executive control and the way that it is affected by mental disease. It is our opinion that future progress in this area will require more computational approaches, because only through such models can competing ideas of executive control be clearly differentiated. Such efforts are already well underway, and various modelling efforts have been applied to executive control and decision making in humans[79,134,135].

Another neuroeconomics concept that is ripe for applications to psychiatry is motivation, which is a measure of how hard an animal works in order to retrieve a reward. Disorders of motivation might play an especially important part in mood disorders, such as depression, and in Parkinson's disease[78,136].

question[43]. Finally, a study showed that the habit system can also learn from observing the outcomes of actions that it did not take, as opposed to only being able to learn from direct experience[118]. This form of 'fictive learning' is not captured by traditional reinforcement-learning models but is common in human strategic learning and suggests that the theory needs to be extended in new directions (to include, among others, imitative learning from observing the actions of others)[119].

Other important questions in the domain of value learning include the following: how does the goal-directed system learn the action-outcome and outcome-value representations that it needs to compute action values? What are the limitations of the habit system in situations in which there is a complex credit-assignment problem (because actions and outcomes are not perfectly alternated) and delayed rewards? How does the habit system learn to incorporate internal and external states in its valuations and generalize across them? How do the different learning systems incorporate expected uncertainty about the feedback signals[43]? To what extent can the different value systems learn by observation as opposed to through direct experience[120]?

The next 5 years and beyond

Although neuroeconomics is a new field and many central questions remain to be answered, rapid progress is being made. As illustrated by the framework provided in this Review, the field now has a coherent lexicon and research aims. The key challenge for neuroeconomics over the next few years is to provide a systematic characterization of the computational and neurobiological basis of the representation, valuation, action-comparision, outcome-valuation and value-learning processes described above. This will prove to be challenging because, as we have seen, at least three valuation systems seem to be at work, fighting over the control of the decision-making process.

Nevertheless, several welcome developments suggest that the next 5 years will produce significant progress in answering many of the questions outlined here. First, there is the close connection between theory and experiments, and the widespread use of theory-driven experimentation (including behavioural parameters inferred from choices that can be linked across subjects or trials to brain activity). Second, there is the rapid adoption of new technologies, such as fast cyclic voltammetry in freely moving animals[121], which permits quasi-real-time monitoring of neurotransmitter levels for long periods. Third, there is the investigation of decision-making phenomena using different species and experimental methods, which permits more rapid progress.

This is good news, because the range of potential applications is significant. The most important area in which knowledge from neuroeconomics can be applied is psychiatry. Many psychiatric disorders involve a failure of one or more of the decision-making processes described here (BOX 5). A better understanding of these processes should lead to improved diagnosis and treatment. Another area of application is the judicial system. A central question in many legal procedures is how to define and measure whether individuals are in full command of their decision-making faculties. Neuroeconomics has the potential to provide better answers to this question. Similarly, an improved understanding of why people experience failures of self-control should lead to better public-policy interventions in areas ranging from addiction and obesity to savings. The field also has the potential to improve our understanding of how marketing affects decisions and when it should be

Credit-assignment problem
The problem of crediting rewards to particular actions in complex environments.

regulated. Artificial intelligence is another fertile area of application: a question of particular interest is which features of the brain's decision-making mechanisms are optimal and should be imitated by artificial systems, and which mechanisms can be improved upon. Finally, neuroeconomics might advance our understanding of how to train individuals to become better decision-makers, especially in conditions of extreme time-pressure and large stakes, such as those that arise in policing, in war and in fast-paced financial markets.

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Acknowledgements

Financial support from the National Science Foundation (SES-0134618, A.R.) and the Human Frontier Science Program (C.F.C.) is gratefully acknowledged. This work was also supported by a grant from the Gordon and Betty Moore Foundation to the Caltech Brain Imaging Center (A.R., C.F.C.). R.M. acknowledges support from the National Institute on Drug Abuse, the National Institute of Neurological Disorders and Stroke, The Kane Family Foundation, The Angel Williamson Imaging Center and The Dana Foundation.

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SCIENCE AND SOCIETY

Neuromarketing: the hope and hype of neuroimaging in business

Dan Ariely and Gregory S. Berns

Abstract | The application of neuroimaging methods to product marketing — neuromarketing — has recently gained considerable popularity. We propose that there are two main reasons for this trend. First, the possibility that neuroimaging will become cheaper and faster than other marketing methods; and second, the hope that neuroimaging will provide marketers with information that is not obtainable through conventional marketing methods. Although neuroimaging is unlikely to be cheaper than other tools in the near future, there is growing evidence that it may provide hidden information about the consumer experience. The most promising application of neuroimaging methods to marketing may come before a product is even released — when it is just an idea being developed.

Despite many common beliefs about the inherently evil nature of marketing, the main objective of marketing is to help match products with people. Marketing serves the dual goals of guiding the design and presentation of products such that they are more compatible with consumer preferences and facilitating the choice process for the consumer. Marketers achieve these goals by providing product designers with information about what consumers value and want before a product is created. After a product emerges on the marketplace, marketers attempt to maximize sales by guiding the menu of offerings, choices, pricing, advertising and promotions.

In their attempts to provide these types of inputs, marketers use a range of market research techniques, from focus groups and individual surveys to actual market tests — with many approaches in between (see Supplementary information S1 (box)). In general, the simpler approaches (focus groups and surveys) are easy and cheap to implement but they provide data that can include biases, and are therefore seen as not very accurate[1–4]. The approaches that are more complex and therefore harder to implement, such as market tests, provide more accurate data but incur a higher cost, and the product, production and distribution systems have to be in place for market tests to be conducted. There are some compromise approaches between these two extremes, which include simulated markets, conjoint analyses, markets for information and incentive-compatible pricing studies (see Supplementary information S1 (box)). As in all compromises, these approaches provide solutions with intermediate levels of cost, simplicity, realism and quality of data (TABLE 1).

The incorporation of neuroimaging into the decision-making sciences — for example, neuroeconomics — has spread to the realm of marketing. As a result, there are high hopes that neuroimaging technology could solve some of the problems that marketers face. A prominent hope is that neuroimaging will both streamline marketing processes and save money. Another hope is that neuroimaging will reveal information about consumer preferences that is unobtainable through conventional methods. Of course, with such high expectations, there is the accompanying hype. Several popular books and articles have been published that push a neuromarketing agenda, and there are now a handful of companies that market neuromarketing itself[5]. In this Perspective, we aim to distinguish the legitimate hopes from the marketing hype. As such, we hope that this article serves the dual purpose of recognizing the real potential of neuroimaging in business and providing a guide for potential buyers and sellers of such services.

Why use brain imaging for marketing?

Marketers are excited about brain imaging for two main reasons. First, marketers hope that neuroimaging will provide a more efficient trade-off between costs and benefits. This hope is based on the assumptions that people cannot fully articulate their preferences when asked to express them explicitly, and that consumers' brains contain hidden information about their true preferences. Such hidden information could, in theory, be used to influence their buying behaviour, so that the cost of performing neuroimaging studies would be outweighed by the benefit of improved product design and increased sales. In theory, at least, brain imaging could illuminate not only what people like, but also what they will buy.

Thus far, this approach to neuromarketing has focused on this post-design application, in particular on measuring the effectiveness of advertising campaigns. The general approach has been to show participants a product advertisement, either in the form of a print advertisement or commercial, and measure the brain's response in the form of a blood oxygenation level-dependent (BOLD) measurement, which is taken as a proxy for neural activation.

The second reason why marketers are excited about brain imaging is that they hope it will provide an accurate marketing research method that can be implemented even before a product exists (FIG. 1). The assumption is that neuroimaging data would give a more accurate indication of the underlying preferences than data from standard market research studies and would remain insensitive to the types of biases that are often a hallmark of subjective approaches to valuations. If this is indeed the case, product concepts could be tested rapidly, and those that are not promising eliminated early in the process. This would allow more efficient allocation of resources to develop only promising products.

Thus, the issue of whether neuroimaging can play a useful part in any aspect of marketing depends on three fundamental questions, which we will address in this paper. First, can neuromarketing reveal hidden information that is not apparent in other approaches? Second, can neuromarketing provide a more efficient cost–benefit trade-off than other marketing research approaches? Third, can neuromarketing provide early information about product design?

Revealing hidden information

Brain activity and preference measurement. Allowing for the assumption in neuromarketing that the brain contains hidden information about preferences, it is reasonable to set aside, for the moment, the issue of 'hidden' and ask what relationships are known to exist between brain activity and expressed (that is, not hidden) preference.

As it turns out, different methods of eliciting a person's preference often result in different estimations of that preference[3,4,6,7].

Table 1 | **Comparison of selected marketing research approaches**

	Focus groups	Preference questionnaires	Simulated choice methods	Market tests
What is measured	Open-ended answers, body language and behaviour; not suitable for statistical analysis	Importance weighting for various product attributes	Choices among products	Decision to buy and choice among products
Type of response process	Speculative, except when used to assess prototypes	The respondent must try to determine his decision weightings through introspection, then map those weightings into the response scale	A hypothetical choice, so the same process as the actual purchase — but without monetary consequences	An actual choice, with customers' own money, and therefore fully consequential
Typical use in new-product development processes	Early on to aid general product design; at user interface design for usability studies	Design phase, when determining customer trade-offs is important	Design phase, when determining customer trade-offs is important; may also be used as a forecasting tool	End of process, to forecast sales and measure the response to other elements of marketing, such as price
Cost and competitive risk	Low cost; risk comes only from misuse of data by the seller	Moderate cost and some risk of alerting competitors	Moderate cost (higher if using prototypes instead of descriptions) and some risk of alerting competitors	High cost and high risk of alerting competitors, plus the risk of the product being reverse engineered before launch
Technical skill required	Moderation skills for inside the group and ethnographic skills for observers and analysts	Questionnaire design and statistical analysis	Experiment design and statistical analysis (including choice modelling)	Running an instrumented market and forecasting (highly specialized)

This makes it difficult to know which method provides the truest measure of 'decision utility' (that is, the expected utility, which would ultimately drive choice in the marketplace). It is clear that market tests give the most accurate answer, but having to run a market test on every product would defeat the purpose of market research — namely, to provide early and cheap information. Similarly, we suspect (and economists are certain) that methods that are incentive compatible are better than methods that are not. Incentive-compatible elicitation methods are methods that encourage the participant to truthfully reveal what is being asked of him because to do so would maximize the participant's satisfaction (for example, he would earn the most money or receive the product he likes the best). In other words, it is in the participant's interest to answer product-related questions truthfully. However, using such methods is not always possible.

One important question for the potential of neuromarketing is whether the neural signal at the time of, or slightly before, the decision (assumed to be a measure of decision utility) can be a good predictor of the pleasure or reward at the time of consumption (the 'experienced utility')[8]. A second question is whether the link between these two signals holds even when the preference elicitation methods are not incentive compatible. If the answer to both of these questions is positive, neuromarketing could become useful for measuring preferences.

Measurements such as willingness to pay (WTP) have only recently come under functional MRI (fMRI) examination. In one experiment, subjects bid on the right to eat snacks during the experiment. The amount they were willing to pay (a measure of decision utility) correlated with activity levels in the medial orbitofrontal cortex (OFC) and prefrontal cortex (PFC)[9,10]. Interestingly, similar activation in the OFC has been observed when subjects anticipate a pleasant taste[11], look at pretty faces[12], hear pleasant music[13], receive money[14,15] and experience a social reward[16,17]. Such generally close correspondence in regional brain activity between the anticipation of rewarding events, the consumption of enjoyable goods and the willingness to pay for them suggests that the representation of expected utility may rely, in part, on the systems that evaluate the quality of the consumption experience. The theme of common systems for expectation and experience also applies to things that are unpleasant or even painful (although this involves a different network including the insula)[18–21]. Such similarities suggest that neuroimaging can become a useful tool in measuring preferences, particularly when incentive compatibility is important but there is no easy way to achieve it (for example, when the products have not been created). However, such similarities do not necessarily mean that brain activation is the same across different elicitation methods, and there are differences between the neural activation representing decision utility and that representing experienced utility[14,22,23]. This caveat aside, the generally close correspondence does suggest that neural activity might be used as a proxy for WTP in situations in which WTP cannot easily be determined — although this has yet to be demonstrated.

Reverse inference and reward. The practice of measuring an increase in BOLD activity in a region such as the ventral striatum or OFC and then concluding that a 'reward-related' process was active has become increasingly common. This form of deductive reasoning is known as 'reverse inference'[24,25]. Given the readiness of many to interpret brain activation as evidence of a specific mental process, it is worth examining this type of inference. Using a Bayesian analysis, it is possible to estimate the specificity of activation in a particular region of the brain for a specific cognitive process. For example, Poldrack used the BrainMap database to analyse the frequency of activation of Broca's area in language studies[24]. He found that activation of Broca's area implied a Bayes factor of 2.3 for language involvement, which means that taking brain activity into account can make a small but significant improvement to one's prior estimate of whether a language process was involved.

Many studies have shown that striatal activity correlates with hedonic rating scales[26]. Neuromarketers have been quick to invert this finding and use ventral striatal activity as an indication that an individual likes something; but what is the evidence for this? Using Poldrack's method to analyse the BrainMap database, we estimated the posterior probability for a reward process given the observation of nucleus accumbens (NAc) activation[27]. The prior probability of engaging a reward-related process was assumed to be 0.5 (1:1 odds). According to this estimation, based on the number of fMRI papers reported in the BrainMap database with and without 'reward', and with and without NAc activation, NAc activation increases the probability of a reward-related process taking place to 0.90 (odds 9:1). This yields a Bayes factor of 9, which is considered moderate to strong evidence for a causal relationship (BOX 1). Although meaningful in a statistical sense, the assumptions behind such a calculation are rather liberal and may suffer from a publication bias for positive results as well as differing definitions of reward. In real-world settings, the ability to infer whether an individual likes something based on NAc activation alone may be substantially less.

In the context of a product likeability experiment, Knutson *et al.* found significant correlations between NAc activity and product preferences in college students[28]. However, in logistic regression (R^2) calculations aimed at predicting consumer choice, self-reported preferences outperformed brain activation alone. Adding brain activation to a logistic model improved predictions, but only slightly (increasing R^2 from 0.528 to 0.533). Re-analysis with more sophisticated machine-learning algorithms further improved the predictive value of brain activation[29].

Although some have argued for the existence of a "buy button" in the brain[5], current evidence suggests that the cognitive processes associated with purchase decisions are multifactorial and cannot be reduced to a single area of activation. Conversely, a given brain region may be involved in multiple cognitive processes. A recent review of value-based decision making divided the process of making a choice into five categories: representation of the decision; assignment of value to different actions; action selection; outcome evaluation; and learning[30]. Even within this simplified framework, current data suggest that responses to marketing efforts and consumer choices depend on an array of neurobiological processes, and that no single brain region is responsible for a consumer choice. But is it possible that some brain regions are more involved than others? Because the field of neuroeconomics grew out of early brain-imaging studies of the neurobiology of reward[31,32], most of the neuroeconomic data are about valuation mechanisms and the associated responses of dopamine-rich brain regions. The OFC and striatum have been consistently implicated in goal-directed action[9,22,33–35]. It is also generally accepted that the insula has a key role in physiological arousal, which is typically, although not exclusively, aversive in nature[21]. But because of the reverse inference problem, using striatal and OFC activity as a read-out of 'liking' and the insula as a 'disgust-meter' is probably too simplistic to be of use in a real-life setting. In the context of neuromarketing, the statistical power of these single-region correlations may be too low for the correlations to be of use as predictors of consumption unless, perhaps, the neuroimaging data is combined with other measures of preference.

fMRI as a brain decoder. Given the limited power of reverse inference from single-region brain activations, more data-driven methods for interpreting brain imaging data have been at the forefront of analysis techniques. These techniques treat sites of brain activity agnostically — that is, without reference to prior hypotheses. The primary assumption is that, regardless of how an individual's brain represents information, it does so consistently. The representations may be spatially dispersed, and they may be distributed differently in different individuals, but they can still be reliably detected through multi-voxel pattern analysis (MVPA). Because MVPA methods are not reliant on the activation of a small subset of brain regions, they have substantially increased sensitivity to detect activation[36]. A crucial advantage of MVPA techniques over approaches in which activation in a particular brain region of interest is measured is that MVPA has the statistical power to predict the individual choices of a subject. Because MVPA involves statistical associations of complex activation patterns that occur when an individual choice is being made, it does not depend on the vagaries of an experimenter interpreting the meaning of an activation map. Some of the most impressive demonstrations of MVPA have been in decoding visual responses to simple stimuli[37–39] and subsequently, to watching films[40], the meanings of nouns[41], event boundaries of written narratives[42] and city navigation[43,44].

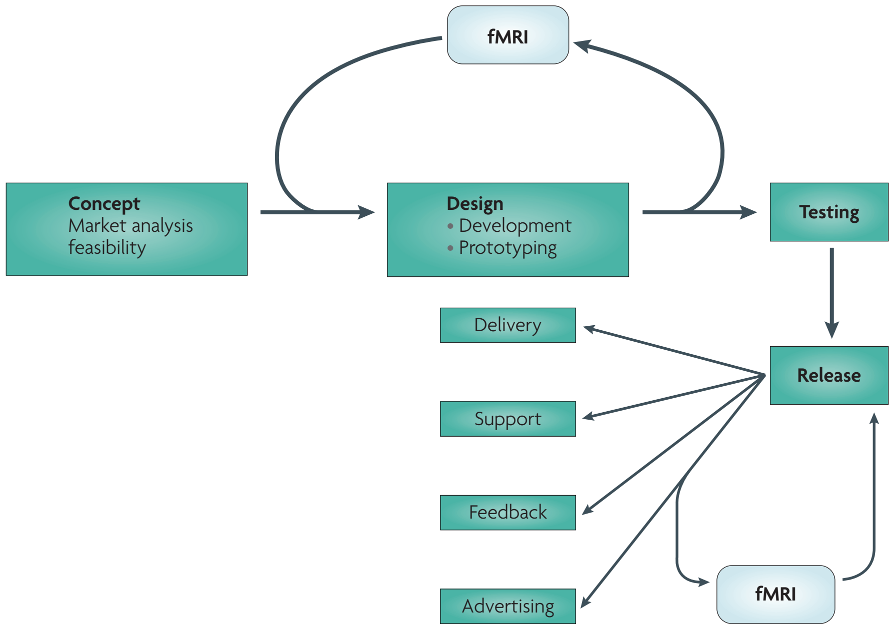

Figure 1 | **Product development cycle.** Neuromarketing applications of functional MRI (fMRI) can potentially enter into the product development cycle in two places. In the first, fMRI can be used as part of the design process itself. Here, neural responses could be used to refine the product before it is released. In the second, fMRI can be used after the product is fully designed, typically to measure neural responses as part of an advertising campaign to increase sales.

Box 1 | NAc activation in studies of tasks with and without reward

The BrainMap database was searched for functional MRI studies with and without a reward task and with and without nucleus accumbens (NAc) activation. The NAc was defined as a bilateral region of interest with vertices from MNI (Montreal Neurological Institute) coordinates (–12, 0, –12) to (12, 12, 0). The frequencies that were obtained are shown in the table below.

Assuming that the prior probability of engaging in a reward-related process is 0.5, calculations showed that NAc activation increases the probability of a reward-related process taking place to 0.90, yielding a Bayes factor of 9:

Probability of NAc activation given a reward task = 27/68 = 0.397
Probability of NAc activation given no reward task = 59/1283 = 0.046

Assuming the prior probability of reward = 0.5, then

$$\text{Probability of a reward task given NAc activation} = \frac{0.397}{(0.397 + 0.046)} = 0.90$$

	Reward task	No reward task
NAc activated	27	59
NAc not activated	41	1,224

It is possible, even likely, that such methods will soon be able to handle almost any circumstance that can be created in an MRI environment. With increasing stimulus complexity, simple interpretations of brain activation will become more difficult. However, for real-world marketing applications, it may be more important to predict future behaviour than to understand the 'why' of behaviour. Such a data-driven application of imaging (perhaps even lacking an underlying theory) is analogous to identifying a genetic polymorphism associated with a particular cancer without understanding what that gene does — which is likely to yield specific but not general insights.

Costs and benefits

As noted above, it is not yet clear whether neuroimaging provides better data than other marketing methods (TABLE 1), but through the use of MVPA methods it might be possible to reveal the 'holy grail' of hidden information. Assuming that this is the case, will using expensive neuroimaging ultimately be more efficient than using cheaper methods? Typical charges for scanning in a university research setting average about US$500 per hour. In a commercial setting, these will be higher. However, actual scan charges account for a small portion of the total cost, with personnel and overhead expenses accounting for at least 75% of the costs of an imaging project. If neuromarketing is to compete with conventional marketing approaches on the basis of efficiency, then the costs of labour and overheads will have to be reduced.

One area in which the cost of neuroimaging can be compared with conventional marketing approaches is in the post-design phase, the goal of which is to increase sales of an existing product — for example, through advertisements and other types of framing effects. Early neuromarketing studies therefore used imaging approaches to evaluate consumer responses to advertisements. At this point, it is important to distinguish between neural responses to the consumption of a product (that is, experienced utility) and neural responses to representations of the product that may lead to future consumption. Only certain types of products can be consumed in an MRI scanner. Therefore, much of the post-design neuromarketing literature has focused on brain responses to visual representations of products, such as pictures[28,45] or advertisements for the product[46–48]; however, these advertisement studies, which used magnetoencephalography and electroencephalography (BOX 2), did not link imaging data to actual purchase decisions or other ratings, so it is not yet possible to determine the value of this approach.

The role of expectations. It has long been known that the manner in which choices are presented can have a dramatic effect on decisions[49]. This is where advertisements and product placement come into play. To date, experiments have examined fairly simple choices and responses to things that can be presented in an MRI scanner. Before neuroimaging can be used to predict consumer choice, a greater understanding of the interplay between the decision maker, the elicitation method and the decision context is needed.

BOLD responses are influenced by so-called 'expectation' effects, which include pricing effects, biases in the way the choice is presented[50] and placebo responses. This suggests that neuromarketing could be helpful in identifying individual differences in consumer reactions to different types of inputs. In a study of neural responses to sips of wine, medial OFC responses were higher when subjects were told that the wine was expensive ($90 per bottle) versus inexpensive ($5 per bottle)[23]. Activity in this region also correlated with self-report ratings of how much participants liked the wine, even though all wines were actually the same. These results suggest that the instantaneous experience of pleasure from a product — that is, experienced utility — is influenced by pricing, and that this effect may be mediated by the medial OFC[9]. This result parallels a similar, behavioural finding that the strength of the placebo effect for analgesia is greater for more expensive 'medications'[51]. Subjects' expectations also play an important part in how the experimenter should interpret striatal responses. Many studies have shown that the reward-related signals in the ventral striatum and NAc can be more accurately linked to prediction errors for reward than to reward itself[22,52,53].

Placebo responses are an interesting aspect of neuromarketing. The mechanism of the placebo response has been debated for decades[54], but ultimately it can be considered an effect of marketing (that is, the actions of a doctor, pharmaceutical company or experimenter). The neural correlates of the analgesic placebo effect are widespread but generally point to a modulation of the cortical pain matrix in the brain[55,56]. Because consumers cannot consciously report placebo effects, the demonstration of neural correlates of these effects suggests that having access to hidden brain information could enable a marketer to measure the effectiveness of a placebo marketing strategy in a particular individual. How well this type of information generalizes to a larger population will determine the cost–benefit ratio of doing neuroimaging.

The aforementioned manipulations of expectations are simple and direct. For example, the experimenter can manipulate a single dimension of expectation, such as price or descriptive words (for example, "ultra" and "new and improved"), and measure the effect on the consumer behaviourally and neurally. More cognitively complex forms of expectations can be created through advertisements and commercials.

Box 2 | **Neuromarketing technologies**

Functional MRI (fMRI)

The technique uses an MRI scanner to measure the blood oxygenation level-dependent (BOLD) signal. The BOLD changes are generally correlated with the underlying synaptic activity. Spatial resolution is 1–10 mm, and temporal resolution is 1–10 s. In general, the higher the spatial resolution, the lower the temporal resolution. Of the three imaging technologies described in this Box, fMRI has a substantial advantage in resolving small structures and those that are deep in the brain. However, some important brain regions, especially the orbitofrontal cortex, are affected by signal artefacts that may reduce the ability to obtain useful information. State of the art MRI scanners cost approximately US$1 million per Tesla and have annual operating costs of $100,000–$300,000.

Electroencephalography (EEG)

EEG uses electrodes applied to the scalp and measures changes in the electrical field in the brain region underneath. EEG has very high temporal resolution (milliseconds) and can therefore detect brief neuronal events. Because the skull disperses the electrical field, EEG has low spatial resolution (~1 cm) that depends on how many electrodes are used. The number of electrodes can be as few as two or range up to hundreds in high-density arrays. The greater the number of electrodes, the better the spatial resolution. Apart from the low spatial resolution, EEG has poor sensitivity for deep brain structures. Equipment costs can be low (<$10,000) but increase with high-density arrays and the concomitant resources needed to process the data. A common technique is to measure the left–right asymmetry of the frontal EEG[78]. This is typically measured by the power in the alpha band (8–13 Hz). This research has suggested that relatively greater activity in the left frontal region is associated with either positive emotional states or the motivational drive to approach an object[79]. Although there are strong correlations between frontal EEG asymmetry and personality traits, the degree to which the asymmetry changes from moment to moment is still debated. Some have suggested a minimum of 60 s to reliably estimate power asymmetry[80], in which case the temporal advantage of EEG over fMRI is lost. Although some have used this approach to measure momentary fluctuations in emotion in response to advertisements[81], without accounting for autocorrelations in time or multiple statistical comparisons, the validity of such approaches is dubious.

Magnetoencephalography (MEG)

An expensive cousin of EEG, MEG measures changes in the magnetic fields induced by neuronal activity. Thus, MEG has the same advantage of high temporal resolution and, because the magnetic field is less distorted by the skull than is the electrical field, it has better spatial resolution than EEG. Like EEG, MEG is most sensitive to superficial cortical signals (primarily in the sulci). MEG requires a magnetically shielded room and superconducting quantum interference detectors to measure the weak magnetic signals in the brain. An MEG set-up costs approximately $2 million.

Transcranial magnetic stimulation (TMS)

TMS uses an iron core, often in the shape of a toroid wrapped in electrical wire, to create a magnetic field strong enough to induce electrical currents in underlying neurons when placed on the head[82]. TMS can be used as a single pulse, paired pulse or repetitive stimulation, and the neuronal effects range from facilitation to inhibition of synaptic transmission. As a research tool, TMS has been used to study the causal role of specific brain regions in particular tasks by temporarily taking them 'offline'.

Post-design applications of neuroimaging have, for the most part, confirmed what was known about the behavioural effects of product placement, which bypass the counter-arguments in which people naturally engage when facing advertisements. The imaging studies confirm that there are neural correlates of exposure to advertisements but do not directly suggest that maximizing activity in a particular brain region results in more sales.

Culture and advertising. Neuroimaging is often hyped as an exciting new tool for advertisers. Despite its enormous cost, advertising effectiveness is a poorly understood area of marketing. Although advertising has been investigated in a few neuroimaging studies[57,58], it is still unknown whether neuroimaging can prospectively reveal whether an advertisement will be effective. In a famous Coke–Pepsi study, participants who described themselves as Coke drinkers showed significant activation in the hippocampus and right dorsolateral PFC when they were cued about the upcoming drink of Coke[45]. Self-described Pepsi drinkers did not have this response. In the absence of brand information, there was no significant difference in preference during a taste test. The study suggested that any differences in the response (behavioural and neural) to the two brands must be culturally derived. One possibility is that brands achieve a life of their own by becoming animate objects, sometimes with human attributes, in the minds of consumers. However, one fMRI study that compared brain responses to persons and brands found that activation patterns for brands differed from those for people — even for brands with which subjects are identified — suggesting that brands are not perceived in the same way as people[59]. Another possibility is that specific emotions can be elicited in response to advertisements, although whether neuroimaging will help to reveal these emotions may ultimately be limited by reverse inference constraints, especially if tied to specific regions.

The issue of how culturally derived identities become embedded in the brain is of great interest, not only from a marketing perspective. Although neoclassical economic theory describes a framework in which individuals assess costs and benefits during their decision-making processes, it is clear that people base many decisions on sociocultural rules and identities. Some are in a commercial context (for example, "I am a PC" or "I am a Mac") but many are not (for example, "I am a Democrat" or "I am a Republican"). These issues extend beyond the mundane questions of advertisement effectiveness and raise the more profound question of how the marketing of ideas affects decision making. But whether neuroimaging provides an efficient tool to answer this question has yet to be shown.

Early product design

As the ability of neuroimaging to predict or influence post-design purchase decisions seems to be limited (see above), neuroimaging may be better suited to gauging responses before products are marketed. The primary reason is that neuroimaging may yield insights into the product experience itself.

Food products. Various food products and beverages have been administered in the MRI scanner, from simple sugar solutions to chocolate, wine, sports drinks and colas. Beverages are particularly easy to administer, with the usual route through a computer-controlled pump attached to a tube that delivers controlled amounts of fluid into the participant's mouth. The perception of flavour is a multisensory integration process and thus provides several opportunities for neuroimaging to disentangle a complex perception that subjects might not be able to articulate; taste, odour, texture, appearance and even sound all contribute to the gustatory experience. These different dimensions have been mapped onto

Box 3 | **The ethics of neuromarketing**

The introduction of neuroimaging into an environment in which the ultimate goal is to sell more product to the consumer may raise ethical issues.

- ***Businesses will be able to read the minds of consumers.*** This concern is about the privacy of thoughts. Can neuroimaging be used to gauge a person's preferences outside of the specific task being performed? Possibly. This concern may be mitigated through transparency of purpose: subjects must know what kind of endeavour they are helping, and their data should only be used for that purpose.
- ***Private versus public information about preferences.*** Individuals need to be able to exercise control over what they choose to reveal about their personal preferences. A privacy breach occurs if neuroimaging reveals a private preference that is outside the scope of the neuromarketer's research question.
- ***Information will be used to discriminate against individuals or exploit particular neurological traits found in a subgroup of individuals.*** Neuroimaging data could potentially target marketing to specific people or groups. Many people would find this tactic repugnant because it exploits a biological 'weakness' that only exists in some people. Similarly, this information could be used to time pricing moves to capitalize on individual weaknesses that are known to coincide with particular biological states (for example, raising beverage prices when someone is known to be thirsty).
- ***Central versus peripheral routes of influence.*** A central route aims to influence consumers' preferences about the functional aspects of the product (for example, fewer calories in a beer). A peripheral route attempts to manipulate preferences through things that are peripherally related to the product (for example, sex appeal of people in advertisements). Neuroimaging could potentially be used to enhance both types of influence, but some consider the attempts to optimize the peripheral route more ethically dubious.
- ***Brain responses obtained from a small group of subjects will be used to generalize to a large population.*** Of course, this is done all the time in the scientific literature. If neuromarketing data are used in product design and the product injures someone, neuroimaging will be partly to blame.
- ***Abnormal findings.*** Approximately 1% of the population will have an abnormality on their MRI[83]. In a population without clinical symptoms, the clinical significance of an MRI abnormality is unknown. Many will be false positives; others will be real and require referral. Currently, there is no standard for how to handle these situations. However, it is standard practice to have a written policy in place for abnormal findings. Failure to do so opens both the neuromarketing firm and their clients to medical liability.
- ***A lack of regulation.*** Traditional marketing methods, because they are not typically viewed as experimentation, have not been subject to institutional review board (IRB) oversight. MRI scans are approved by the US Food and Drug Administration (FDA) for clinical use but, because no diagnosis is being made in a marketing setting, there is the potential to circumvent both FDA and IRB requirements. The burgeoning neuromarketing industry would be well advised to adopt an industry standard of independent review. Clients should demand it.
- ***Management of perceptions.*** How will the public react when they discover that neuroimaging has been used to design or market a product? The public's response to genetically modified food could provide an indication.
- ***Companies might not be primarily concerned with the best interests of the consumer.*** Companies and consumers maintain complex relationships in which some of their goals are compatible while others are in conflict. On the one hand, companies seek to design, manufacture and sell products that consumers seek to buy, resulting in compatible goals that benefit both parties. On the other hand, companies also aim to maximize their short- or long-term profits, sometimes to the detriment of their consumers. Much like marketing itself, understanding consumer preferences can be used for goals that are in the best interests of both the company and their consumers or for objectives that are in the interests of the company and to the detriment of their consumers. Which approaches neuromarketers choose is an open question.

distinct brain regions but with substantial overlap[60,61]. The OFC is consistently linked to perceived pleasantness, whereas viscosity and fat content seem to be represented in the insula[62]. The use of neuroimaging by commercial manufacturers to design a more appealing food product is both feasible and likely. For this to work, however, one would need to identify which dimension of gustation is to be studied (for example, taste, odour or texture) and maximize a brain response to variations in that dimension.

The drawback to such an approach is the possibility of creating food products that are so highly tuned to neural responses that individuals may over-eat and become obese (see BOX 3 for a discussion of some ethical issues related to neuromarketing). Is it possible that such a neuroimaging approach could create a 'super-heroin of food' — a product so delicious that all but the most ascetic individuals would find it irresistible? It is an extreme but real possibility. However, that does not mean that neuroimaging is necessarily problematic for food product development. Indeed, the same techniques could be applied to making nutritious foods more appealing.

Entertainment. As a typical big-budget Hollywood film costs over $100 million, with almost as much spent on marketing, it would be surprising if film producers were not interested in using neuroimaging to improve their product. After static images, films are probably the easiest product to present in the scanner. Moreover, an fMRI measurement is time locked to the film timeline. A film presents the same basic visual and auditory stimuli to everyone viewing it and thus should serve as a cognitive synchronizer. Indeed, an fMRI study of subjects viewing a segment of the classic Western *The Good, the Bad and the Ugly*[40] showed that large extents of the cortex responded similarly in time across subjects, suggesting that much of the cortical response is essentially stereotypical. In another study, the ability to recall narrative content of the TV sitcom *Curb Your Enthusiasm* three weeks later was correlated with the strength of hippocampal and temporal lobe responses during viewing[63].

Such stereotypical responses suggest that fMRI could be used during the editing process. For example, different cuts of a movie could be measured against these cortical responses, which could then be used to select the final cut for release. Although it seems hopelessly complex to interpret such brain responses, it may not be necessary if the only goal is to release the most profitable movie. Provided there were a metric of quality (for example, box office returns or test audience reports), brain activation patterns could be chosen to optimize outcomes without any knowledge of what the patterns meant. Several neuromarketing companies have targeted their efforts towards the entertainment industry but, as most of this work is unpublished, it is difficult to evaluate the quality of the product. However, guidelines for general quality of scientific work can be formulated based on two decades of neuroscience research. Thus, without passing judgment on whether neuromarketing works, we can at least identify the items to look for in a quality operation (BOX 4).

Box 4 | **What to look for when hiring a neuromarketing firm**

We provide a list, which is by no means exhaustive, of what could be considered standard practice in the application of neuroimaging methods in cognitive neuroscience and related fields. It is based on standard criteria for reviewing research proposals and adapted to a business setting.

- What is to be gained from neuroimaging? Good neuromarketers will begin by discussing the pros and cons of the proposal in detail. For example: what will neuroimaging yield over traditional methods? Ask for data about the predictive value of neuroimaging findings in a real-world setting.
- What are the dependent and independent measurements? Assessing brain activation is not generally useful without correlating it with some other measurement. It is necessary to have another behavioural measurement to anchor the interpretation of the brain activation. Be wary if someone claims to know what a person thinks based solely on brain activation.
- How many subjects are needed? Apart from the simplest of tasks, any task invoking a response that is expected to vary across individuals demands a sample size of at least 30 (REF. 84). If groups of individuals are being compared under different treatments or conditions, the sample size will need to be much greater to detect differences between groups and between different treatments.
- What is the nature of the stimuli? Simple stimuli are the easiest to analyse. Real-world images, as might appear in an advertisement, become difficult to characterize unless one element at a time is varied. For statistical power, a minimum of 10 repetitions within a stimulus category are required, although 20–30 would be more likely to achieve meaningful results.
- What type of software will be used to analyse the neuroimaging data? Several software packages exist, and although these programmes make neuroimaging seem simple, it takes a minimum of 1 year of training to be able to use them and 3 years to become fully competent.
- How will motion correction be performed?
- Are conditions balanced in time? If not, how will subjects' drifting attention be compensated for?
- Is this a whole-brain analysis or is a specific part of the brain being examined? These necessitate different thresholds of identifying activation. The chance of an activation appearing somewhere in the brain is high due to random noise.
- Will regions of interest be defined *a priori*? If so, what is the justification for this? Conclusions based on activation of a single region will have relatively little predictive power over conventional behavioural methods.
- If multi-voxel pattern analysis (MVPA) methods will be used, will they be completely data-driven (principal component analysis or independent component analyses) or will they be based on classifier training of subject responses (support vector machine, relevance vector regression or Gaussian process regression)? How will the resulting activity maps be interpreted?
- How robust are the results? Ask for a 'bootstrap' — for example, testing on a 'fresh' subsample of data.
- What type of scanner will be used? Either 1.5 or 3 Tesla scanners can yield images of acceptable quality. Open MRIs do not have the field homogeneity or the gradient technology necessary for fMRI. What quality control checks are performed to make sure the scanner is operating optimally and consistently from day to day? What steps will be taken to minimize signal artefacts in areas with poor signal?

Architecture. A growing number of neuroscientists and architects have begun to consider the relationships of the brain to the architectural experience[64]. The neuroscience of architecture could be considered from two perspectives: first, the neural activity associated with seeing specific aspects of a building; and second, the use of neural responses to guide the architectural design process. Clearly, one would need to identify these neural responses before attempting to use them in architectural design, but it is precisely the application in design that places neuroimaging within the neuromarketing framework.

Virtual reality can provide a surprisingly accurate simulation of an architectural experience and can be used in an MRI scanner. It has already been used to understand neural activation during automobile driving[65,66]. In spatial navigation tasks such as driving, and presumably navigating a building, the hippocampus has a key role. These early virtual reality experiments suggested that the hippocampus is active when the subject makes navigation decisions but not when they are externally cued[65]. Perhaps taking into account 'hippocampal load' may be a useful tool in architectural design — for example, to make buildings easier to navigate. Extending this idea by considering the neurobiological changes associated with ageing, it might be possible to design buildings and retirement communities that mitigate the memory loss associated with Alzheimer's disease.

Political candidates. Finally, neuromarketing might be applied to perhaps the greatest marketing campaign of all: politics. According to the Federal Election Commission (see Further information), the cost of the 2008 US Presidential race was approximately $1.6 billion. It was also around that time that neuroimaging made its way into politics, perhaps most prominently in the form of a *New York Times* op-ed piece[67]. Peer-reviewed studies have shown a complex pattern of activation in response to statements about candidates; these patterns have been interpreted as evidence that motivated reasoning involves activation in the ventromedial PFC, the anterior cingulate cortex, the posterior cingulate cortex and the insula[68]. Subsequent studies have suggested that activation of the medial PFC might be associated with maintaining a subject's preference for a candidate in response to advertisements, whereas activity in the lateral PFC might be associated with changing candidates[69].

In marketing terms, the political candidates are the products that must be sold to the electorate. Therefore, like other products, candidates and their campaigns have pre- and post-design phases. Political marketing is aimed at selling an existing candidate but, with more foresight, can also be used to 'design' a better candidate. The aforementioned neuroimaging studies have focused on the post-design responses to advertisements for political candidates[68,69].

Could neuroimaging also be used to design a candidate? Although potential nominees already go through a 'grooming' process, it is worth examining this prospect. A candidate's appearance, trustworthiness and message content might determine a voter's decision. Considerable neuroimaging work has been done on the perception of human faces[70] and features such as facial symmetry, skin colour and attractiveness. Key brain structures in visual processing include the fusiform face area for basic face processing[71], the superior temporal sulcus for gaze direction and intention and the NAc for attractiveness[12]. A recent study on the effect of political candidates' appearance found that insula activation in response to seeing a picture of a candidate was associated with a greater likelihood of that candidate losing the election[72]. In addition, dorsolateral PFC and anterior cingulate cortex activation occurred when subjects viewed images of a candidate of a political party different from their own[73]. The neurobiology of trust has also become quite popular to study with both fMRI and, more recently, pharmacological manipulations[74–76]. These studies have found that different dimensions of trust, such as reputation, fairness and uncertainty, correlate with activity in different brain regions. Moreover, the hormone oxytocin affects human behaviour in various economic exchanges that depend on social interactions[77]. Finally, a candidate's message content could be viewed as an experiential product. One could theoretically attempt to maximize striatal and OFC responses to platform statements although, for the reasons stated above, this is not necessarily predictive of success.

Conclusions and future directions

Neuromarketing has received considerable attention in both the scientific community and the media. Although few scientific neuromarketing studies have been conducted, the existing evidence suggests that neuroimaging could be used advantageously in several domains of marketing. For a marketer, neuroimaging could be attractive because it might be cheaper and faster than current marketing tools, and because it could provide hidden information about products that would otherwise be unobtainable. We think it unlikely that neuroimaging will be more cost-effective than traditional marketing tools, and so the first point is mostly hype. However, continuing developments in analytical tools for neuroimaging data — for example, MVPA — suggest that neuroimaging will soon be able to reveal hidden information about consumer preferences. Although this information could boost post-design sales efforts, we think that the real pay-off will come during the design process. Using fMRI data during design could affect a wide range of products, including food, entertainment, buildings and political candidates.

There are two sides to the use of such information. Product manufacturers could use neural information to coerce the public into consuming products that they neither need nor want. However, we hope that future uses of neuromarketing will help companies to identify new and exciting products that people want and find useful. One example is a new trend in 'user design' in which companies allow consumers to participate, through the internet, in the design of new products and by doing so create products that are more useful for the companies and for their customers. Perhaps a next phase in user design is one that incorporates not only what consumers express, but also what they think.

Finally, we return to the opening question: hope or hype? It is too early to tell but, optimists as we are, we think that there is much that neuromarketing can contribute to the interface between people and businesses and in doing so foster a more human-compatible design of the products around us. At the same time, neuromarketing as an enterprise runs the risk of quickly becoming yesterday's fad. Seasoned marketers still remember the hype around subliminal advertising, which quickly faded and died despite the research interest that surrounded it (and research on subliminal priming remains a large part of academic research in social psychology). How can we make sure that neuromarketing will not suffer a similar fate? For one, the academic community should take this topic seriously and not leave it to the neuromarketers and the op-ed page of the *New York Times*. We should also ask deeper questions on how marketing works — and not simply examine whether type X of advertising works better or worse than type Y. If we take neuromarketing as the examination of the neural activities that underlie the daily activities related to people, products and marketing, this could become a useful and interesting path for academic research and at the same time provide useful inputs to marketers.

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doi:10.1038/nrn2795
Published online 3 March 2010

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Acknowledgements
This work was supported by grants to G.S.B. from the National Institute on Drug Abuse (R01DA016434 and R01DA025045), the Office of Naval Research and Air Force Office of Scientific Research, and the National Science Foundation (BCS0827313).

Competing interests statement
The authors declare competing financial interests: see web version for details.

FURTHER INFORMATION
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Mark Lett (2012) 23:473–485
DOI 10.1007/s11002-012-9188-z

Decision neuroscience and consumer decision making

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Published online: 26 May 2012

Abstract This article proposes that neuroscience can shape future theory and models in consumer decision making and suggests ways that neuroscience methods can be used in decision-making research. The article argues that neuroscience facilitates better theory development and empirical testing by considering the physiological context and the role of constructs such as hunger, stress, and social influence on consumer choice and preferences. Neuroscience can also provide new explanations

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for different sources of heterogeneity within and across populations, suggest novel hypotheses with respect to choices and underlying mechanisms that accord with an understanding of biology, and allow for the use of neural data to make better predictions about consumer behavior. The article suggests that despite some challenges associated with incorporating neuroscience into research on consumer decision processes, the use of neuroscience paradigms will produce a deeper understanding of decision making that can lead to the development of more effective decision aids and interventions.

Keywords Consumer neuroscience · Decision neuroscience

Neuroscience has become both a useful tool and a source of theory development and testing in decision-making research. Some researchers express high hopes that a neuroscience perspective will provide a deeper understanding of marketing and consumer decision making, whereas other researchers appear more skeptical. In this paper, we tackle two related questions. How can insights from neuroscience shape future theory and models in consumer decision making? How should neuroscience methods be integrated into the research methodology of consumer decision making? We argue that neuroscience provides constraints to facilitate better theory development, provides new empirical tests of standard theoretical claims, can provide explanations for observed heterogeneity within and across populations, and can provide a mechanism for considering the physiological context and the role of constructs such as hunger, stress, and social influence on consumer choices and preferences. We present a few key arguments and examples of how the use of neuroscience paradigms can illuminate our understanding of decision processes. Our primary goal is to appeal to a broad audience and to stimulate further study in this important area. Readers, who want background on specific measures, paradigms, methods, and reviews of recent findings related to decision neuroscience, should consult Glimcher et al. (2009) or Vartanian and Mandel (2011).

1 The role of neuroscience in consumer decision making

The prospect of turning to the biological variables of neuroscience to inform models of marketing and consumer decision making may, at first, seem far-fetched. Indeed, some economists (e.g., Gul and Pesendorfer 2008) have argued that because economic and decision-making models tend to be silent about the underlying biological mechanisms, neuroscience and biological variables would be irrelevant in theory testing. We categorically disagree with this view.

Decision-making research has benefited from the revealed preferences perspective, which follows the behaviorist tradition of focusing on the observation of what people actually choose (or state that they will choose). This perspective has gone a long way in promoting empirically testable theory. In its extreme form, the revealed preference approach ignores the black box in which decisions are made. However, this view has been somewhat limiting. Many researchers build models about the processes occurring inside the black box, but under the revealed preferences approach those models are evaluated using data from the output stage only. While some decision scientists have been reluctant to consider data in addition to choice, others, including many in marketing, consider additional variables (e.g., attitudes, memory, stated intentions, willingness to pay, response time, and priming manipulations) to be important in theory development and empirical observation. These additional variables can facilitate insights because they provide context and testable constraints. As judgment and decision-making research has demonstrated, there can be empirically testable hypotheses about the workings and mechanisms inside the black box, especially when coupled with a revealed preferences approach.

We propose that neuroscience adds value to decision-making research by enhancing the ability to make inferences beyond our usual variables and paradigms. We assert that more comprehensive theories—those making empirically testable claims about both decision processes and their output, for example, or about both biological and social variables—will be useful as the decision neuroscience field continues to develop. Two decision behaviors may be identical but may have different underlying neural circuitry. One may ask why the circuitry is relevant if at the end of the day the choice is the same. But if one understands the underlying mechanism that led to the observed choice, then one is in a better position to (a) generalize this knowledge, (b) understand contextual influences that may interact with the different neural circuitry leading to different choices, and (c) create interventions or influence those decisions more effectively. Such process knowledge can be important in many domains including policy, marketing, legal decisions, and medical decisions. In much the same way that eyetracking or verbal self-report can provide additional information about potential process, the tools of decision neuroscience can yield valuable information that can provide additional constraints on the interpretation of choice data.

Many of us have naïve intuitions about biology being fixed and unmalleable. One of the lessons from modern neuroscience is that biological variables are instead plastic and malleable. In recent years, it has become increasingly clear that although the brain is biologically based, it is also shaped by environmental, cultural, and contextual factors. Armed with knowledge of how these variables interact, decision research scholars and practitioners may be in a better position to develop more effective, more personalized and more tailored interventions and decision aids that can improve decision making.

2 Understanding heterogeneity

Understanding both inter- and intra-personal sources of heterogeneity remains a core goal of consumer behavior research, as seen in the emphasis on improving the efficiency of marketing campaigns through population segmentation (for related ideas, see Venkatraman et al. 2012). Neuroscience provides a framework in which to study and ultimately account for individual differences. Specifically, individual differences in choice need not be arbitrary or idiosyncratic. Instead, they could reflect predictable interactions between genetic markers that code for brain function (e.g., genes that shape our dopamine system), hormone and neurotransmitter levels that fluctuate with disease and state variation (e.g., sleep deprivation), and environmental variation (e.g., stressors and life events). Many of these variables are simply outside the scope of standard models but may be highly relevant for consumer behavior.

Recent work at the interaction of biology and social sciences suggest that genes can play important roles in shaping response tendencies in dynamic interaction with the environment. Research in gene × environment interactions and in epigenetics suggest that it is not genes alone, but the interactions between the genetic code and environment that are associated with our behaviors. For example, prior studies have found that DRD4—a dopamine receptor gene that is implicated in ADHD and other behavioral disorders—functions differently depending on the quality of parenting. Long-allele versions of the gene are associated with sensation-seeking, high-intensity pleasure seeking, and impulsivity, but only in children who were subjected to poor quality parenting (Sheese et al. 2007). There is promise in exploring genetics and gene × environment interactions in decision-making research; examples of recent studies include Krugel et al. (2009) and Doll et al. (2011).

Functional magnetic resonance imaging (fMRI) could inform hypotheses about heterogeneity in decision processes. There could be sub-groups of individuals that approach the same decision problem using different strategies, suggesting that these different sub-groups may exhibit different patterns of brain activation. Neuroscientists have been developing techniques that discriminate brain activity in groups of subjects performing different tasks (Poldrack et al. 2009); these techniques could be used to test whether sub-groups of subjects exhibit different brain activations in the same task. This kind of approach is analogous to the market segmentation approaches familiar to consumer researchers.

Decision theorists talk much about heterogeneity in decision-making parameters (such as utility function parameters or temporal discounting parameters), and the field has developed good models to understand that heterogeneity. Neuroscience can take that understanding to a new level by adding a biological substrate to the explanation. Take for example the role of stress on decision making. Decision-making researchers may get more mileage from their paradigms if they also examine additional biological variables related to stress, e.g., hormones like cortisol. Fluctuations in cortisol can be related to decisions and so can fluctuations (possibly experimental manipulations) of the stressor. In this case, the researcher can go beyond merely examining the association of the stressor to the choice (the black box model) and say something about the underlying mechanism in the sense that the stressor initiates a biological response, which can in turn be related to the choice. For example, Mehta et al. (2010) show that fluctuations in cortisol have implications for economic decision making during negotiation and bargaining games. Stress has not typically been seen as relevant to consumer decision making. However, we believe it is an important factor in some decisions such as food choice under time or budget constraints, which may be associated with stress (e.g., grocery shopping after a stressful day at work when cortisol levels may be high). Furthermore, the cortisol variable can also act as a "manipulation check" on the experimental stressor, and could provide additional information about other processes such as habituation to the stressor. Biological data could provide evidence that the participant is habituating to the stressor, and thus provide one way to interpret an observed change in the choices the participant makes in the face of a repeated stressor. This is a type of intrapersonal heterogeneity for which biological variables can provide additional explanatory power.

A biological variable like cortisol can also elucidate why one participant did not change their choices in the presence of a stressor but another participant did. If the participant who changed her choices responded to the stressor with elevated cortisol levels but the other participant's cortisol did not fluctuate in response to the stressor, then this points to a type of heterogeneity in, say, the effect the stressor has on the participant. If the cortisol levels are the same in the two participants, then the potential explanation that each responded to the stressor differently (at least in terms of a biological response) can be ruled out. In these examples, we have focused on cortisol as the biomarker for the stress response but there could be other biological variables and measurements, such as fMRI, that could also be informative about the heterogeneity. As can be seen through these examples, the inclusion of biological information in our behavioral decision-making models may go a long way toward accounting for the observed heterogeneity, at both intrapersonal and interpersonal levels, in decision behavior.

3 Understanding value and its computation

A major question in decision neuroscience has involved understanding how goods are represented and valued by consumers. A number of studies have documented the key role of the orbitofrontal cortex in the valuation process (e.g., Kringelbach 2005; Kable and Glimcher 2009). An open question in the neuroscience of decision making has been whether the brain has implemented a system that tracks the subjective value of items for choice, how these systems are at play when consumers "miscompute" their subjective value resulting in disadvantageous decision-making outcomes such as obesity, and whether brain activity in these systems can be consciously regulated. Answers to these questions have potentially important implications for understanding the underlying neuropsychological mechanisms of consumer decision making and for designing public policy interventions.

We illustrate with an example investigating brain systems that track decision values of hungry subjects using fMRI. Based on the results of several previous studies using monkey electrophysiology and human fMRI, one can hypothesize a priori that activity in the medial orbitofrontal cortex (mOFC) would be involved in decision value (DV) computations. To test this hypothesis, Plassmann et al. (2007, 2010) used fMRI to scan hungry people's brains while they placed bids for the right to eat 50 different junk foods (e.g., chips and candy bars) in a Becker–DeGroot–Marshak auction. The participants placed bids for the right to eat a snack at the end of the experiment in 100 different bidding trials. In each trial, they were allowed to bid \$0, \$1, \$2, or \$3 for each food item.

Plassmann et al. (2010) found that right mOFC and ventromedial prefrontal cortex (VMPFC) and right dorsolateral prefrontal cortex (DLPFC) encode for DV during choice between unhealthy but appetitive food items. However, DV computations occur when choosing among appetitive and aversive items. Since dissociations between appetitive and aversive components of value signals have been shown in other domains such as anticipatory and outcome values, it is an important question as to whether appetitive and aversive DVs are computed in similar brain regions, or in separate ones. In a follow-up study, the investigators found that activity in a common area of the mOFC/VMPFC and DLPFC correlated positively with appetitive DVs and negatively with aversive DVs. These findings suggest that the mOFC might comprise a common valuation region that encodes for both appetitive and aversive DVs (Litt et al. 2011). These results and related ones using monetary gambles and trinkets (Chib et al. 2009), or immediate and delayed rewards (Kable and Glimcher 2007, 2010) provide evidence that the brain encodes a "common currency" that allows for a shared valuation for different categories of goods (see Kable and Glimcher 2009, for a review).

4 Understanding strategic contributions to choice

The assignment of subjective values during decision making constitutes one of the fundamental computations supporting human behavior. However, different sorts of computations may be evoked under different circumstances. Individuals may have difficulty overcoming immediate hedonic concerns to achieve a long-term goal, as in the case of decision-making disorders such as obesity, addiction, and pathological gambling, suggesting that this process may sometimes be more sensitive to immediate hedonic concerns than to long-term goals and outcomes. When this happens, strategies such as cognitive reappraisal and regulation may be required in order to modulate the computations of the value system. Different decision contexts may allow individuals more or less flexibility. Some choices may demand a rapid decision and are best suited to a simplifying, heuristic approach, while other decisions may allow for a more considered, analytic choice process. Across these and many other cases, decision makers are faced with the challenge of selecting the decision *strategy* that maximizes outcomes in the face of constraints.

Recent neuroscience work has provided insight into how individuals engage cognitive strategies to shape their decision process to modify the computations involved in determining the preference for a food, and can also diminish their motivation to obtain a food through activation of regions involved in executive control and behavioral inhibition. Similarly, there may be different roles for conscious and unconscious mechanism in our decisions, and for the role of mood, emotions, and stress. These findings may have important implications for how public policy interventions are designed to fight obesity, and also how health information on food packaging could be more effectively presented. Admittedly, there is much more research needed before we fully understand the policy implications and can develop new interventions and policies based on information from neuroscience studies.

Inter- and intra-individual variation in decision strategies can result from different underlying processes. For example, a study by Venkatraman et al. (2009) investigated how people selected between multi-attribute monetary gambles whose outcomes varied from very good (e.g., win $100) to very bad (e.g., lose $80). Because of the complexity of the problem—which has parallels in the multi-attribute nature of many consumer decisions—different individuals approached this decision with different strategies. Some individuals generally used information about outcomes in a largely compensatory manner consistent with standard economic models, whereas others often adopted a simpler, aspiration-level rule: "Choose the gamble that maximizes my overall chance of winning." The authors found that these inter-individual differences were well-correlated with the response of the brain's reward system to gains and losses, with those individuals whose reward system were most sensitive to the valence of outcomes also showing the greatest tendency toward using the simplifying rule (i.e., choosing based on valence but ignoring magnitude). Moreover, switches from one sort of strategy to the other were associated with increased activation in the dorsomedial prefrontal cortex (DMPFC), a region broadly associated with the strategic control of behavior.

Finally, the very concept of subjective value can be parsed into distinct components, each potentially associated with distinct underlying mechanisms. Decision theory has recently been exploring the role of different types of utility in decision making (e.g., experienced utility, decision utility, remembered utility, and anticipated utility). For example, recent work indicates that rewarding visual images (e.g., photographs of attractive faces) simultaneously generate two sorts of subjective value signals within the VMPFC (Smith et al. 2010): an experienced value signal associated with the attractiveness of the face being viewed, and a DV signal proportional to an individual's relative willingness to pay small amounts of money to see attractive faces. Neuroscience can provide a framework for these different definitions and components of utility that can supplement the information that emerges from traditional the revealed preference paradigm. Neuroscience can help assess whether there is more to value than what is expressed in action. Similarly, neuroscience can inform our understanding of the mechanisms of temporal discounting, and its relation to other constructs such as impulsivity and other paradigms such as delay of gratification.

5 Hypothesis generation and constraints

A subtle detail in the previous section is that neuroscience can lead to new predictions and new paradigms for dissociating processes that may not be so easy to separate using nothing more than behavioral data and traditional research designs. It is not the case that imaging data merely lead to a search for high correlations. The food example above drew on a body of prior work to generate testable hypotheses about food choice.

More generally, neuroscience provides constraints on hypotheses that can be used to account for choice data. For example, we can reject a hypothesis about decision making that implies an unrealistic biological mechanism. A model about decision making under stress that does not have fidelity with respect to our biological understanding of the stress response would not go very far in furthering our understanding or in suggesting successful interventions for responding to stress that lead to effective decision making. Similarly, a decision-making model for stress or a model for pathological decision making that accords with our understanding of biological mechanism, but does not adequately represent decision-making processes is unlikely to yield a useful model.

Neuroscience can suggest new hypotheses, whether they be about the prediction of choices or about underlying mechanisms. One such recent example is by Ho and Spence (2009) who predicted that behavioral responses by drivers to in-car warning signals will be facilitated by designing warning systems that incorporate insights about constraints of the brain. Drawing on neuroscientific findings that humans (and other animals) pay greater attention and respond more rapidly to sensory stimuli occurring in peripersonal (i.e., close to the body) than extrapersonal space, they find support for the idea that peripersonal warning signals, compared with traditional warning signals, afford significant performance advantages. In another example, Wadhwa et al. (2008) generated novel hypotheses, based on physiological theories of "reverse alliesthesia" and neuroscience research on the dopamine system, that consumption cues that are high in incentive value (such as sampling a food or brief experiences with hedonic cues) can strengthen subsequent goal pursuit of reward-seeking behaviors (defined as a representation of an internal state associated with a desirable outcome). The authors found support for their predictions, which ran counter to common views held by marketing practitioners and health experts, that sampling a food generally leads to lower subsequent consumption. Neuroscience also brings into decision-making research variables that have not been traditional key variables in behavioral models or paradigms. For example, recall our previous examples about the examination of hunger on our choice of food or the role of stress in decision making. The use of new hypotheses, variables, and paradigms can enrich decision-making research and potentially lead to interesting new findings.

The concept of optimization, held so dearly by many decision theorists, can also be extended by taking a biological approach. Biology may provide additional concepts and other objective functions that may lead to different predictions and conceptions of optimality. So, for example, models for foraging may provide new intuitions and predictions for food decisions. Or, a series of decisions that may not appear optimal when viewed in isolation may become evident as optimal when viewed in the context of a broader system where there are additional objectives and constraints. Behaviors and decisions leading to long-term gene propagation at the expense of the immediate and direct benefit to the individual, might not appear locally optimized but make sense from an evolutionary perspective and thus might be driven by specific biological mechanisms. New insights may come into play when analyzing the biological mechanisms underlying different strategies that a decision maker may employ (not only the usual strategy of maximizing a utility integral, but other strategies such as choosing the option with maximum probability to win or minimize maximum loss).

6 Hypothesis testing

An important issue in decision and consumer neuroscience is whether neuroscience evidence can be used to test a psychological or behavioral hypothesis, or can only speak to hypotheses about neural processes. Many have argued, quite correctly, against the validity of "reverse inference" in fMRI (e.g., Poldrack 2006). Reverse inference is concluding that participants were using a particular psychological process or experiencing a particular psychological state because of the presence of activation in a certain brain region. An example would be concluding that participants felt fear because the amygdala was active during the task. While we agree that researchers should guard against reverse inferences, such thinking can play a role in generating hypotheses for further testing.

More importantly, reverse inference is not the only way that functional imaging can be used to test hypotheses about psychological processes. Functional MRI can validly speak to whether two tasks use identical psychological processes—because if they do, they should result in similar brain activation. It is the similarity/difference of the brain activation, not the anatomical location, that is crucial here. Yoon et al. (2006) used this logic to show that thinking about brands does not engage the same psychological processes as thinking about people since the brain activity for brand judgments was quite different from that involved in person judgments. Kable and Glimcher (2010) used similar logic to argue that people do not value immediate and delayed monetary rewards using fundamentally different mechanisms since the brain networks activated by both kinds of rewards were almost identical.

7 New types of predictions

The use of neural data in models of consumer decision making holds the promise of better predictions about consumer behavior across different time scales. Knutson et al. (2007), for example, distinguished between purchased-item trials and non-purchased-item trials, and found significant differences in nucleus accumbens (NAcc) activation during preference formation, and both MPFC and insula deactivation during price processing. In line with their a priori hypotheses, they then estimated brain activity in these three regions of interests and entered them as covariates in a logistic regression, along with self-report measures of preference and net value, to predict subsequent purchasing decisions. The results indicated that the full model (i.e., including the neural measures) provided significantly better predictive power, albeit one offering a small advantage over a model including only self-report measures (see also Tusche et al. 2010).

Berns and colleagues demonstrated that neural responses can be used to predict purchases that are made several years later. Berns et al. (2010) conducted a study with adolescents, from October 2006 to August 2007, in which behavioral measures of preferences and neural responses were collected while participants listened to 15-s clips of songs downloaded from http://MySpace.com. They found that likability ratings of songs were highly correlated with activity in the caudate nucleus (an area implicated in reward and valuation). The researchers also found that the tendency among participants to change their evaluations of a song in line with its popularity (i.e., reference group's ratings) was positively correlated with activation in the anterior insula and anterior cingulate (ACC). In a subsequent study, the investigators found that the individual neural responses (in OFC and NAcc) to songs in their initial study predicted purchase decisions by the general population assessed via total number of units sold through May 2010 (Berns and Moore 2012).

8 Multiple methods are advised

Neuroscience offers a wide range of variables and paradigms. Our suggestion is that researchers use multiple methods and paradigms from multiple disciplines. Of course, within the neuroscience domain fMRI has received much attention lately because of the compelling images it produces of the functionally related blood oxygen level-dependent responses, which reflects metabolic changes associated with neuronal activity. But, there are many other techniques within the neuroscience domain that may be useful to decision researchers. Measurements of brain structure, including diffusion tensor imaging, can provide insight into differences across individuals; e.g., as when examining changes in brain regions or their connecting pathways over the lifespan. Recordings of changes in brain electrical activity, such as electroencephalography and magnetoencephalography, provide better temporal resolution at the expense of poorer spatial resolution. Newer methods based on infrared technology show good temporal and spatial resolution (though currently limited to recording near the surface of the cortex) in a more mobile context than fMRI.

Multiple methods not only have different strengths, in terms of the biological variables they can measure, they can also permit fundamentally different inferences. None of the techniques above allow one to infer that a neural process is necessary for a decision or that it plays a causal role in generating behavior. Lesion studies, in contrast, do test necessity. One can use lesion studies and animal models of decision making to test process and mechanism. There is also a way to mimic a lesion study by temporarily disrupting a particular brain region using repetitive transcranial magnetic stimulation (rTMS) or transcranial direct current stimulation. Further, there are psychopharmacological manipulations, the multisensory nature of perception, psychophysiological variables and genetics that can be added to the decision researcher's toolbox, each providing different paradigms, variables and constructs. Of course, there are startup and transaction costs in adopting these technologies in one's research paradigm, but those costs should be judged against the potential benefit in the more pointed theory testing that emerges from considering the interplay of biological, cognitive, affective, and behavioral variables.

An example of multiple methods comes from work by Plassmann et al. (2010) who observed decision-making-related value signals in the mOFC and DLPFC. But these value signals could be an output of decision making rather than an input. If these value signals are used in decision making, then individuals with damage to this area should behave less like value maximizers. This is exactly what Fellows and Farah (2007) observed in a choice experiment with food, famous people and colors. Patients with damage to mOFC and VMPFC were more inconsistent in their choices. Plassmann et al. (2010) demonstrated that the signals in DLPFC play an important causal role in valuation. Using rTMS while participants were involved in an economic valuation task involving the consumption of real foods, they found that applying transient disruption of the DLPFC resulted in a decrease in the values assigned to the stimuli relative to a control group. The results are consistent with the possibility that the DLPFC plays a causal role in the computation of DV at the time of choice. These results show that a manipulation of brain activity encoding DV can alter behavioral preferences of consumers.

Our general point is that the field of decision making has much to gain by taking a multidisciplinary approach to its research questions. Neuroscience is a natural discipline to add to the list of disciplines that relate to the field of judgment and decision making.

9 The neurobiology of social influence

Consumer decision making hardly ever occurs in isolation. Implicitly or explicitly, consciously or unconsciously, the social context influences choice. People demonstrate various forms of herding—alignments of the thoughts or behaviors of individuals in a group (herd) without centralized coordination (Raafat et al. 2009). The conformity literature has focused on the influence of descriptive norms, which provide information about the behavior of relevant others (such as one's peers) and are distinguished from injunctive norms that specify what "ought" to be done (e.g., "do not drink and drive"). Although the phenomenon of social conformity and the power of descriptive norms have been studied extensively in traditional behavioral research paradigms, recent evidence points to relevant neural mechanisms. For example, Klucharev et al. (2009) used fMRI to reveal that social conformity follows principles of reinforcement learning. The results indicate that a conflict with group opinion triggers a neuronal response in the NAcc and the rostral cingulate zone (RCZ), a dorsal aspect of the MPFC similar to the 'prediction error' signal suggested by neuroscientific models of reinforcement learning (Schultz et al. 1997). Moreover, the amplitude of this neural response predicted the magnitude of the subsequent conforming behavioral change, and the overall size of the neural signal was related to individual differences in behavioral conformity. A follow-up study by Klucharev et al. in which they down-regulated the RCZ by means of rTMS indeed reduced conforming behavior, thus providing strong evidence of the causal role of the RCZ in social influence.

As discussed already, Berns et al. (2010) demonstrated that participants changed their opinion about a music clip when receiving information about the popularity of that clip; and that tendency to change the opinion due to the perceived opinion in their reference group was positively correlated with activation in the ACC and anterior insula. Furthermore, the MPFC was also found to be central to learning about social information (advice) and for determining the extent to which it guides behavior (Behrens et al. 2008).

The hypothesis that social conformity has a basic neural mechanism generates relevant insights for consumer behavior and marketing. First, an automatic response to deviating behavior from others makes it difficult for consumers to resist such an influence. For social norm campaigns such as encouraging people to eat healthy, drive safely, or donate their organs, one may expect that providing descriptive social norm information will generate the automatic tendency to conform. Second, understanding the dopamine system as well as conflict/error processing and its pathologies may inform us about when and for whom large effects of social influence can be expected. We speculate that if aging affects the dopamine system by weakening the reward prediction signals, then the elderly may be less affected by descriptive norm information and exhibit less social conformity. Of course, one needs to be careful making inferences about neurotransmitter systems from imaging studies and, likewise, about drawing policy implications from relatively preliminary evidence. We assert that a neuroscience perspective to the problem provides novel insights and directions for testing hypotheses, and suggests new interpretations that can be tested in subsequent studies. This is exactly the kind of generative process one likes to see in research programs.

10 Consumer neuroscience concerns

Our enthusiasm for the promise of adding neuroscience approaches to the traditional study of consumer decision making is tempered by some concerns. First, we recognize that the startup costs in terms of training are exceptionally high. Researchers and graduate students need proper training. It is more than merely learning about a new variable or a new paradigm. Doing this research properly requires a new way of thinking that must be incorporated into one's overall theoretical perspective. This will require a change to an already over-cramped graduate school curriculum. Some of the startup cost can be absorbed through careful collaboration but there is no substitute for the behavioral researcher learning the basic paradigms, models and analysis issues in neuroscience, and likewise for the neuroscientist collaborator to learn about the basic behavioral paradigms, models and analytic issues. Furthermore, the research is relatively expensive and requires a different type of infrastructure than is common in decision-making research.

Second, we should calibrate expectations for what the field can realistically deliver, especially for practitioners. This nascent field should not promise the royal road to perfect (or better) prediction of choice. Some people can get seduced by the dramatic brain images in *Time Magazine* and the like, and think that it must be "real science," which they assume is better than the usual behavioral work (Weisberg et al. 2008).

The fields of decision neuroscience and consumer neuroscience are academic disciplines that use a multidisciplinary and multimodal perspective to tackle its research questions. There is no magic: one cannot peek inside a decision maker's head and predict individual's selection of toothpaste or tomorrow's visit to the grocery store. We must be mindful of the limits of the techniques we use. For example, fMRI methodology cannot allow definitive inferences about the neurotransmitter system in play for a particular activation. But, our general point is that what is going on inside the head as measured by various imaging and biological correlates like genes and hormones can provide new insights and new ways to test theory. This is a great opportunity for the decision-making researcher.

Where do we go next? As the field of consumer neuroscience moves into the mainstream, we need to develop publication standards, establish training centers to educate graduate students and provide additional training for faculty who want to retool. Most importantly, the field needs to tackle the exciting research questions that are now possible with the new tools in our research toolbox. Unprecedented research opportunities are now available by adopting a multidisciplinary perspective on decision making that incorporates biological approaches.

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Available online at www.sciencedirect.com
ScienceDirect
International Journal of Psychophysiology 63 (2007) 199–204
INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY
www.elsevier.com/locate/ijpsycho

What is 'neuromarketing'? A discussion and agenda for future research

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Received 1 February 2006; received in revised form 1 March 2006; accepted 30 March 2006
Available online 12 June 2006

Abstract

Recent years have seen advances in neuroimaging to such an extent that neuroscientists are able to directly study the frequency, location, and timing of neuronal activity to an unprecedented degree. However, marketing science has remained largely unaware of such advances and their huge potential. In fact, the application of neuroimaging to market research – what has come to be called 'neuromarketing' – has caused considerable controversy within neuroscience circles in recent times. This paper is an attempt to widen the scope of neuromarketing beyond commercial brand and consumer behaviour applications, to include a wider conceptualisation of marketing science. Drawing from general neuroscience and neuroeconomics, neuromarketing as a field of study is defined, and some future research directions are suggested.

Keywords: Neuroscience; Neuromarketing; Neuroeconomics; Marketing; Neuroimaging

1. Introduction

Recent years have seen an explosion in the abilities of neuroscientists to directly study cortical activity in terms of frequency, time, and space. The psychological and physiological sciences have been quick to apply such techniques to make startling advances in our understanding of the brain and cognition. However, most social sciences have yet to adopt neuroimaging as a standard tool or procedure for research. In particular, while economics has begun to utilise neuroimaging techniques in its research – resulting in the creation of 'neuroeconomics' (e.g. Braeutigam, 2005; Kenning and Plassmann, 2005; Rustichini, 2005) – marketing science has been far slower to wake up to the benefits of imaging research, despite both fields of study sharing many common concerns regarding decision making and exchange.

There are a number of possible reasons for the lack of take-up of brain imaging methodologies in marketing science. From the perspective of the marketing academic, neuroscience and cognitive psychology in general can be intimidating subjects. Furthermore, many marketing academics may see imaging techniques as simply 'unattainable' to them in their own departments. However, this is generally not the case, as most business academics work within the context of a larger university with considerable facilities for brain imaging. Even if instruments such as positron emission tomography (PET), magnetoencephalography (MEG), or functional magnetic resonance imaging (fMRI) are unavailable, electroencephalography (EEG) and galvanic skin response (GSR) technology will likely be. However, the lack of knowledge of even the existence of such techniques leads to a situation where they are not considered as potential avenues of exploration.

One possible solution to this is cross-school or departmental collaboration between business and neuroscience research groups — both in terms of project design and procedure. However, from the perspective of the neuroscience researcher, there also appear to be some barriers to collaboration. In particular, while neuroeconomics appears to have raised nary a ripple of moral concern, recent opinions on 'neuromarketing' within the neuroscience literature have strongly questioned the ethics of applying imaging techniques to the purpose of "finding the 'buy button in the brain' and …creating advertising campaigns that we will be unable to resist" (see the July 2004 Editorial of Nature Neuroscience, p. 683). Emotive language such as this does little to further the possibility of academic collaboration between marketing and neuroscience researchers. Furthermore, it seems such views are reasonably widely held

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doi:10.1016/j.ijpsycho.2006.03.007

within neuroscience research groups. This is interesting, since many of the problems investigated by neuroeconomics research are virtually identical to what a marketing researcher would recognise as part of their functional domain (cf. Braeutigam, 2005; Kenning and Plassmann, 2005; e.g. Deppe et al., 2005). Yet it is marketing, not economics, which has caused such disquiet within neuroscience circles. Unfortunately, this concern (see also the February 2004 Edition in The Lancet, p. 71) – while containing possibly more than a grain of truth – exhibits a fundamental misunderstanding of marketing science in an *academic* (rather than commercial) sense.

More specifically, without entering the long and wide-ranging debate over the scope of marketing, marketing research in business schools is essentially about understanding, explaining, and predicting individual, group, and organisational behaviour relevant to markets. Such a remit encompasses a much wider range of fields than simply how to influence consumers to buy a product. The 'buy button' would be a finding of interest to academic marketing researchers certainly, but then so would something like the 'love button' to psychological scholars. Commercial interests are of course free to apply insights from academic marketing research (as they are from psychological and economic research), but this is not *necessarily* the remit of the marketing academic. Unfortunately, the barely concealed disdain for the idea of 'neuromarketing' in the neuroscience literature is clearly based on the opinion that marketing research is a commercial activity purely designed to sell products to the public, which seems to be behind the editor of *Science*, Donald Kennedy's, concern that "brain imaging will be used in ways that infringe personal privacy to a totally unacceptable degree" (The Lancet, February 2004).

This note is aimed at providing a scholarly perspective on the emerging and controversial field of 'neuromarketing'. In doing so, we aim to define what we feel neuromarketing itself is, as well as provide a brief overview of the prior work in the area. Following this, we will set out a number of key issues within marketing research which neuroimaging is likely to help provide insight into. These problems are intended to highlight how collaboration between neuroimaging and marketing researchers can advance our knowledge of many key areas pertaining not only to consumer choice, but how we interact, relate, and behave in the context of markets and organisations. Our aim is not to set boundaries on what can and cannot be investigated in such a context, but to try to encourage and inspire thought about how neuroimaging can enhance our understanding of what is – for good or ill – an unavoidable part of contemporary society.

2. Exploring and delineating the scope of neuromarketing

In recent times, 'neuromarketing' has come to mean the application of neuroimaging techniques to sell products, or to — as *The Lancet* puts it "dazzle potential clients with snazzy imaging technology" (February 2004, p. 71). A number of agencies have emerged offering neuroimaging (particularly fMRI) solutions to commercial marketing problems. In the US, BrightHouse has developed a particularly high profile, while in the UK Neurosense and Neuroco have also recently opened for business. Furthermore, the Centre for Experimental Consumer Psychology at University of Wales (Bangor) collaborates with many consumer goods firms, including Unilever. Unfortunately, much of the output of such centers is commercially sensitive, meaning that there is little information available about what they actually *do*, even though newspapers and other outlets find such ideas compelling. Nevertheless, neuromarketing agencies have been involved in work as diverse as evaluating car preferences for DaimlerChrysler (Erk et al.'s published output of which is referred to below), the relationship between smells and colors of food products, and which advertising media are most likely to be successful in delivering different types of messages.

It is evident that the idea of evaluating the neurological correlates of consumer behaviour has caused considerable excitement within the marketing profession (e.g. Marketing Week, 2005; Mucha, 2005). Articles such as these, and the aforementioned editorials in the neuroscience literature, give the impression that neuromarketing is solely the application of neuroimaging to consumer behaviour, and how we respond to brands and advertisements. Yet even a cursory glance at the academic literature will show the scope of marketing research to be considerably broader than the response to products, brands and advertising, and even consumer behaviour in general. Any definition of neuromarketing must take into account this diversity of research. Neuroeconomics defines itself as "the application of neuroscientific methods to analyze and understand economically relevant behaviour" (Kenning and Plassmann, 2005, p. 344). Following this lead, neuromarketing as a field of study can simply be defined as the application of neuroscientific methods to analyze and understand human behaviour in relation to markets and marketing exchanges. Such a definition has two main upshots: firstly, it moves consideration of neuromarketing away from being solely the use of neuroimaging by commercial interests for their benefit; secondly, the scope of neuromarketing research is widened from solely consumer behaviour, to include many more avenues of interest, such as inter and intra-organisational research, which are common in the marketing research literature.

The contribution neuroscientific methods can make to understanding of marketing-relevant human behaviour is likely to be considerable. The advantages of physiological measurement for marketing have been noted for at least two decades (e.g. Weinstein et al., 1984). In particular, the self-assessment measures commonly used in marketing research rely totally on the ability and willingness of the respondent to accurately report their attitudes and/or prior behaviours (Petty and Cacioppo, 1983). Physiological responses, however, can be collected when respondents are directly participating in the behaviour, are difficult for subjects to control (although not difficult to affect), and although there are individual differences in physiological responding, variations in social situations and stimuli have also been shown to have a powerful effect across individuals (Cacioppo and Petty, 1985). As seen above though, neuromarketing has not been without critics and, even within academic circles, concerns have been raised over the ability of neurological methods to adequately take into account the panoply of relevant variables in marketing theories (e.g. Stewart, 1984; 1985).

Despite its vast potential, it is clear that prior applications of neuroimaging within the marketing literature have been solely focussed on brands and consumer behaviour. In particular, EEG has been used to explore reactions to TV advertisements in a number of ways. For example, Young (2002) explored whether specific moments within ads are primarily responsible for brand development and attention. Memory and information processing have also been of interest, with Rossiter et al. (2001) using EEG to show that certain visual scenes – showing fastest activation in left frontal cortices – are also better recognised. In the neuroscience literature, Ioannides et al. (2000) and Ambler et al. (2000) report the results of MEG experiments showing how cognitive and affective advertisements elicit activity in different cortical centers. Taken together, such findings suggest that different aspects or types of advertising generate significantly different types of brain activity, possibly leading to differences in recall and/or other measures of ad effectiveness. Yet such research is piecemeal at present.

Consumer choice-making has also proved a popular subject for neuroimaging research, although it has yet to find its way into the marketing literature. Braeutigam et al. (2001, 2004) for example have explored the difference between predictable and unpredictable choices, where predictability can be related to both the frequency of prior usage of the item, and the time gap between the choice and exposure to marketing stimuli. This research suggests that different brain regions are activated according to choice predictability, with unpredictable choices eliciting activity in regions associated with silent vocalisation and judgement of rewards. Gender differences were also found. Interestingly, recent research has suggested that a variety of brain areas are associated with pleasure and rewards (e.g. Senior, 2003), and a number of these areas have been implicated in prior research. Erk et al. (2002) found that objects of high social value (sports cars) resulted in higher reward center activity (orbitofrontal cortices, anterior congulate regions, occipital cortices) than lesser-valued objects such as small cars. Finally, in a study which received substantial attention, McClure et al. (2004) discovered that there was a higher preference for Coke over Pepsi, and also the recruitment of emotion and affect-related areas of the brain (hippocampus and dorsolateral prefrontal cortex), when respondents were told they were drinking Coke. However, blind testing suggested no such thing. Such work reinforces the complexity of choice-making, as well as the value of emotional, situational, and informational resources.

3. Some directions for scholarly neuromarketing research

Research in marketing is considerably broader than simply exploring end consumers and their decision making though. The following section is aimed at giving a flavour of the types of questions deemed important by marketing scholars, where neuroimaging techniques may prove illuminating. The importance of such areas is evidenced by their appearance in the calls for research by institutes such as the *Marketing Science Institute* and the *Institute for the Study of Business Markets*, as well as in calls for papers by numerous top-level marketing academic journals. We give special attention to non-consumer level questions in an attempt to broaden the scope of debate as to the application of neuroimaging to marketing research. Interestingly, many of these questions have been investigated in the context of neuroeconomics, yet marketing research has much to offer in such areas, among others.

3.1. Trust

Trust is an issue which has been increasing in prominence within marketing for the last decade. However, while consumer trust in brands and products is of course vital, marketing research has investigated trust on many other levels. Inter-organisational dealings such as joint ventures, strategic alliances, and business-to-business buyer/seller dyads depend on mutual trust between parties. On one hand, consumer trust in marketing claims is crucial if they are to be believed, and ultimately lead to purchase behaviour from consumers. The social utility of trust is clear when one considers that firms selling ‘fair trade’, ‘organic’, or other socially beneficial products must rely on consumer trust in their claims for success. Furthermore, in an organisational context, relationships depend on mutual trust between the parties. Without trust, opportunistic behaviour dominates interactions, negating the possibility of long-term relationships between parties and again leading to a suboptimal situation for all. Marketing research has commonly conceptualised trust as more than a simple rational economic calculation (Morgan and Hunt, 1994), and it seems likely that neuroscientific methods can provide considerable insight into the nature and development of trust.

Neuroeconomic research has begun to investigate concepts of trust beyond rationality in recent times (King-Casas et al., 2005). Neuromarketing research can also be insightful to the investigation of trust. First and foremost, it is clear that – despite the centrality of trust to marketing relationships at a number of levels – controversies over the very nature of trust still exist (e.g. Ali and Birley, 1998; Geyskens et al., 1998). Neuroimaging is likely to offer considerable insight here. Research suggests that the caudate nucleus, which is often active when learning about stimuli–response relations, is involved in experimental games requiring some kind of trust (King-Casas et al., 2005). Yet is trust a simple response to a repeated positive stimulus, or something more? More interestingly, is the trust a buyer says they have in a seller, or a consumer in a product claim, similar in terms of the nature and location of brain activity to the trust that individual says they have in a close friend or family member? In particular, measuring both the spatial and temporal characteristics of neuronal activity may be important — for example does trust in an advertising claim or new business partner require increased information processing effort and time than trust in a long-term friend? This will have important implications as to the nature of trust. Furthermore, is consumer trust in claims relating to a product similar to a purchasing agent's trust in a contract with a supplier, and in turn is this of the same nature as the purchasing agent's trust in the individual sales executive they have negotiated with? Can trust be transferred from an organisation to a representative of that organisation? Finally, does trust evolve throughout the course of an inter-organisational relationship, or with continuing loyalty of a consumer to a single brand? Is 'trust' ever truly existent in short-term marketing relationships? Exploring and understanding such questions about the nature of trust will then lead to greater ability to explore the antecedent factors to trust, and an ability to enhance firms' ability to build trust with customers and collaborators for mutually beneficial outcomes.

3.2. Pricing

Pricing is a key tool used by organisations in the positioning of their products. Commensurate with this, much marketing research has investigated the effects of price on consumers (Bijmolt et al., 2005). Despite the amount of academic knowledge available, companies appear to use little of it when setting prices, leading to suboptimal situations for both consumers and firms. Understanding the psychology of pricing is of crucial importance if firms are to make optimal decisions and in fact has considerable utility in a broader sense. Pricing research has implications for how we understand information processing in any decision context where resources and information are scarce and costs must be weighed against benefits. Recent behavioural research for example has explored errors made by consumers when they process prices ending in 0.99 rather than a whole number — suggesting that individuals pay less attention to later numbers in a sequence (Bizer and Schindler, 2005). Other research has begun to investigate the social role of price, and how individual differences can influence how prices are perceived (Amaldoss and Jain, 2005).

At this stage however, almost all pricing research is behavioural in nature, and relies on 'assumptions' about what actually occurs when individuals process pricing information. In fact, pricing seems to lend itself almost perfectly to neuroimaging research. For example, simultaneously exploring the temporal and spatial nature of brain activity may help us understand exactly why prices such as '$4.99' are perceived as significantly cheaper than those such as '$5.00'. Do individuals really ignore the final two digits, or are they processed in a different manner or at a later time — for example only when detailed comparative decisions must be made? Furthermore, do time or other pressures influence the processing of prices? Also, neuroimaging looks likely to provide considerable insight into the nature of price information. Is the price of products a purely rational piece of information, or does it have emotional and/or reward-based connotations? It seems likely that the price of a basic product such as sugar is very different in nature from the price of a conspicuous product such as a Nike sports shoe, or a Porsche sports car, which should be evidenced in changes in the location of brain activity when these prices are viewed alongside their associations. Research such as this will allow us not only to understand how prices are processed, but will afford insight into all situations where seemingly rational information is processed in decision-making situations.

3.3. Negotiation

With exchange being such a central concept in marketing, negotiations are of critical importance. For example, consumers are often in situations where they must negotiate prices or other benefits with marketing operatives — especially for big ticket items such as cars, houses, and the like. Negotiation though is an unpleasant experience for many consumers, so much so that some organisations differentiate themselves by explicitly stating 'no negotiation' (Trocchia, 2004). Inter-organisational negotiations are also a key contributor to the efficient functioning of markets, whether they be for strategic alliances, short-term collaborations, or even manufacturer–supplier negotiations.

Game theory has proven of considerable interest in economic and marketing research when examining interactions in situations where differing payoffs exist which are known to participants (e.g. Welling and Kamann, 2001). Game theoretic models have also proven useful in the evolution of neuroeconomic research (Braeutigam, 2005; Kenning and Plassmann, 2005; Rustichini, 2005). Neuroeconomic research on games can offer considerable insight into cortical activity in decision making (Rustichini, 2005). However, they tend to be focussed on competitive/cooperative behaviour (McAfee and McMillan, 1996) rather than the negotiation processes which may lead to behaviour. Unfortunately, the marketing literature currently provides little insight into the underlying processes which lie behind negotiating behaviour, and how others evaluate various negotiation strategies (Trocchia, 2004).

By contrast, neuroimaging research has already begun to investigate negotiating behaviour. Specifically, evidence suggests that emotion as well as rational cognition is a major influence on negotiating behaviour, especially when offers are considered to be unfair (Sanfey et al., 2003). In a marketing context, research such as this looks likely to help understand when and how consumers (as well as organisational agents) are likely to let their emotions override their rationality in negotiating prices or other deals. This may ultimately help consumers get a better deal and reduce those times when we look back with regret at a purchase. Other (fMRI) research has suggested that those who cooperate in an exchange are more likely to exhibit activity in the areas associated with our understanding of others' intentions (McCabe et al., 2001). Extending such research using newer multi-modal methods may further enhance our ability to understand exactly why people do or do not cooperate, even in situations where it may be optimal. For example, what situations cause us to ignore other people's benefits and solely focus on our own, or vice versa? Exploring differential brain activity in both a temporal and spatial sense may provide insight here. Furthermore, what areas or types of cortical activity are associated with risky negotiating tactics or negotiation tactics deliberately intended to harm another party? Investigating the neuronal activity underlying such suboptimal behaviours may allow us to reduce their likelihood and increase mutually beneficial outcomes to negotiation.

3.4. Marketing and society: ethics

The last decade has seen an explosion of interest in the impact of various marketing activities on society, with particular focus on ethical issues within marketing. This interest has not been restricted to marketing research, but also from disciplines like communications, sociology, politics, and not least psychology. Most obvious of these areas has been advertising's impact. Ethics in marketing is not solely concerned with the impact of advertising messages on society though. Other scholars have concerned themselves with the impact of globalisation of markets, such as fair trade and ethical production. Research has also begun to consider the idea that consumers may be harmed by a constant bombardment of marketing, with overconsumption and purchase addiction being one possible result. In sales research, much research has explored unethical selling activities and the negative outcomes of such tactics.

Neuroimaging is likely to contribute to marketing ethics in many ways of which there is space to explore here but a few. First of all, research into advertising effectiveness – which has caused so much consternation in neuroscientific circles – can contribute more than just finding the aforementioned ‘buy button’ in the brain. In fact, exploring exactly what elements of an advertisement are critical to awareness, attitudes and evaluations of products, and whether these differ for different groups, should *reduce* firms' reliance on the ‘blunt instruments’ of blanket coverage, shock tactics, or sexual imagery. The application of neuroscience to marketing may form a basis for understanding how human beings create, store, recall, and relate to information such as brands in everyday life. Furthermore, it may be possible to discover whether certain aspects of advertisements and marketing activities trigger negative effects, such as overconsumption. Exploring why certain individuals become compulsive credit-users could provide outcomes of considerable social utility — are there differential locations and/or times of brain activity when a purchase is made or marketing message is viewed between those who are compulsive overpurchasers and those who maintain more appropriate levels of spending? Finally, in the sales arena, can we differentiate between the brain activity of salespeople who apply highly ethical principles to their interactions, and those who would employ less ethical action? Are less ethical individuals more likely to fixate on short-term payoffs for themselves? Neuroeconomic research has investigated altruism, suggesting that cooperation is linked to activation of reward areas (Rilling et al., 2002). However, are these same areas activated when unethical salespeople for example perform an unethical act? Investigations into such problems could in fact be amongst the most compelling within neuromarketing.

4. Concluding remarks

While neuromarketing has only recently begun to concern neuroscientists, this article has shown that neuroscientific techniques have been used on an ad-hoc basis to investigate marketing problems in an academic sense for a number of years. Furthermore, the recent interest in neuroeconomics was shown to have considerable overlap with the domain of marketing research. We have tried to show here that the popular neuroscientific perception of neuromarketing as unethical, fundamentally flawed, and potentially harmful, should not mistakenly be applied to scholarly marketing research. Instead, we see no reason why marketing research should not be able to benefit from neuroimaging at least as much, if not more, than economics research has begun to. Indeed, the field of neuromarketing should be considered as a legitimate and important area for future research, which will allow us to more fully understand human behaviour in an extremely important context. Applying neuroimaging to marketing research problems should allow us to understand far more clearly the impact of marketing techniques, as well as gain insight into key problems concerning business relationships, answers to which have previously remained elusive.

That said, it must be stressed that neuroimaging research itself is constantly evolving, both in terms of technology as well as insights into exactly what activity and processes in various areas of the brain actually mean. For example, as technology evolves we are able to measure frequency, temporal, and spatial characteristics of brain activity more accurately and in a complimentary fashion, potentially leading to new insight into what were previously well-accepted brain functions and areas of activity. A field such as neuromarketing adds what could be called a ‘layer of theory’ on top of the actual cortical activity measure. It should not be forgotten that this layer of theory is essentially subjective and cannot directly ‘prove’ a posited relationship between marketing constructs. Nevertheless, better and more objective measurement and observation, as can be provided by neuroimaging in many cases, allows us to get closer to understanding what really happens in response to marketing stimuli, and in marketing-relevant situations.

The purpose of this article was to provide a perspective on neuromarketing which was concerned not with commercial applications, but with developing a greater understanding of a critical area of contemporary human society. While we understand the concern amongst neuroscientists regarding inappropriate application of their techniques, we looked to show that neuromarketing itself can be a valid field of study, and a rich source of problems to be investigated using insight from neuroimaging. We hoped to stimulate greater attention to neuromarketing issues within both neuroimaging and marketing research groups, as well as to expand the scope of debate and discussion on neuromarketing and other applications of neuroimaging. Both fields have much to learn from each other's perspective, and scholarly neuromarketing research, conducted in a collaborative and non-judgemental spirit, is likely to offer us much insight into how humans behave during what is a large part of our modern lives.

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ABOUT THIS COMPENDIUM

The original purpose of this compendium has been for the use in my own lectures in consumer neuroscience and neuromarketing at the Copenhagen Business School. However, I also recognise that this volume can also be a potentially valuable resource for both newcomers as well as experienced people within this discipline. Neuromarketing is today very much a conglomerate of divergent solutions; hyped up talks; and a mixture of true science and pop science gone terribly wrong. This collection of papers represent my own take on what the basics should entail

This book is also intended as a supplement to my book "Introduction to Neuromarketing & Consumer Neuroscience", which you can read more about here: http://neuronsinc.com/publications/introduction-to-neuromarketing-consumer-neuroscience/ (also see next page).

The selection of texts are not intended to be an exhaustive listing of all relevant articles. I have worked from two basic premises: 1) that the article is available freely on the web; and 2) that the article represents some of the leading thoughts (and scholars) in this field.

If you have suggestions or comments, please send me an email at tzramsoy@gmail.com

DISCLAIMER

Happy reading!

All the best,

v 2.0 – August 2014

WHO MADE THIS?

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Thomas is considered one of the leading experts on neuromarketing and consumer neuroscience, and he is an innovator by heart. With a background in economics and neuropsychology, he holds a PhD in neurobiology from the University of Copenhagen.

Thomas has published extensively on the application of neuroimaging and neurophysiology to consumer behaviour and decision making. He is the Director of the Center for Decision Neuroscience, where his research team uses an eclectic mix of technologies and the sciences of economics, psychology and neuroscience. Beyond this, Thomas is the CEO of Neurons Inc, where he consults companies around the globe on the use of science and technology in business.

More information about Thomas can be found on the following resources:

Professional pages
DNRG CBS – http://cbs.dk/DNRG
DNRG HH – http://drcmr.dk/research/DecisionNeuroscience
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