CHAPTER 2

The Emergence of Social Neuroscience as an Academic Discipline

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Abstract

The term 'social neuroscience' combines two topics of scientific enquiry—the 'social' and the 'brain'—whose relation can be analyzed from two different perspectives: either from a broader historical one focusing on the emergence of modern brain research even before neuroscience was formed, or from a narrower one, based on a conceptual idea of how disciplines and research fields are characterized in contemporary science. This chapter analyzes the latter aspect, although it begins with some remarks on the former perspective. The analysis is made from the 'external' perspective of history and sociology of science intending to reconstruct origins, properties, and discourses that lead to today's understanding of social neuroscience as a disciplinary field.

Keywords: history of neuroscience, social brain, social neuroscience, academic discipline, bibliometry, impact analysis, science studies, interdisciplinarity, discipline building

The Social and the Brain—Some Basic Clarifications

The term "social neuroscience" combines two topics of scientific enquiry—the "social" and the "brain"—whose relation can be analyzed from two different perspectives: a broader historical one focusing on the emergence of modern brain research even before neuroscience was formed (the term "neuroscience" was first used in its modern sense by Ralph Gerhard in the late 1950s, Adelman & Smith, 2004), or from a narrower one, based on a conceptual idea of how disciplines and research fields are characterized in contemporary science. This chapter analyzes the latter aspect, although we begin with some remarks on the former perspective. Our analysis is made from the "external" perspective of history and sociology of science intending to reconstruct origins, properties, and discourses that lead to today's understanding of social neuroscience as a disciplinary field.

The advent of modern brain research in the beginning of the 19th century was accompanied with a conceptual shift concerning the understanding of the brain's role in mediating human behavior. Whereas Cartesian dualism assigned to the brain the role of being an executor of the soul—the brain as the "organ of the soul" had been the dominant paradigm for about 150 years—the work of Franz Josef Gall (and others) established a new significance to the brain as the originator and elicitor of the various expressions of human nature (Hagner, 1997). This shift was not only the precondition for introducing many modern neuroscientific concepts (Clarke & Jacyna, 1987), it also made it in principle possible to relate brain functions to human behavior and its social consequences like criminality,

immorality, or gender and racial differences. This assumption of a relation between brain and behavior was also the basis of 19th century phrenology. Thus, the "social brain" was already present in the 19th century—but not in the sense that the interplay between neural mechanisms and social behavior was a topic of research. Phrenologists like Gall and neuroanatomists like Theodor Meynert or Paul Flechsig only located cognitive and social properties in the brain. However, one cannot claim that the early social brain was just considered to be a placeholder for immovable human character traits that determine individual behavior in its social environment. There was indeed a debate on how social circumstances influence human character dispositions (e.g., in the philosophy of Karl Marx), although no systematic attempt to relate social entities with brain structures and their mutual development was made. Allowedly, in the late 19th century, a research tradition began with John Hughlings Jackson (cf. his *Croonian Lectures on Evolution and Dissolution of the Nervous System, 1884*) to study the evolution of the human brain and its capacities. This tradition, however—that included Walter Cannon, James Papez and Paul MacLean—was marginalized for the best part of the 20th century until it was rediscovered by evolutionary psychology in the 1980s, especially with the social brain hypothesis (see e.g., Brothers, 1990 or Dunbar, 1998). These scientists were not interested in social behavior themselves but their focus on evolutionary structures of the brain and/or emotions made them important predecessors for social neuroscience's conceptualizations of the brain.

In that sense, the "social" and the "brain" engaged in a complex relationship long before "social neuroscience" emerged in today's understanding. In particular, one has to distinguish between the "social brain" as an epistemic object—whose history is interwoven with the emergence of modern brain research and that is both a natural and a cultural object (Hagner, 2004)—and "social neuroscience" as an attempt to understand the mutual development and interplay of social and neuronal entities. Furthermore, it would be a mistake to describe the emergence of social neuroscience as a direct consequence of developments that lead to different notions of the social brain. These developments—now and then—have to be interpreted in a broader cultural and historical context. For example, the attempt of Constantin von Monakow—a leading figure in brain research in the early 20th century—to develop a brain-based theory of human conscience and morality (von Monakow, 1950) or Kurt Goldstein's holistic notion of brain and organism (Goldstein, 1934/1995) cannot be interpreted without taking into account the fundamental trauma World War I caused among European intelligentsia (Harrington, 1996). Understanding the various attempts to explain social phenomena by neuronal functions requires the comprehension of the conditions and contexts under which scientific research took place.

Thus, analyzing the emergence of social neuroscience as an academic discipline goes hand in hand with describing the boundary conditions in which scientists today work and scientific fields develop. In particular, one has to take into account that the concept of "discipline" itself changes in time. Although the attributes of disciplines—journals, academic societies, courses, conference series, labs/departments, curriculae, and in particular the emergence of a more or less coherent body of knowledge related to a specific set of scientific questions and practices (Stichweh, 1992, 2001)—basically remain the same, the dynamics of their development have changed. Two examples may clarify this point: The increased competition for funding requires researchers to carve out territories in the scientific landscape and to promote their broader significance towards the public more pronouncedly. Furthermore, today's information technologies substantially ease the formation of journals and social organization of scientists. Thus, the number of scientific fields declaring themselves as disciplines increased substantially in the last few decades (Stichweh, 2003).

This brief portrait of social neuroscience cannot take into account all these aspects that influence the forming of an academic discipline in today's scientific system. In this contribution, we will use qualitative and quantitative (in particular: bibliometric) tools to sketch and critically examine the main definitions of the field given by its exponents, to describe the founding phase of social neuroscience (which we localize in the 1990s) and to present its differentiation and impact on other fields in this decade. Methodological issues are described in the appendix.

"Social Neuroscience" and the Search for Explanatory Connections between Biological and Social Entities

Social neuroscience today holds many attributes of a discipline—i.e., journals, academic societies, courses, conference series, and labs/research groups (see below). Besides these structural attributes, the commitment on a specific set of scientific questions

and (to a lesser degree) methods, that allow the growth of a coherent body of knowledge (although it will certainly also contain competing hypotheses) is crucial for the emergence of a discipline. This commitment is usually formalized in a definition of the field and the debate about this definition is an inherent part of the process of discipline formation. Handbooks—such as this inaugural handbook of social neuroscience—play a major role in this "stabilization" of the definition of a discipline.

In this section, we first clarify ways of attributing the term social to different sets of entities; second, we list programmatic definitions of social neuroscience (or branches of social neuroscience) given by exponents of the field in review papers, introductions to textbooks, and journal editorials; and third, we discuss these definitions critically. One has to be aware that these definitions reflect the spectrum of legitimate research questions and the setting of priorities, i.e., broader definitions (as given in this handbook) leave space for more "branches" within social neuroscience. Furthermore, the set of questions and methods considered as characteristic for social neuroscience is by no means uncontested within the field at this point. The ongoing debates on these issues indicate that social neuroscience is not yet a stable discipline, but has the more diffuse character of being a disciplinary field in which various disciplinary traditions merge.

Social Entities

What are the classes of entities that should be called "social"? The possibilities span from including all species whose members are in a considerable relation over time (e.g., all species that exchange DNA), up to restricting the term for humans alone. In the history of science, all positions find their advocates—although in recent time a consensus emerged that also animals can be called "social species." From a historical point of view, one has to take into account that regarding the content of the term "social," different priorities can be set–and these priorities are related to dominating paradigms of societal organization. For example, the highly functional differentiation of social insect states has been taken as a positive example for societal organization (Geiger, 1933) as well as a reference point for satirical descriptions of society, exemplified in Bernard Mandeville's famous *The Fable of the Bees*. The remarkable observation that today's characterizations of the content of the term "social" often sets priorities on "positive" issues like cooperation, empathy, care, etc., probably reflects dominating guiding principles of western societies. This indicates that the term "social" is tricky and its relation to biological entities is often contaminated with specific ideals of societal organization—an aspect that we cannot outline further at this place.

However, it is plausible to assume that possible ambiguities in the definition of social neuroscience are partly explained by differences in attributing the term "social" to biological species and (relatedly) the content of this term. The larger the class of species considered as being social species, the smaller is the discriminative power of the term social—and discussions on this issue are widespread in several disciplines. An example is the debate on "animal culture" in primatology (Laland & Galef, 2009). We will come back to this issue in the third part of this section.

Finally, we add that the search for explanatory connections between biological and social entities has found various occurrences in Western thinking for quite a few centuries before social neuroscience came into existence. Anthropologist Marshall Sahlins argues that

> ". . . since Hobbes, at least, the competitive and acquisitive characteristics of Western man have been confounded with Nature, and the Nature thus fashioned in the human image has been in turn reapplied to the explanation of Western man. (. . .) Human society is natural, and natural societies are curiously human. Adam Smith produces a social version of Thomas Hobbes, Charles Darwin a naturalized version of Adam Smith; William Graham Sumner thereupon reinvents Darwin as society, and Edward O. Wilson reinvents Sumner as nature" (Sahlins, 1976, p. 93).

Since Darwin, he says, the motion of this pendulum has accelerated with new and more refined notions of humans as species and species as human in every decade. The most recent undertaking in that respect (before social neuroscience) was sociobiology with its focus on the relation between genes and social behavior beginning in the 1940s. The critical appraisal of sociobiology showed some limitations of the scope on social entities from the vantage point of evolution, i.e., natural selection, adaptation, and fitness. This perspective made it difficult for social sciences and humanities to take part in this endeavor that called itself "integrative," since this focus on biology may not be very helpful for explaining complex cultural, social, or philosophical questions. However, there are ways of thinking

about human social behavior, taking into account evolutionary perspectives without taking biology or "nature" as the basis of human developments. The concepts of "Evolution in Four Dimensions" (Jablonka & Lamb, 2005) or the dual inheritance model (e.g., Tomasello, 1999) both consider the reciprocity of human-made environments and evolution. The concept of evolution in four dimensions argues that next to the genetic inheritance system, three more dimensions and the interactions between all dimensions are crucial for human evolution: the epigenetic, the behavioral, and the symbolic inheritance systems. The dual inheritance model argues that to live culturally is a biological, inherited capacity. In the course of evolution, human-shaped culture again influenced biological evolution by shaping the environment humans had to adapt themselves to (Rose & Rose, 2009). It would be worthwhile but beyond the scope of this contribution to investigate parallels in the current acknowledgement of social neuroscience with the earlier discussions on the relevance of sociobiology and other attempts in order to understand social behavior.

Proposed Definitions

The term *social neuroscience* was coined in 1992 by John Cacioppo and Gary Bernston. In their paper on social psychology's contribution to the decade of the brain, they sketch programmatic principles for understanding mental and behavioral phenomena and their underlying (neuro-)biological processes, called "Doctrine of Multilevel Analysis." They claim that although the brain is the essential component of social beings, the nature of brain, behavior, and society is too complex to be reduced merely to neural processes and that theories of social behavior require the consideration of both social and biological levels of organization. The examples they use in their argumentation (emerging e.g., from behavioral genetics, drug abuse research, and cancer research) demonstrate that the term "social" includes also nonhuman social species and that the understanding of these phenomena indeed requires a "multilevel integrative analysis," i.e., the integration of knowledge and theories gained both about the elements on each structural level (by its associated discipline) and on the relational features of these elements *across* the levels. This multilevel analysis should follow the principles of multiple determinism (one event may have multiple causes on different levels), nonadditive determinism (the whole may be different from the sum of its parts), and reciprocal determinism (mutual influences between factors on different levels) to take into account the complexities of the phenomena studied. Both neuroscience and social psychology should benefit from cooperation in developing a more general psychological theory (pp. 1026–7). Thus, the project of social neuroscience is described as a cooperative project between researchers emerging from two different scientific disciplines (social psychology and neuroscience) in order to avoid the pitfalls of reductionism—an aspect, that is again emphasized in their 2005 textbook ("the broader the collaboration between different disciplines, the better the understanding of mind and behavior," p. xiii).

Coming from a different research tradition and almost a decade later, Kevin Ochsner and Matthew Lieberman (2001) use the term "social cognitive neuroscience" for describing an interdisciplinary approach integrating data from three levels of analysis: the *social level*, characterized by the experience and behavior of motivated people in personally relevant contexts; the *cognitive level*, characterized by information processing mechanisms underlying phenomena on the social level; and the *neural level*, on which those brain systems are analyzed, that instantiate the processes on the cognitive level. However, their emphasis is on the *cognitive* level, since social psychology and cognitive neuroscience both are concerned with describing psychological processes in terms of information processing, and the emphasis regarding the biological basis is on the *neural* level. In this way, compared to the former proposal of Cacioppo and Bernston, they have a narrower view of the field, also by setting their focus on *human* social behavior—a specification that is reflected by their term *social cognitive neuroscience*, which would only be a branch of social neuroscience defined according to Cacioppo and Bernston. In his historical overview of social cognitive neuroscience, Ochsner (2007) himself argues that this research field is distinct from social neuroscience, focusing on human social cognition, while social neuroscience integrated approaches linking social variables to psychophysiological, endocrine, and immunological parameters both in humans and in animals.

We add two additional short proposals made in the last few years for defining social neuroscience: In the editorial of the launching issue of *Social Neuroscience*—one of the two journals of the field—it is stated,

> "social neuroscience may be broadly defined as the exploration of the neurological underpinnings of the

processes traditionally examined by, but not limited to, social psychology" (Decety & Keenan, 2006, p. 1).

Thus, they clarify their disciplinary counterpart although indicating an openness concerning the research traditions that deal with "the social." Eddy Harmon-Jones and Piotr Winkielman (2007) define social neuroscience as

> "an integrative field that examines how nervous (. . .), endocrine and immune systems are involved in socio-cultural processes. Social neuroscience is nondualist in its view of humans, yet it is also nonreductionistic and emphasizes the importance of understanding how the brain and body influence social processes as well as how social processes influence the brain and body. In other words, social neuroscience is a comprehensive attempt to understand mechanisms that underlie social behavior by combining biological and social approaches" (p. 4).

In 2005, a workshop supported by National Institute of Mental Health brought together a group of researchers in order to discuss the scope and the future of social neuroscience (Cacioppo et al., 2007). The workshop outlined the "epistemic frame" in which social neuroscience should operate: "constitutive reductionism, a systematic approach to investigating the parts to better understand the whole" (p. 101). Thus, social neuroscience should also aim to find the "bridging principles" (following the terminology of Nagel, 1961) between the organizational levels used to describe and explain social behavior. In the workshop, the following topics were identified as "most active areas of research" within social neuroscience: brain-imaging studies in normal children and adults; animal models of social behavior; studies of stroke patients; imaging studies of psychiatric patients; and research on social determinants of peripheral neural, neuroendocrine, and immunological processes. Studies in these fields should give insight, e.g., into developmental processes, psychopathologies, the role of hormones, and of social contexts on social behavior, group processes, and the evolution of the social brain.

This short overview demonstrates that social neuroscience has the potential to include a large number of research topics, which can be classified along three classes of levels of analysis: the social, the cognitive, and the biological. In each class, many levels of organization can be distinguished, yet the questions about which levels are present, which are relevant, and what are the bridging principles between those, constitute one major scientific challenge for social neuroscience. In the following, we present only a selection of research topics proposed in the literature.

First, on the social level, Todorov, Harris, and Fiske (2006) claim the existence of a "core social motive" that belongs to a social group. From this motive, the cognitive motives "understanding" and "controlling" as well as the affective motives "self-enhancing" and "trusting" would emerge (p. 78). Another important research topic is the individual or a group of individuals being in a social world (Lieberman, 2007). It is claimed that individuals aim to create a "coherent" social world, requiring the coordination of activities with those around us, the use of feedback from others to understand ourselves, and the development of self-theories and attitudes towards social groups (p. 270–1). Thus, several research topics are identified in order to understand interpersonal relationships—one of the main concerns of social neuroscience.

Second, on the cognitive level, social neuroscience is concerned with social perception and cognition; the latter requiring the ability to "understand others" and to "understand oneself." The research frame of understanding others includes theory of mind, empathy, cheating and bargaining, fairness, and justice. The research frame of understanding oneself includes recognizing oneself (through the lens of others), reflecting on oneself, self-knowledge, and self-concept. Other research topics on the cognitive level are self-regulation (intentional and unintentional, emotion processing, motivation, attitudes, stereotypes, and prejudices) (for overviews see e.g., Liebermann, 2007; Todorov et al., 2006; Blakemore, Winston, & Frith, 2004).

Third, research on the biological level includes a variety of different topics. On the neural level, it tackles the identification of core processing (automatic vs. controlled; internally-focused vs. externally focused; Lieberman 2007, p. 261), the relations and interactions of different brain regions (e.g. prefrontal cortex and amygdala), the structure of brain regions, the localization of brain activities related to social behavior, or the impact of mirror neurons. Research on the genetic level may be particularly helpful for understanding psychiatric disorders. On the neuroendocrinological level the influence of hormones on social behavior, but also the influence of social context on hormone production, is investigated (Cacioppo et al., 2007, pp. 104–106).

The separation in levels is helpful to distinguish where the various research interests of social neuroscience come from and it may also be helpful to start

an investigation at the level from which the question originates. The aim of social neuroscience, however, is to integrate all levels and thus to get a deeper and broader understanding of social behavior. To give two examples of cross-level research: In 1999, Michael Meaney and colleagues investigated the influence of maternal care and deprivation on stress in offspring and the nongenetic transmission of certain modes of behavior from one generation to another in rats (Francis et al., 1999). And four years later, Caspi et al. (2003) presented a long-term study investigating the gene-environment interaction in depression. As Blakemore et al. observed, social neuroscience does not avoid the classic nature-nurture debate (Blakemore et al., 2006, pp. 219–20). With its methods and concepts this field may overcome the assumed bias between these two poles of Western thought.

After reviewing these programmatic papers, it remains still open whether social neuroscience will indeed reciprocally investigate behavior, interactions, and structures on the one hand and biological structures and functions on the other hand or whether it will set its priorities on the "biological" side and take neural, hormonal, and genetic aspects as pivot points for its investigations. There are indeed very different questions that can be asked within social neuroscience. Furthermore, different opinions on the relevance of nonhuman research in social neuroscience can be observed—an aspect that also depends on the understanding of the term "social" and the willingness to integrate an evolutionary perspective when understanding social behavior, that goes along with enlarging the focus on other social species—in particular other primates.

Critical Appraisal

We focus our critical appraisal of these self-definitions of social neuroscience on two noticeable aspects. First, the exponents of the field stress the importance of the fact that the interactions of social beings create "emergent" structures and processes, whose understanding requires the cooperation of different disciplines, whereas an "individualistic" approach focusing on the single organism (or brain) is not sufficient. This "integrative view"—a central point in the definition of social neuroscience along Cacioppo and Berntson—of social neuroscience is typical for a specific understanding of science that recently gained importance in several scientific fields, e.g., in the emergence of complexity theory in the late 1980s (Cowan, Pines, & Meltzer, 1994). It is based on a *topos* of modern science that understands nature (and society) as a hierarchy of structures, whereas this hierarchical order results from the evolutionary dynamics that explain the natural history of the world (Bonner, 1988). Within this framework, the term "emergence" is prevalent, but often obscure in its function. Originally introduced by John Stuart Mill ("emergent properties" as an antonym of "resultant properties"), it gained popularity in evolutionary theories of the 1920s by offering an alternative in the dispute between mechanists and vitalists; but the concept was demystified by the critique of Ernest Nagel in the 1960s, turning it to a rather weak concept within the reductionism debate (Nagel, 1961). The concept of emergence regained interest first in the context of the mind-body problem in the 1970s and later in complexity theory in the 1980s. This rebound, however, does not mean that the difficult conceptual issues that go along with "emergent organizations" and the like have been solved (Bunge, 2003). From a theoretical point of view, the issues of epistemic, ontological, and methodological reductionism associated with (social) neuroscience are complex (for a detailed discussion see Bennett & Hacker, 2003).

In neuroscience, it is quite common to establish a new discipline as resulting from the equitable cooperation of existing ones (see the example of the Neuroscience Research Program, Swazey, 1992). However, whether this equality in terms of methodology and epistemic standards is theoretically sound and reflects the reality of scientific practice may be questionable. Phrases in titles of social neuroscience papers like "the neural basis of . . ." or "neural foundations of . . ." could imply that the epistemic order is not as equally as pictured in the above definitions and motivate the suspicion that the non-reductionist wording may be more declarative than descriptive. At least, the issues of the methodological and epistemic equality of the disciplines involved in the formation of social neuroscience and the various problems of reductionism that emerge with the "neurological underpinning" of social and cognitive entities require a detailed analysis.

Second, the epistemological question what "social" means in social neurosciences remains open. Currently, in neuroscience, the concept of "social" is a relatively static factor in experimentation (Cromby, 2007, p. 163), whereas in social sciences it is a highly contested term. Depending on what theory is referred to it can be anything from the sum of individual actions to power relations—factors that form a society. There is indeed a danger that the concept of a "society"—with its structures, constraints,

inequalities, and possibilities—disappears, if interactions, emotions, actions, and behaviors are all located within neural structures of individuals or the evolutionary make-up of "social species." The methodological framework of social neuroscience is considerably (with the exception of genetic and hormonal studies, that can include larger populations) limited to inter-individual interactions in small groups—although an enlarged scope of interest including cultural phenomena can be observed recently (Chiao, 2009). Currently, most of the entities on the social level relevant for social neuroscience (e.g., "core social motives," "trust between individuals," "attitudes towards social groups") represent only a minor fraction of possible entities on this level. Surely, methodological constraints explain the selection to some degree. But maybe it is not a coincidence that the investigation of social interactions via social structures or collective processes is replaced by the investigation of processes that take place within individuals at the same time when, in a broader societal setting, collectivist solutions have been replaced by more individual solutions (e.g., in welfare). Paul Rabinow (1999) described this development as the transformation towards a "biosociality"—social structures become less important while identities are more and more based on individual (i.e., genetic) attributes than on social or group attributes. The approach towards studying the social via communal genetic make-up or individuals' brains is rather different from studying the external conditions for a social structure. In this approach, sociality becomes something innate and thus every normal individual is capable of behaving sociably. (Consequently, deviant behavior is defined by the lack sociality in individuals, e.g., in autism or psychopathy).

The Roots of Modern Social Neuroscience in the 1990s

The period of the emergence of social neuroscience was not the first time that human social behavior became a relevant issue in brain research (see above). However, if the growth of the annual fraction of neuroscientific publications using a social terminology relative to the whole body of neuroscientific publication is taken as a first proxy for the scientific dynamic of the field, a steady and remarkable increase can be detected beginning in the early 1990s (Figure 2.1, for methodological issues see the appendix). This indicates a growing interest in the social brain in contemporary neuroscience and we take this observation (together with the qualitative analysis of social neuroscience publications) as evidence for our hypothesis, that social neuroscience as an academic discipline emerged in the 1990s and stabilized in this decade. In this section, we first sketch changes in the "thought style" (Ludwik Fleck, 1979) during the last few decades within life sciences generally and neuroscience specifically that helped to prepare the ground for social neuroscience. Second, we identify main methodological and conceptual innovations that characterize the emerging social neuroscience. Third, we use a quantitative approach to identify high-impact papers of emerging social neuroscience published between 1990 and 1999 and discuss their disciplinary roots and cross-disciplinary impact.

Changing Thought Styles

The bacteriologist and sociologist of science Ludwik Fleck introduces the term "thought style" to define the sum of factors that shape the way of thinking in a certain (scientific) community at a certain time (Fleck, 1979). Accordingly, Fleck defines a scientific fact

> "as a thought stylized conceptual relation which can be investigated from the point of view of history and from that of psychology, both individual and collective, but which cannot be substantively reconstructed in toto simply from these points of view" (p. 83).

Seen in this way, a scientific fact is what a given group perceives as true on the basis of scientific cognition at a given time. But it cannot be explained only by looking at this group. Other factors like social, economic, or political circumstances have to be taken into consideration, because they are interdependent with the scientific knowledge. A fact is built upon a common basis of preconditions and notions, which change over time. This is the precondition for development in scientific and other kinds of thinking.

To give an example: The nature-nurture debate can be seen as a debate oscillating between two thought styles regarding the causal role of biological respectively social entities for human behavior. This debate, which can be traced far back in Western intellectual history, became most prevalent with the rise of genetics in the second half of the 20th century and was severely fought over in psychology (Lewontin et al., 1984; Lewontin, 2000). Novel attempts regarding this discussion usually claim to "bridge the gap" but whether these are indeed a synthesis that can abstract from the subtle influences of

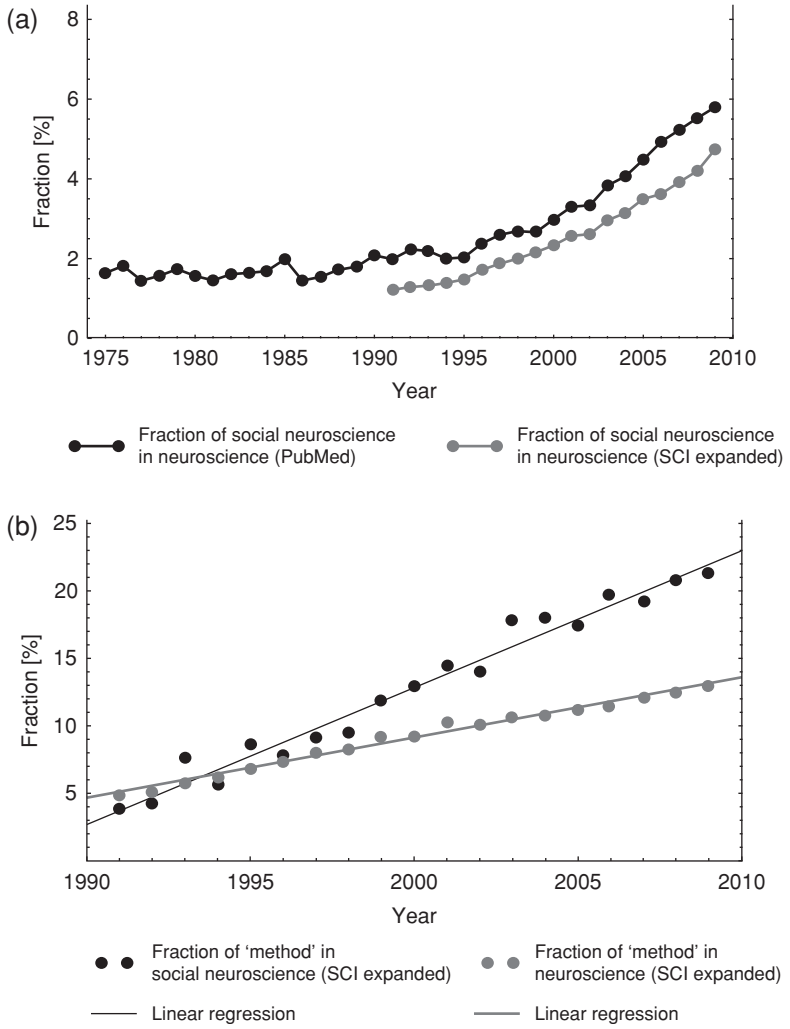

Fig. 2.1 Publication Dynamics of Social Neuroscience: a) Growth of social neuroscience papers relative to neuroscience papers measured in two different publication databases: A steady increase is identifiable beginning in the mid-1990s. b) Growth of "methodology papers" within social neuroscience compared to neuroscience in general (only measured based on SCI expanded). The slope of the linear approximation in former is 2.27 times larger than in latter, indicating an increased importance of non-invasive imaging methodologies for social neuroscience compared to neuroscience in general.

an intellectual climate remains open. Sociobiology and its follower, evolutionary psychology, attempted this synthesis (e.g., Barkow, Cosmides, & Tooby, 1992)—but at the same time discredited social science approaches towards human behavior (Rose & Rose, 2000). Thus, although the polarity of the nature-nurture debate probably has been outdated on the level of scientific explanations of some phenomena (e.g., in genetics the gene-environment interaction, see Fox Keller, 2008), it still may correctly describe thought styles that promote specific approaches towards the project of explaining human behavior and constrain others. The last few decades have seen an increased interest in enterprises that were looking for biological underpinnings of social behavior and for including a notion of sociality (or at least environment) in investigations of human nature (e.g., epigenetics or plasticity of the brain)—indicating an assemblage of intra- and extra-scientific factors that was friendly to emerging social neuroscience. Within the broad scope of social neuroscience, some approaches attempt to overcome the bias between nature and nurture by focusing on epigenetics and gene-environment interaction (see above).

Yet, a change in thought styles could not only be observed in this broader cultural and scientific context. Also within brain research a series of conceptual shifts took place. In the mid-20th century, the information perspective (Aspray, 1985) became

dominant in neuroscience: Processes in molecular biology, developmental biology, and neuroscience have been considered increasingly as processes in which information is "read," "transformed," "computed," or "stored" (Kay, 2000). This information perspective on biological processes was part of the cognitive turn within neuroscience and psychology (Gardner, 1985). The cognitive turn reflects a challenge to the prevailing behavioral model of human functioning, which had dismissed the need to examine interior mental processes and looked for lawful relationships in learning experiments. This new dominating thought style of cognition marginalized specific questions within neuroscience, in particular the role of emotions (LeDoux, 2000). This changed again during the 1980s, as (among other developments) the neuroanatomy of fear conditioning had been analyzed in animal models. In the 1990s, interests in neuroscience (and various other fields) were increasingly directed towards emotions, indicating the emergence of a new thought style that paved the ground for social neuroscience.

Innovations

A friendly intellectual climate both in neuroscience as well as in the broader context alone is not sufficient for a new discipline to emerge. Innovations both on the conceptual and the methodological and technological level (see e.g., Cambrosio, 2009; Rheinberger, 2007) are required to enable a sufficient number of scientists to start working on similar questions. For social neuroscience, at least three such innovations can be identified: the study of higher cognitive functions with imaging technologies; the combination of tools of cognitive neuroscience and neuroendocrinology with methods of behavioral research in animals, social psychology, and behavioral economics (e.g., games); and the discovery of mirror neurons in macaque monkeys.

We have to remember that other methodologies—in particular lesion research in animals and humans and studies about the biological underpinning of animal (social) behavior like affiliation and pair bonding—also play an important role in the course of the development of social neuroscience. As these methodologies and their associated research fields have historical origins that are (partly) many decades old (e.g., the fact that the use of full metal jacket bullets in the First World War made head-shot soldiers survive their injuries and allowed significant progress in lesion research in humans), it is difficult to assess, since when these research fields should be associated with the endeavor of social neuroscience. These methodologies have existed for several decades without leading to the emergence of social neuroscience as a distinct disciplinary field. Hence, in the following, we will focus on the three mentioned innovations that are strongly connected with conceptualizing research in the framework of social neuroscience.

The importance of (functional) imaging technologies must be emphasized here. Imaging technologies (in particular fMRI and PET, but also EEG-based methods like event-related potentials) are a crucial tool in social neuroscience research—a point that is also confirmed by our bibliometric analysis: Although the fraction of papers with a vocabulary reflecting imaging methodologies generally increase within the neuroscience publication body, the annual increase of such publications within the social neuroscience publication body is considerably larger (Figure 2.2.). Furthermore, this technology has been used in 62% of all non-review papers (95 out of 153) of the most often cited papers analyzed by us (see next section). Imaging technologies provide both the means for testing hypotheses and a catalyst for the emergence of new theories, although there are important constraints when using such technologies (Cacioppo et al., 2003; Logothetis, 2008). This enables social neurosciences to take the powerful position in contemporary public discourse they have (Hagner, 1996; Beaulieu, 2001, 2002), although it only is one of several methods used. Without doubt, using imaging technologies is demanding and requires diligence for each of the four stages of the process (experimental design, measurement, data analysis, data presentation; see Dumit, 2004). The recent debate on dealing with the selection bias may serve as an example for the methodological challenges associated with imaging (Miller, 2008; Abbott, 2009).

A second methodological innovation is the combination of methods emerging from genetics, neuroendocrinology, and neuroimaging with experimental paradigms drawn from social psychology and behavioral economics (e.g., experimental games). These studies are not limited to humans and demonstrate the extension of concepts like "fairness" usually restricted to human beings, to other social species (e.g., in Brosnan & De Waal, 2003; Tomasello & Warneken, 2006).

The discovery of mirror neurons in the frontal area F5 macaque monkeys (di Pellegrino et al., 1992; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) was a third important step towards conceptualizing and, in particular, popularizing the social brain and

its capacities like theory of mind or empathy—two prominent topics in social neuroscience (for review see Jackson & Decety, 2004; Gallese, Keysers, & Rizzolatti, 2004; Iacoboni, 2009). In popular scientific publications, mirror neurons have become a prominent theme in explaining various aspects of human social behavior. In the scientific literature, however, mirror neurons are less predominant and recently, both the existence of mirror neurons in humans (Lingnau, Gesierich, & Caramazza, 2009) as well as their explanatory power for understanding social capacities has been more and more criticized (e.g. Hickock, 2008; Jacob, 2008).

Pioneers

For a more detailed view on the developments in the 1990s, we performed a bibliometric analysis to identify the top 100 papers published between 1990 and 1999 that contained those terms of our social neuroscience vocabulary, for which the number of the associated papers showed the most significant increase during that period (see appendix for further explanations). In this way, the 100 most highly cited papers that reflect the scientific production within the emerging social neurosciences have been identified. The majority of these papers were published in the late 1990s and originated from North America (mostly the U.S.) and the United Kingdom (Figure 2.2). Based on these quantitative results, social neuroscience can be identified as a scientific discipline emerging in the Anglo-Saxon academic culture that gets appreciation in the second half of the 1990s.

By performing an impact analysis, we identified the disciplinary origins and disciplinary appreciations of these papers within eight disciplinary clusters (Figure 2.3). The analysis reveals two aspects. First, regarding their origins, not only "neuroscience," but also "psychology" and "psychiatry" are important disciplinary origins (these three clusters include 73% of all entries). Compared to the decade 2000–2009, a much smaller fraction has been published in journals classified as "multidisciplinary sciences"

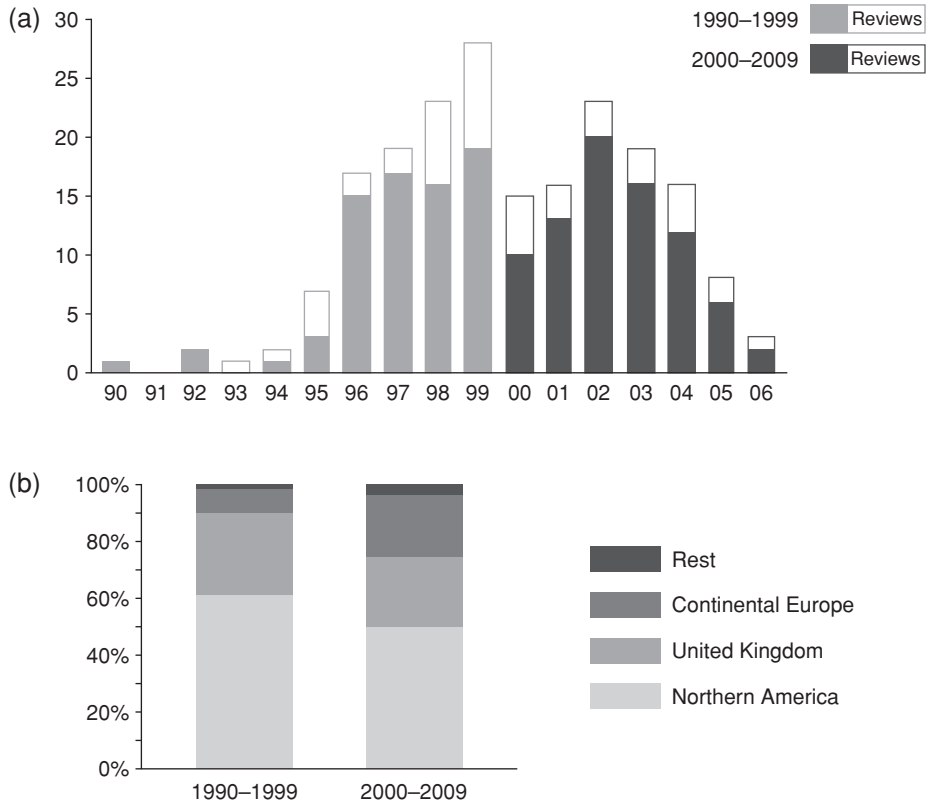

Fig. 2.2 Top 100 Papers in Terms of Citation of the Decades 1990–1999 and 2000–2009: a) The distribution of the total 200 most-cited papers in social neuroscience of the decades 1990–1999 and 2000–2009 clusters around 1996–2004: 87.5% of all papers were published in these years. 23 (first decade) resp. 29 (second decade) publications are classified as "review papers." b) The geographic origin of the top 100 papers of the first decade is more centered in the Anglo-Saxon academic culture (89.7%) compared to the second decade (74.3%).

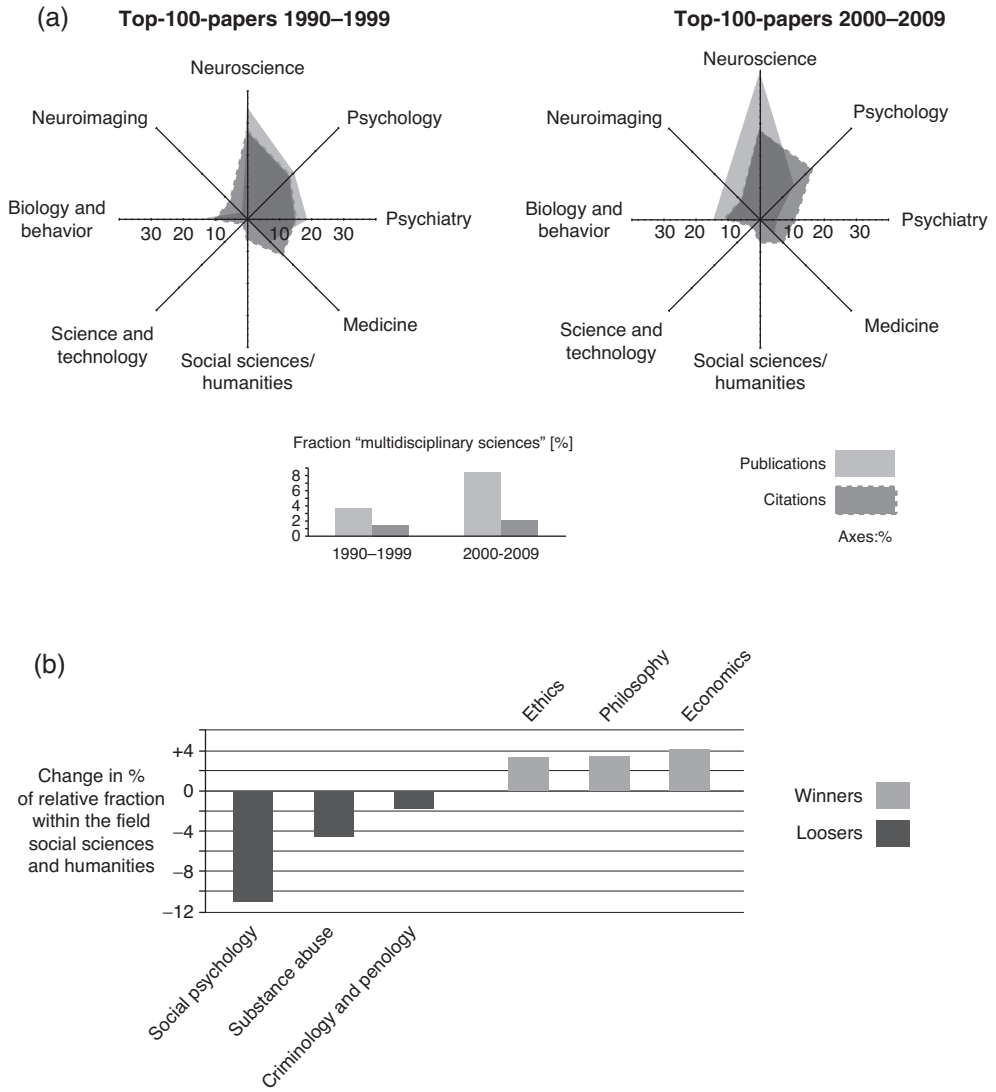

Fig. 2.3 Impact Analysis for Top 100 Papers of the Decades 1990–1999 and 2000–2009: a) The top 100 papers in social neuroscience of the second decade have a different impact profile than those of the first decade and show a larger net-transfer to other disciplinary clusters: 27.9% compared to 17.6%. This is partly explained by the larger fraction of papers from the second decade published in interdisciplinary journals. b) Top 3 winning and losing subject areas forming the cluster "social sciences and humanities" when comparing the appreciation of social neuroscience papers of the 1990s and the 2000s. The papers gained interest in core fields of social science and humanities, namely economics, philosophy, and ethics.

(in particular journals like *Science*, *Nature,* and *PNAS*). When looking at the distribution of the papers between the dominant journals (Figure 2.4; for the concept of "dominant journal" see appendix), the relevance of psychiatry as a field for publishing and thus promoting the emergence of the field is striking. Just as remarkable is the fact that none of these journals (*Biological Psychiatry, American Journal of Psychiatry, Neuropsychologia, Psychiatry Research—Neuroimaging*) is classified as dominant in the decade 2000 to 2009.

Second, regarding their impact, the analysis reveals a comparably low transfer to other clusters. The overlap of the distributions "publications" and "citations" along the eight axes for the papers emerging from the first decade is considerably larger compared to 2000–2009. This also results from the fact that the "disciplinary basis" (measured in terms of items originating from different disciplinary clusters) was larger in that time. Some impact of these papers on the cluster "social sciences and humanities" can be detected, although it is rather low and does not

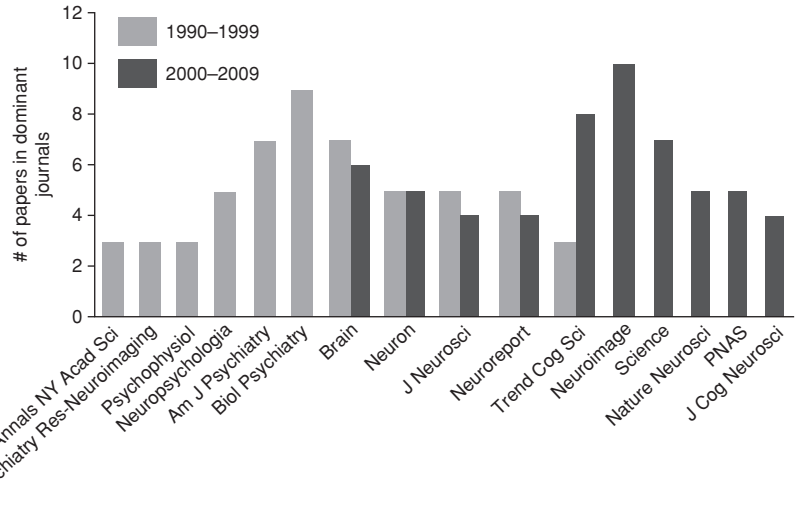

Fig. 2.4 Dominant Journals for Top 100 Papers of the Decades 1990–1999 and 2000–2009: Top 100 papers of the second decade are to a large degree published in other journals than those of the first decade. 55 (first decade) resp. 58 papers appeared in these dominant journals. The chart only includes those papers that define the category "dominant journal," that is, one cannot conclude that, for example, no top 100 paper of the first decade was published in *Science*.

increase much in the decade 2000–2009. However, within this cluster, some changes are remarkable. Regarding impact, the subject categories "social psychology" (the justification for attributing the subject category "social psychology" to the disciplinary cluster "social sciences and humanities" is given in the appendix) and (to a lesser degree) "substance abuse" and "criminology and penology" are considerably more important in the 1990s than later. This again reveals that questions related to psychiatric issues were more important in the 1990s than later. Interesting is that publications are surprisingly often cited in papers in the cluster "neuroimaging," indicating that the early papers may also may have had some effect on developing this methodology.

The Establishment of Social Neuroscience as an Academic Discipline

In the years 2000 to 2009, social neuroscience obtained various attributes of a discipline: People started to use the term to describe their own work, departments created positions for social neuroscience and after a while, journals (*Social Neuroscience*, first issue: March 2006; and *Social Cognitive and Affective Neuroscience*, first issue: June 2006) and conferences using this label were formed. Researchers that worked in the 1990s rather independently on issues like stereotyping, empathy, emotion processing, mentalizing, and the like met first coincidentally, then in a more organized way in workshops and pre-conferences of meetings of both the Society for Personality and Social Psychology and the Cognitive Neuroscience Society. For example, in 2001, a first conference using the term "social cognitive neuroscience" took place in Los Angeles. In 2004, the conference "Social Neuroscience: People Thinking About People" accompanied the establishment of the University of Chicago Center for Cognitive and Social Neuroscience. Since 2007, the Social Affective Neuroscience Conference takes place annually. A dinner to discuss the challenges and opportunities in the interdisciplinary field of social neuroscience at the Society for Neuroscience meeting (Chicago, November 2009) resulted to meetings led by John Cacioppo and Jean Decety with social neuroscientists, psychologists, neuroscientists, and neurologists in Argentina, Chile, The Netherlands, Japan, China, Hong Kong, Singapore, South Korea, Australia, and New Zealand. It was noted that, as a social species, humans create emergent organizations beyond the individual—structures that range from dyads, families, and groups to cities, civilizations, and international alliances. These emergent structures evolved hand in hand with neural, hormonal, cellular, and genetic mechanisms to support them because the consequent social behaviors helped humans survive, reproduce, and care for offspring sufficiently long that they too survived to reproduce, thereby ensuring their genetic legacy. Social neuroscience was defined broadly as the interdisciplinary study of the neural, hormonal, cellular, and genetic mechanisms underlying the emergent

structures that define social species. Thus, among the participants in these meetings were scientists who used a wide variety of methods in studies of animals as well as humans and patients as well as normal participants. The consensus also emerged that a Society for Social Neuroscience should be established to give scientists from diverse disciplines and perspectives the opportunity to meet, communicate with, and benefit from the work of each other. The international, interdisciplinary Society for Social Neuroscience (http://S4SN.org) was launched at the conclusion of these consultations in Auckland, New Zealand on January 20, 2010, and the inaugural meeting for the Society was specified as the day prior to the 2010 Society for Neuroscience meeting (San Diego, CA). In this section, we first characterize the field and its impact by qualitative and quantitative methods and discuss whether specific topics gain more cross-disciplinary attention than others. Second, we speculate about the effect of thematic differentiations within social neuroscience and their effect on the stability of this research field.

Topics and Impact

The large variety of topics addressed in this handbook itself is a portrait of social neuroscience demonstrating a broad spectrum of research topics. Using our approach for identifying the top 100 papers published 2000 and 2009, we see indeed changes regarding the origin and appreciation of these papers. Not surprisingly, most papers have been published in the early years of this decade. In respect of their geographical origin, the concentration in North America and the United Kingdom is less pronounced, although still clearly present (Figure 2.2). The transfer between the disciplinary clusters, however, is clearly stronger than in the 1990s (Figure 2.3): Almost two-thirds of the papers fall into the clusters "neuroscience" or "neuroimaging," whereas they show increased appreciation by psychology, psychiatry, medicine and, to a lesser degree, in social sciences and humanities. The number of papers that appeared in journals like *Science* and *Nature* (classified as "multidisciplinary sciences") doubled, which partly explains the increased cross-disciplinary transfer. Finally, the characteristics of the dominating journals also changed: Psychiatric journals are no longer represented, whereas the importance of imaging methodologies is emphasized by the fact that 10 of the top 100 papers appeared in *NeuroImage*.

The three winners in terms of citations within the disciplinary cluster "social sciences and humanities" are the subject categories "economics," "philosophy," and "ethics." Thus, although the general impact within this cluster did not increase much compared to the 1990s (from 6.0% to 7.3%), social neuroscience obtained more appreciation in disciplines that are closer to the core of social sciences and humanities compared to the 1990s. In that sense it is justified to claim that social neuroscience gained attention within the fields whose knowledge and research traditions they want to use and influence. However, one has to take into account that this quantitative analysis cannot reveal whether this appreciation is positive or critical.

Finally, we broadened our impact analysis to four subjects (taking all 200 papers into account) that fall into the thematic range of social neuroscience and that received a comparable number of citations (Figure 2.5): papers on moral issues (moral decision making, moral emotions etc.), papers on psychopathy and sociopathy, papers on empathy and papers on trust, cooperation and punishment (i.e., attributes of social interactions). Their impact was calculated separately and compared to the mean impact of all 200 papers along the eight axes (black line). Regarding the first two issues, papers on psychopathy and sociopathy had the largest impact within psychiatry, whereas moral issues had most impact in social sciences and humanities—actually, these issues had the strongest impact within this cluster of all issues we analyzed. Regarding the second two issues, papers on empathy were by the majority cited within psychology, whereas papers of the group trust-cooperation-punishment had a highest appreciation within social sciences and humanities.

In summary, the quantitative impact analysis of the most highly cited papers that characterize the formation (1990s) and establishing (2000s) phases of social neuroscience reveals the following:

- The disciplinary basis of social neuroscience narrowed over time: being comparably strongly founded in neuroscience, psychology, and psychiatry (73% of all entries) in the 1990s, neuroscience (and neuroimaging) became dominant clusters (~60%) for publications in the 2000s.
- The interest in "anormal" social being (e.g., psychopaths) shifted to an interest in issues of "normal" social behavior.
- Although the impact in the disciplinary cluster "social sciences and humanities" is not that large, social neuroscience results gained more attention in core disciplines of this cluster.

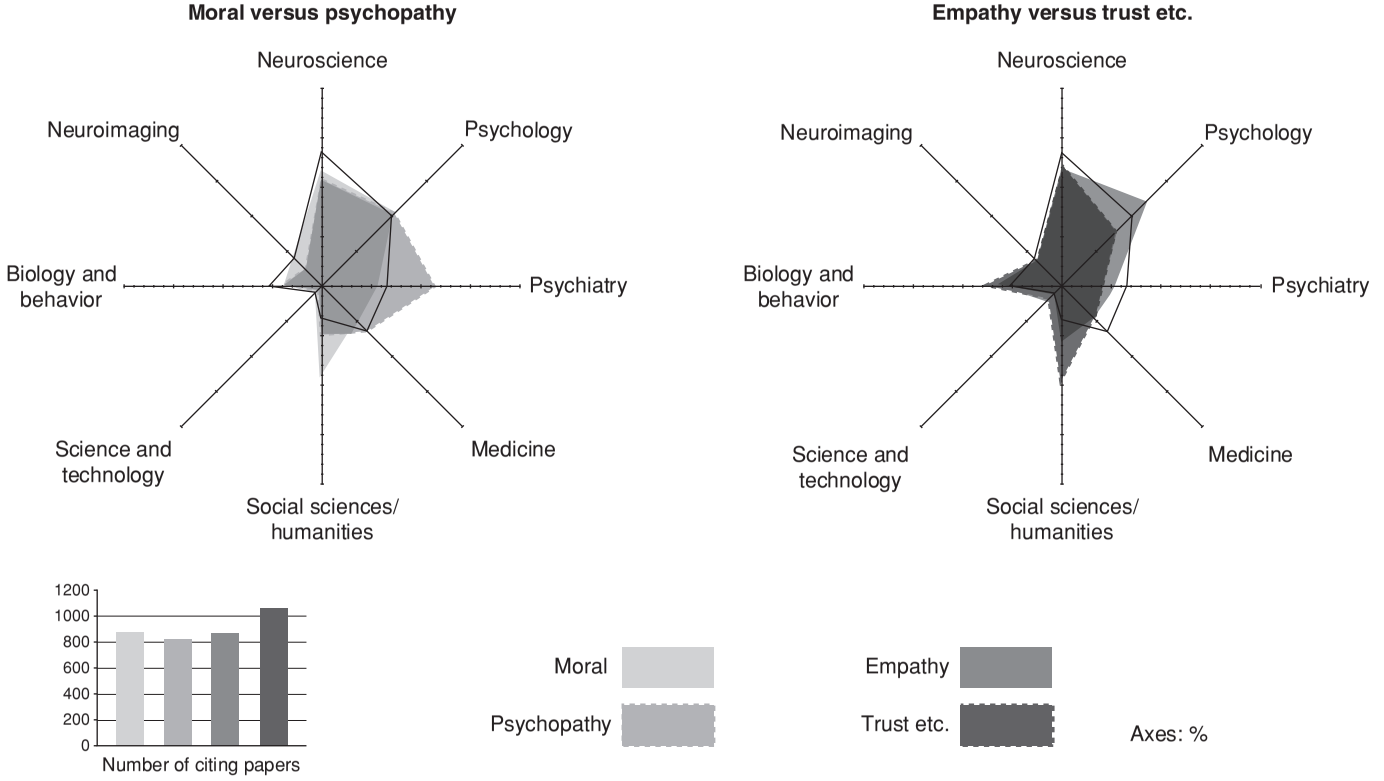

Fig. 2.5 Impact Analysis for Selected Topics of Social Neuroscience: Impact analysis for four selected topics "moral," "psychopathy/sociopathy," "empathy," and "trust, cooperation, punishment" that gained a similar total number of cited papers. The black line in the graph indicates the total number of citations of all 200 papers along the eight disciplinary clusters.

We have to remind the limits of such quantitative approaches. First, we clarify that the search for the top 100 papers has been limited to the Science Citation Index (SCI) expanded database. Due to this constraint, the focus is on contributions with a (neuro-)scientific origin as defined by the Institute for Scientific Information (ISI), neglecting papers from journals classified as emerging from social sciences and humanities. This choice was made intentionally in order to assess the impact of social neuroscience papers with a "scientific" publication origin. We are aware that this does not generate a complete picture of a disciplinary field that intends to merge different disciplinary traditions. Second, although the ISI database is rather large, a well-known selection bias for English journals and conference proceedings distorts in particular the appreciation of social neuroscience papers in humanities, where language diversity is higher. Furthermore, citations in monographs—an important publication category in humanities—are not captured. The method thus probably underestimates the impact of social neuroscience papers in social science and humanities. Additionally, one may also include the impact of social neuroscience in grey literature and media reports, which was beyond the scope of this contribution. Third, an additional limitation is that the methodology does not assess the type of appreciation—i.e., whether the social neuroscience papers are cited with affirmative or critical intention. This aspect requires a qualitative approach.

Is Social Neuroscience a Stable Discipline?

We close this chapter by some considerations regarding the stability of social neuroscience as a discipline (or disciplinary field). This question emerges, as the domain of the "social" offers potentially enormous opportunities for research from a neuroscientific point of view—but also for the establishment of new and fruitful research questions that emerge in the boundary zones of classical disciplines. This huge reservoir for potential research questions results from both the vagueness and the restrictedness concerning the domain of social entities that are considered valuable research objects in social neuroscience. This may lead to a differentiation within social neuroscience that can already be observed: Neuroeconomics, neuromarketing, neurofinance, neuropedagogy, moral neuroscience and many more subfields have emerged in the last few years—a process of disciplinary differentiation that is not undisputed both in social neuroscience and in neuroscience in general.

This process raises two questions: First, one has to ask what effect such a "neuralization" of social research topics may have on the existing disciplines within social sciences: Will it influence these fields regarding methodology and epistemic standards? Will it require new curriculae—taking into account the fact that most students in social sciences are not trained to become social scientists but to become professionals in companies, governmental institutions, etc.? Today, the position of these established disciplines within social science towards social neuroscience often lies between ignoring and hostility—a third one is slowly emerging that is asking how traditional disciplines in the social sciences can benefit from neuroscientific knowledge.

Secondly, and this is important for social neuroscience itself: Is there a danger for fragmentation—given its general goal to understand mechanisms that underlie social behavior—by combining biological and social approaches? May this new attempt to understand social phenomena from a generalized perspective end up in a plethora of neuro-xxx-fields, each of which is struggling with its own problems regarding methodology? The alternative would be that social neuroscience helps to widen the perspectives of psychology, neuroscience, and other disciplines by integrating questions and methods from all of them. Given the historical experience, this process will probably go hand-in-hand with the emergence of new types of problems that are considered as relevant and it will require changes both regarding the training of new students and funding schemes that are more open for interdisciplinary research. In this way, the future development of social neuroscience is embedded in broader changes the university and research system currently undergoes.

We want to thank the editors for their critical remarks on preliminary versions and Michael Hagner for his helpful comments.

Appendix

Publication Quantification and Social Neuroscience Vocabulary Identification

The numbers of publications in neuroscience ("neuro"), in neuroscience methods ("method"), and in social neuroscience ("social") were estimated by identifying publications that include specific words or word stems in title or abstract within the databases SCI expanded (accessible via ISI Web of Knowledge) and PubMed. The Boolean search expression for the set "neuro" was: neuro* OR neural OR brain* OR amygdala OR cerebellum OR cortical OR cortex OR hippocampus (= NEURO). The "method" set included all noninvasive imaging technologies mentioned in Huesing, Jaencke, & Tag (2006), a reference study on impact assessment of neuroimaging (including TMS, although this method is used to stimulate neural tissue). The Boolean search

expression for the set "method" was: NEURO AND ("brain imaging" OR "computer tomography" OR "functional magnetic resonance imaging" OR "functional MRI" OR fMRI OR "magnetic resonance imaging" OR MRI OR "positron emission tomography" OR PET OR SPECT OR Electroencephalography OR EEG OR Magnetoencephalography OR MEG OR "diffusion tensor tomography" OR "diffusion tensor imaging" OR "voxel-based morphometry" OR "deformation-based morphometry" OR "tensor-based morphometry" OR "near infrared spectroscopy" OR "transcranial magnetic stimulation" OR TMS) (= METHOD). The Boolean search expression for the set "social" was: NEURO AND (social* OR socio* OR cultura* OR emotion* OR econom*) (= SOCIAL). "Methods" papers within the set "social" were identified by the Boolean search expression NEURO AND METHOD AND SOCIAL. In all cases, the number of publications published in the time span of one year (from 01.01.XXXX to 31.12.XXXX) was evaluated. In PubMed, the time span was 1975–2008, in SCI expanded, the time span was 1991–2008, as before 1991, the entries in SCI expanded did not include the abstracts. The analysis was performed on September 11th 2009.

The social neuroscience vocabulary was identified by following the intuition that the number of social neuroscience publications with those expressions shows a considerable increase in the last two decades—i.e., the expressions refer to topics that gain interest when time elapsed. The vocabulary was constructed as follows. In the first step, by analyzing 20 review papers, books, or known high impact papers of social neuroscience, 57 expressions or word stems that may be typical for social neuroscience publications were identified, i.e., expression referring to topics (aggression, disgust, etc.) or methodologies (ultimatum game, TMS, etc.). In the second step, the distribution of logarithmized mean relative frequencies of publications containing an expression X within the sets "neuro" and "social" were evaluated. By defining a cut-off criterion (excluding the left and right tail of the distribution), expressions that generally appear very often or very rare within the sets "neuro" and "social" were excluded (12 expressions). In the third step, for the remaining expressions, the annual frequency of publications within the set "social" normalized with the total number of publications within "social" of the same year was evaluated in the database SCI expanded and the time span 1991–2008. Furthermore, a more sophisticated analysis was performed by identifying the frequency of these expressions in the sets Neuro in general, evaluating the distribution of frequencies and defining a cut-off criterion based on these distributions in order to identify very frequent terms. An example of such a Boolean expression is "aggression AND SOCIAL AND NEURO." This led to a time series showing the frequency of publications containing an expression X relative to all social neuroscience publications. In this way, the remaining 45 expression have been classified into three groups: 1) expressions that show a steady or stepwise increase in the 1990s (21 expressions), 2) expressions that show this increase in this decade (14 expressions), and 3) expressions whose frequency did not increase considerably in the last two decades (10 expressions). The class 1 expressions are: amygdala, antisocial, autis*, disgust, embarrassment, emotion regulation, empathy, executive function, fMRI/functional MRI/functional magnetic resonance imaging, guilt, justice, orbitofrontal cortex, personality, prefrontal cortex, psychopath*, social cognition, social learning, sociopath*, theory of mind, utilities (= SET1). The class 2 expressions are: agency, aggression, altruism, cognitive control, cooperation, dilemma, face*, fairness, mirror neuro*, moral*, neuroeconom*, shame, TMS/transcranial magnetic stimulation, ultimatum game (=SET2). The analysis was performed on October 27th/28th 2008.

Identification of Top 100 Papers

The Top 100 Papers in terms of citation for the period 1990–1999 and 2000–2009 were identified as follows. Using the Boolean search expression NEURO AND SOCIAL AND SET1 resp. SET2 (the expressions in SET 1/SET2 were concatenated using OR), an ordered list of the 500 top cited papers of each group, was created. The analysis was performed on September 16th 2009. From these lists, three independent coders selected those papers classified as "social neuroscience papers"—in particular by excluding papers where not a single reference to neuroscience is made (in terms of methodology, topic, etc.), papers that exclusively refer to animal behavior (without any linkage to human social behavior), and papers whose main focus is in finding or understanding psychiatric diseases like depression, schizophrenia, etc. By this exclusion we set the focus on neuroscientific explanations of normal human social behavior. Papers on which the coders came to divergent conclusions were individually discussed and finally classified based on mutual agreement. The geographical origin of these papers was evaluated using the corresponding function of SCI expanded.

The dominant journals were evaluated as follows: For each group of papers, a list of journals sorted in descending order by the number of top 100 papers published in that journal was created. Those journals on the top of that list that contained more than 50% of all publications were classified as "dominant," whereas the cut-off was made after those journals that had the same number of publications. For example, for the papers of the time span 2000–2009, three journals had 5 resp. 4 papers each. Up to the group of 5-paper journals, the total numbers of papers was 46. By including the three 4-paper journals, the total sum reached 58 and was thus above 50%.

Impact Analysis

In the SCI database, each publication is related to one or several ISI subject categories based on the journal the publication has been published in. This allows a so-called impact analysis (Christen, 2008) which compares pooled subject categories of a set of publications and the set of publications that cite former. In order to evaluate the impact of social neuroscience publications in other disciplines, we created eight so-called disciplinary clusters that pool the SCI subject categories in a way suitable for our analysis. These subject categories are (in parentheses are listed those ISI subject categories that include >90% of all entries for the citation analysis. They are sorted according to their contribution of all entries of a single disciplinary cluster. For the first subject category, its fraction of all entries in each cluster both for the 1990–1999 and 2000–2009 data is specified as well):

- **Neuroscience** (neuroscience: 100%/100%)
- **Neuroimaging** (neuroimaging: 52%/52%; radiology, nuclear medicine & medical imaging)
- **Biology & Behavior** (behavioral sciences: 54%/54%; physiology; biochemistry & molecular biology; biology; zoology; genetics & heredity)
- **Psychology** (psychology, experimental: 47%/40%; psychology; psychology, multidisciplinary; psychology, developmental, psychology, biological)
- **Psychiatry** (psychiatry: 79%/78%; psychology, clinical)

- **Medicine** (clinical neurology: 47%/48%; pharmacology & pharmacy; endocrinology & metabolism; pediatrics; rehabilitation; medicine, general & internal; ophthalmology; anesthesiology; geriatrics & gerontology; medicine, research & experimental; surgery; public, environmental & occupational health; gerontology; gastroenterology & hepatology; obstetrics & gynecology)
- **Social Sciences & Humanities** (psychology, social: 31%/20%; substance abuse; linguistics; social science, interdisciplinary; philosophy; law; economics; social sciences, biomedical; ethics; history & philosophy of sciences; criminology & penology; business; education, special; management; social issues; anthropology; sociology; nutrition & diethetics; communication; sport sciences; political sciences; medical ethics; education & educational research)
- **Science & Technology** (computer science & artificial intelligence: 41%/41%; engineering, electrical & electronic; food sciences & technology; computer science, theory & methods; engineering, biomedical; computer science, interdisciplinary applications; computer science & cybernetics; robotics; biophysics; automation & control systems)

Both for the top 100 papers of 1990–1999 and for 2000–2000, all of their subject categories as well as the subject categories of all papers that cite these top 100 papers (excluding self-citation) were evaluated using the corresponding functionality of the SCI database. All entries of the subject category "multidisciplinary sciences" were excluded and were displayed separately, as those entries refer to journals like *Science*, *Nature,* and *PNAS* that cannot be attributed to the clusters defined above. In the spider diagram (Figure 2.5), the axes have been arranged in order to express disciplinary closeness as optimal as possible (the circular sequence is: neuroscience—psychology—psychiatry—medicine—social science & humanities—science & technology—biology & behavior—neuroimaging). For each axis, the fraction of the pooled subject categories of each disciplinary cluster compared to all entries is shown. The net transfer is the sum of all negative (or positive) differences of the percentages of publication vs. citation for all eight clusters.

The impact analysis for the four specified topics was made using all 200 top cited papers of the time span 1990–2009. Those papers were attributed by three independent coders to 17 topics. Papers in which the coders came to divergent conclusions were individually discussed and finally classified based on mutual agreement. Then, for each topic, the number of citations the papers of a single topic was evaluated. We chose four topics with comparable numbers of citations for the impact analysis: "moral behavior/moral decision making/moral emotions" (6 papers, 880 citations); "psychopathology/sociopathology" (7 papers, 1059 citations); "empathy" (6 papers, 825 citations) and "trust/cooperation/punishment" (5 papers, 867 citations). The citation analysis was then performed analogously as described above.

Data collection: Svenja Matusall, Ina Maria Kaufmann, Markus Christen; data analysis: Markus Christen; writing: Svenja Matusall, Markus Christen

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