The neuroscience of translation

Maria Tymoczko
University of Massachusetts

The neurological mechanisms involved in translating and interpreting are one of the chief known unknowns in translation studies. Translation studies has explored many facets of the processes and products of translation and interpreting, ranging from the linguistic aspects to the textual aspects, from the politics of translation to implications from cognitive science, but little is known about the production and reception of translation at the level of the individual brain and the level of molecular biology.[1] Much of this terra incognita will be explored and illuminated by neuroscience in the coming quarter century, and significant discoveries pertaining to language processing in translation will be made during the coming decade, linking observable behaviors at the macro level with knowledge of what happens in the production and reception of translation at the micro level of the neuron and the neuronal pathways of the brain.

In the past two decades powerful new techniques for observing brain function in healthy living individuals have been devised. To a large extent neuroscience has become a rapidly developing field because of new technologies that make it possible to monitor the brain as it actually works, to document neural pathways, and even to track the activity of specific neurons. This article focuses on discoveries in neuroscience pertaining to perception, memory, and brain plasticity that have already achieved consensus in the field and that have durable implications for the ways we will think about translation in the future.

Keywords: neuroscience, perception, memory, plasticity, brain, cultural shaping

1. Introduction

The neurological mechanisms involved in translating are obviously one of the chief known unknowns in translation studies. Translation studies has explored many facets of the processes and products of translation and interpreting from the perspective of linguistics, textual studies, cultural studies, and cognitive science (among others), but little is known about the production and reception of

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translation at the level of the individual brain and the level of molecular biology. This is a frontier of research on translation. Scholars have initiated research monitoring translation processes through think-aloud protocols (TAPs), eye tracking, keystroke tracking, and various forms of analysis of interpreting. Some neuroimaging of translators translating has even been undertaken. Nonetheless, to a large extent the individual translator is still conceived in translation studies as a "black box". Moreover, translation studies has hardly even begun to inquire about the reception of translations at the cognitive or neurological level of the individual receiver. Much of this *terra incognita* will be explored and illuminated by neuroscience in the coming quarter century, and significant discoveries pertaining to language processing in translation will be made during the coming decade, linking observable behaviors at the macro level with knowledge of what happens in the production and reception of translation at the micro level of the neuron.

In 2005, addressing the topic "Trajectories of Research in Translation Studies" at the fiftieth anniversary celebration of the founding of *Meta*, I suggested that one of the most important areas of future research in translation studies would involve neuroscience.

> Perhaps the most radically new and illuminating research in the coming decades will result from the investigation of translation by neurophysiologists. At present the activity of individual translators continues to be opaque to scholars. Some clues are garnered by tracking the working choices of translators with computers that remember and time all work; other research attempts to open up the process by looking at translators' journals or recording their think-aloud protocols. But all these methods are primitive at best in indicating what actually occurs in the brain as translators move between languages…
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> [The] immensely powerful, interesting, and important areas of research opening up in the near future will radically change the way translation is thought about and approached. They will also radically change the structure of research in translation studies. Biologists interested in language, language acquisition, and bilingualism will become central players in translation studies. The locus of research will move from individuals to groups, and research teams will evolve that bring together translation scholars, cognitive scientists, literacy and language experts, and neurophysiologists (Tymoczko 2005: 1092–93).

When I made these statements, I little expected that I would begin to investigate this subject myself.

My interest in the neuroscience of translation was piqued, however, in the course of writing *Enlarging Translation, Empowering Translators* (2007). Before beginning to write that book, I had become interested in how to theorize a cross-cultural field such as translation studies and how to think about and define a cross-cultural concept such as translation. These were subjects central to my interest in internationalizing translation studies, moving the field beyond the parochial presuppositions and interests of Eurocentric cultures. I had become dissatisfied with the treatment of the concept of translation in the discipline because I felt that most studies underestimated the problematic of defining and modeling translation itself, particularly in the face of radically different cultural and linguistic circumstances, including those in which translation is primarily an oral phenomenon governed by the patterns of oral cultures.

In writing *Enlarging Translation*, therefore, I undertook in-depth explorations of approaches in cognitive science to concepts and categories. The more research I did, the more it became apparent that translation studies needed to take a more sophisticated and nuanced approach to the concept of translation itself, not to mention cross-cultural manifestations of translation. This research is reflected in Chapters 2 and 3 of the book, and it underlies my approach to the translation of culture in Chapter 6 as well. Even as I wrote, however, I realized that issues of cognition led directly to the problematic of ethics in translation, a central topic engaged in the second half of the book. When I finished *Enlarging Translation*, therefore, I knew that I wanted to continue research on the cognition of translation and in particular to investigate whether work in neuroscience might bear upon central issues pertaining to the theory and practice of translation.

Somewhat fortuitously I found my way into the subject through popularized sources and soon friends, relatives, and colleagues were giving me things to read. The purpose of this article is to report on some current areas of research in neuroscience, indicating how that field will impinge on the concerns of translation studies, even though the actual productive areas of inquiry and the actual outcomes of the scientific investigations are not as yet known or even fully defined. Note that the purpose of the article is *not* to review work approaching translation studies from the perspective of cognitive science (or even the tentative beginnings of the use of neuroimaging in the field of translation studies): the latter endeavors represent some of the known *knowns* of translation studies.[2] In accordance with the topic of this special issue, I will concentrate on three main areas of research in neuroscience that impinge directly on translation in ways that are not yet fully understood, namely perception, memory, and plasticity. I have chosen these topics from among a wide array of possibilities illustrating the unknowns of translation at the level of molecular biology because they provide convenient entry points into the technical field of neuroscience that are conceptually familiar at the macro level to translation studies scholars. Moreover, discoveries in neuroscience related to these three topics challenge many common views in translation studies and thus illustrate the gains to be made by integrating findings of neuroscience into the field.

Let us begin with a brief survey of the methodologies of neuroscience. Until recently most knowledge about the functioning of the human brain at the neurological level was almost entirely the result of accident in the most literal sense. When an accident caused injury to specific areas of a person's brain, the resulting behavioral and cognitive impairments of the person could be observed; thus it was possible to correlate certain mental faculties with specific areas of the brain, namely those that had been injured. Such observations pointed to the use of a specific part of the brain for a particular function. In some cases, moreover, gifted researchers, such as Brenda Milner or V.S. Ramachandran, have been able to make determinations about brain function by examining people with specific syndromes or pathologies through experiments and the invention of successful therapies. Many brain functions could thus be investigated while human subjects were still alive and could, of course, be verified after death when the injured brain could be examined in an autopsy.

In the past two decades, however, powerful new techniques for observing brain function in healthy living individuals have been devised. To a large extent neuroscience has become a rapidly developing field because of new technologies that make it possible to monitor the brain as it actually works, to document neural pathways, and even to track the activity of specific neurons. These techniques include forms of neuroimaging such as fMRI (functional magnetic resonance imaging) and various forms of tomography such as PET (positron-emission tomography), as well as powerful techniques at the level of molecular biology that reveal the mechanisms of neural development and change and the networking of the brain. New approaches of these sorts are continually being developed and perfected, and old ones such as EEG (electroencephalogram) are being deployed for innovative and productive purposes. Thus it has already become possible to image and observe the brain of an individual at work, and the techniques are becoming focused enough so that researchers will soon be able to tell how a working translator's brain activity relates to specific aspects of translation, as opposed to stray thoughts or sensory input.

The discoveries in neuroscience discussed below pertaining to perception, memory, and brain plasticity have all been reported in summary articles in reputable sources such as *Scientific American* or more extended accounts of these subjects such as Eric Kandel's *In Search of Memory* (2006), all of which are written for general audiences.[3] One advantage of using credible popularized sources for an explanation of the known unknowns of the neuroscience of translation is that the reported findings in such sources should be accessible to scholars in translation studies who wish to become conversant with these ideas. In addition, however, such publications indicate that most of the findings are not new per se: in fact much of what follows has been accepted by neuroscientists and molecular biologists for more than a decade and the results are derived from large programs of scientific research which in most cases date to the 1990s. The materials have gained enough credibility to be reported in journals with mass circulation; thus most of the studies discussed below represent current dominant thought in neuroscience that should have a certain durability for the foreseeable future. All this is to say that my discussion below does not convey particularly recondite or controversial research in neuroscience as such. What is new here is the attempt to relate these materials from neuroscience to translation studies, so as to better understand the phenomenology and sociology of translation.

2. The neuroscience of perception

As neuroscience has learned more about the human brain, the notion of perception itself has been radically shifted. Far from being simple reception of "sense data", human perception has been shown to be shaped by culture and experience. This is immediately relevant to translators because what and how we translate depends on what we see and perceive; moreover, how audiences receive translations depends on what they see and perceive.

In terms simply of physical and neurological capacity, humans do not all have the same perceptual capabilities; in the case of vision, for example, we do not all see the same things because some people are nearsighted and others farsighted, some see the range of colors the eye can normally perceive and some are colorblind, and so forth. A graphic illustration of the role of physical differences in what we see is illustrated by comparing human sight to the sight of birds (Goldsmith 2006). Humans do not see the same things that birds see, because birds come equipped with four types of color receptors in the retina (vs. the two color receptors common to most mammals and the three of primates including human beings). Thus birds see the near ultraviolet range and this shades all the other colors that they perceive.

But what humans see is not dependent solely on our physical capacities and neurological potentials. As Ramachandran notes, "Your eyeball distorts the image — it's curved … Your lens inverts it — it's upside down. And your two eyes double it. The brain *interprets* the image" (quoted in Colapinto 2009: 80; original emphasis). The relationship between seeing, interpreting the physiological and biochemical signals, and translating — or between seeing and the reception of translation — is most noticeable in the domains of culture. How we translate aspects of culture depends on what we see, but in turn how we see and perceive culture depends not just on our physical capacities and our neurological wiring, but also paradoxically on culture itself which influences and shapes perception. That is, there is a recursive relationship between perception and culture.

This recursive relationship is hard-wired into the brain, and culture begins to define and limit human perception very early on. Babies at six months of age babble in the entire range of sounds used in all human languages around the world, but by nine months of age babies babble only in the phonemes of the language or languages of their own immediate cultural environonment.[4] Similarly, when they are six months old, babies can easily distinguish the special characteristics of individual monkey faces, while at nine months they have lost this ability. Lisa S. Scott, who has done the research on this topic, observes that by nine months babies are "starting to learn the things that are relevant in their environment … They realize it's not important to discriminate between two monkey faces, but it is between two human faces. They're realizing things that are important and things that aren't" in their cultures. At the same time she notes that human babies are "narrowing their ability to discriminate perceptual information" (2007). Thus, human perception of what we actually see and hear begins to be overridden by cultural categories and cultural imperatives long before our personal memories begin.

As well as being shaped by culture, perception is increasingly recognized as being constructed, rather than being merely a direct reception of external sensory data. Neuroscientists have discovered, for example, that visual images are not simple transmissions from the retina to the brain. Instead visual images are compiled by the brain out of at least a dozen separate streams of information which are controlled and sent to the brain by distinct receptors in the retina; these streams convey specific information about a visual stimulus including such features as edges, contour, form, depth, hue, shadows, highlights, motion, and so forth (Werblin and Roska 2007). The brain compiles such features of the object in the visual field in order to make a determination about what is being seen. As a consequence sight is not a unitary thing and it is possible that the very process of compiling the streams of data from the retina is not necessarily the same for all. Human beings must learn to see, and not all of what we have learned is consciously remembered. Oliver Sachs writes, "There may be some objects that are recognized at birth, or soon after, like faces. But beyond this the world of objects must be learned through experience and activity: looking, touching, handling, correlating the feel of objects with their appearance" (2010: 27).[5] This foundational learning is rarely accessible in conscious memory.

In general, moreover, humans are largely unconscious of how the construction of perceptions — shaped by personal experiences as well as cultural frameworks — influences judgments about what we see and hear, including our emotional, ethical, and value assessments of the sensory world.[6] It is clear, however, that memory and other mental functions play a large role in perception. Eric Kandel says that the sensory systems are merely "hypothesis generators"; he continues "we confront the world neither directly nor precisely" (2006: 302). To a large extent memory is responsible for the outcome of perception. Thus perception and memory (implicit and explicit) are indisolubly intertwined. As the example of the retina indicates, the images in our minds are rich, but the information we work from is poor (cf. Gawande 2008: 63). Perception is actually the brain's "best guess" about what is happening in the outside world (Gawande 2008: 63). In the case of vision, the mind fills in most of the picture, drawing on memory in the process. This is indicated by the neural structure of the brain's primary visual cortex where only 20 per cent of the neural network is from the retina and the other 80 per cent relates to regions of the brain governing functions such as memory (Gawande 2008: 63). Richard Gregory, a British neuropsychologist, estimates that visual perception is more than 90 per cent memory and less than 10 per cent sensory nerve signals (quoted in Gawande 2008: 63).[7] Perception is thus a process of inference, in which the mind integrates scattered, weak, and rudimentary signals from a variety of sensory channels, information from past experiences, and hard-wired processes (Gawande 2008: 63).

Finally, not only is perception shaped by unconscious effects of culture and experience, neuroscience has shown that many other aspects of perception are nonconscious. Again in the case of vision, not all of what is seen is available to the conscious mind (cf. Raichle 2010). There are some 30 sites in the brain associated with vision, which break down into the so-called old visual pathway and the new visual pathway (Ramachandran 2004: 24–39). If the new visual pathway is destroyed in one eye, say by an accident, a subject can still "see" with that eye, but the person is not conscious of seeing. Indeed such a person reports being unable to see an object in question with the eye, even if he can reliably touch it when asked to do so. This is a phenomenon called "blindsight". Ramachandran (2004: 29) asks what it means for someone to be able to reach out and touch something that he cannot see or at least that he is not conscious of seeing. The blindsight of people with damage to their new visual pathway is an example of the many nonconscious aspects of perception and cognition that neuroscience is discovering. It indicates the importance of taking nonconscious knowledge and perceptions into account as translation studies attempts to understand and model the process of translation and the responses of receivers of translations.[8]

3. Implications for translation studies from the neuroscience of perception

Obviously the findings of neuroscience related to perception have fundamental implications for the translation of culture and for the decision processes of translators. Research in neuroscience raises questions such as the following. What do we perceive that we are not conscious of? Equally important, what do we *not* perceive that we are not conscious of? How do nonconscious aspects of perception affect translation choices? How is what we perceive consciously affected by things we perceive unconsciously? How do our unconscious perceptions affect how we translate? In particular how does what we perceive unconsciously affect how we assess, judge, and transmit culture in translations? If culture and experience actually shape perception, how do translators overcome the difficulties in perceiving cultural difference and conveying such differences to the receivers of their translations? In turn, in what ways do the receivers of translations experience difficulty assessing, accepting, and integrating unfamiliar cultural differences? The findings of neuroscience related to perception seem to suggest that there may be a hard-wired tendency toward ethnocentrism on the part of all translators and their audiences, with the transmission of cultural variation going against the grain not just of culture and ideological frameworks but of human bodies, brains, and perceptual systems as well. How can such cultural bias be mitigated in translation processes and products?

The fact that so much of the construction of perception is nonconscious also complicates the way that translation can be modeled. What translators (and audiences) perceive in a text (both source text and target text) may not only be unconscious but also heavily structured by their own cultural frameworks and their personal experiences. If this is so, expanding or changing perception and sensitivity to newness and difference is not simply a matter of will, goodwill, or desire; it is probably primarily a matter of shifting nonconscious and ingrained responses that are physically patterned into the brain. Should translators consciously work to become self-aware of the nonconscious components and the gaps in their perceptions? Is it in fact possible to deconstruct or bring to light fundamental formative experiences and neurological processes shaping perception such as those discussed above? And if it were indeed possible to develop such self-reflexivity, how might this process be incorporated into translation training?[9]

We can also ask whether it is possible for translators to defamiliarize what seems "natural" and to familiarize what seems culturally "unnatural" so as to enable the perception and conveyance of cultural difference. How are neurological networks related to perception, culture, and categories altered when a person becomes multilingual and multicultural? How would such changes in perception intersect with what molecular biology is revealing about the hard-wiring of the brain? Is it possible to induce parallel experiences and similar shifts vicariously in people who are the receptors of translations? These are questions that cognitive science has begun to explore and that neuroscience will address in the near future.

4. The neuroscience of memory

We have seen that memory is an important factor related to perception, but neuroscientists have discovered other interesting features of memory that have implications for translation. A major step in the development of modern neuroscience was the discovery that there are two major types of memory. This discovery came about through the research of Brenda Milner on a famous patient known as H.M., in work that was published in the 1950s and 1960s. Because H.M. was suffering from massive epileptic seizures that completely debilitated him, he was given an operation that removed his hippocampus and other parts of the temporal lobes on both sides of his brain. As a result of the operation, H.M. ceased to have seizures, but he was also unable to convert short-term memories to long-term memory, an unforeseen result. H.M. could not remember events, people, names, words, and so forth that he experienced or came into contact with after his operation — indeed, though Milner worked with him for decades, he always greeted her as if he had never seen her before. It was thought that H.M. could not learn, but Milner discovered that he did have a memory pathway that permitted him to perfect certain physical skills. As a result of this research, it is now acknowledged that memory is a distinct mental function, that loss of the hippocampus destroys the ability to convert new short-term memory to new long-term memory, and that there are at least two types of long-term memory (cf. Kandel 2006: 129). These two types of long-term memory are conscious and nonconscious memory, generally referred to respectively as explicit memory and implicit memory or declarative memory and procedural (or non-declarative) memory (Kandel 2006: 132). In what follows the distinction will be generally referred to as explicit versus implicit memory.

We could not negotiate the world without depending on nonconscious knowledge and awareness. Implicit or procedural memory is essential and makes possible driving an automobile and simultaneously carrying on a conversation and enjoying the scenery. In general people are not consciously aware of implicit or procedural memories: for example, we do not think explictly of what we need to do physically at each moment to ride a bicycle nor are the automated morphosyntactical aspects of processing one's primary language driven by explicit memory (cf. Paradis 2004: 15). Implicit memory is also important in emergencies when fast response is required. There is an analogue to these two types of long-term memory in the conscious sight of the new visual pathway discussed above and the so-called blindsight of the old visual pathway. Differences in the neural pathways and networking of explicit and implicit memory have begun to be established.[10]

Many of the mechanisms of both short-term memory and long-term memory have also been established at the level of molecular biology, a process in which the Nobel prize-winning Eric Kandel played a central role.[11] A critical feature of the establishment of long-term memory is that it involves physical changes to the brain, notably the growth of new terminals on the axons of brain cells (Kandel 2006: 254–75) or the growth of new neurons and the development of new neural networks. Long-term memory and learning change the body in a tangible physical manner. As Kandel (2006) indicates, neuroscientists with interests in memory are currently investigating complex thinking and looking for the mechanisms that make consciousness possible.

The convergence of research about perception and memory on the importance of nonconscious knowledge and memory is striking, but in many ways current work on the neuroscience of memory is even more exciting than work on perception in terms of its implications for translation studies. One interesting set of experiments on mice, for example, has begun to investigate how complex long-term memories are laid down and how they are retrieved (Tsien 2007). In the research mice were subjected to simulated dangers — simulations of such things as "an earthquake" (being shaken in a box), "an elevator drop" (being in a box while it was in a controlled fall), or "a predator attack" (having a sharp gust of air blown across their backs) — while researchers monitored a large sample of neurons in the hippocampus, an area of the brain that in humans is central to transferring short-term memory to long-term explicit memory. The research concluded that memories are stored in "cliques" that fire together in the hippocampus when the memory is retrieved. In turn the cliques are organized componentially (comprised of separate multisensory signals representing such things as location, color, danger, and bodily motion) and hierarchically (where danger includes both the subsets attack and unusual bodily motion, for example, and bodily motion in turn includes shaking and dropping). Once established, these memory patterns are durable and occur spontaneously in the brain waves of the mice, sometimes even while the animals are asleep.

If similar findings are sustained for human beings, the research will be particularly relevant to the concerns of translation studies. It suggests the congruence of memory structures with componential and hierarchical features of language that have been widely recognized and discussed in the literature of translation studies. For decades it has been recognized that asymmetries in componential features of words and concepts across languages pose a central problem for translators and a central question to face in making translation choices; the same is true of hierarchical structures of language.[12] Should it turn out that long-term memory in general is organized componentially and hierarchically, the research will suggest a general framework for the operation of language at the biomolecular level, indicating how declarative aspects of language intersect with the implicit categorical organization of the brain. It is likely that such hierarchical and componential aspects of memory constructed by culture and experience are germane to the process of translating and the reception of translations both at conscious and nonconscious levels. Clearly this is an area of neuroscience to watch closely.

Finally, as noted already, research on the conversion of short-term memories to long-term memories is well developed. It has been known for some time that for long-term memories to be established, redundancy is essential: generally a stimulus must be repeated several times with appropriate intervals of rest (approximately 20 minutes) between repetitions (Fields 2005, cf. Kandel 2006: 264–66, 309). During the resting periods, moreover, the subject cannot be exposed immediately to new stimuli that will cause interference and effacement of the short-term memory, thus disrupting the establishment of a long-term memory. One-time exposure does not necessarily or even normally suffice for a concept or an experience to be remembered unless that single exposure has a striking or catastrophic impact on the organism. Such cases usually entail a massive amount of simultaneous neuronal firing and often involve emotionally charged and multisensory stimulation.[13] Only in such cases (here compare the traumatized mice discussed above) will a single event suffice to establish a long-term memory.

5. Implications for translation studies related to the neuroscience of memory

Research in neuroscience on perception stands as a reminder that translation does not depend simply on the nature of the perceptible world or on conscious knowledge, but that translators and receivers of translation are all shaped in their perceptions by their cultures and recursively predisposed to produce or consume translations in culturally formed ways. In cultural translation these formations inextricably link perception and memory. They constitute potential nonconscious limitations on the process of translating cultural difference and potential resistance to cultural alterity in the reception of translation. Memory research also indicates the fundamental role of implicit (or procedural) memory, as well as nonconscious neural networks (both sensory and experiential) that impinge on explicit memory and knowledge. Translation studies will be able to address such nonconscious dimensions related to translation in productive ways by integrating the advances of neuroscience about memory into its discourses.

The value of research on memory in neuroscience is not limited to the question of implicit aspects of the cognition of translators or users of translations. Memory research raises intriguing questions pertaining to conscious learning in relation to translation methods, speaking to conditions that facilitate learning of new information, new patterns of semiosis, and new aspects of culture. Here again the neuroscience of memory touches on cultural translation, speaking to questions such as resistance to cultural hegemony that have been central discourses in translation studies for at least two decades. The importance of redundancy interspersed with rest in exposure to new stimuli and new experience for the formation of long-term memory suggests possibilities for effective translation techniques that can foster the integration of new information and alternate cultural dispositions in the explicit memories of target audiences. This research points to opportunities and strategies that translators might consider.

Moreover, research about the neuroscience of memory offers intriguing possibilities for fostering concept flexibility in translators and audiences alike. If memory is componential and hierarchical to a significant degree, translation studies will want to explore how new components of concepts and new hierarchical orderings found in a second or third language and culture get learned, integrated, and solidified in a translator's thought at the implicit level of cognition. Does this integration involve expansion of the translator's original set of memories or is an alternate set of memories patterned into the brain such that the brain toggles between the two sets, only connecting and integrating the two patterns at specific moments such as the process of translation? Is it possible that both alternatives exist and that translators' processes are therefore highly variable? Or, finally, is it possible that the new material from the second language pertaining to conceptual thought is never fully integrated with implicit memory related to the first language? Obviously whatever is learned about such questions will have immediate relevance for translation pedagogy, for translation practice, and also for translation theory.[14]

Questions about the neurological structure of category and concept memory are relevant to the activities of translators, but they are perhaps even more pertinent to the responses that target audiences have to translations. How can a translator allow for and manage the nonconscious cognitive responses of the target audience that are coded in long-term memory and that shape or even limit the reception of translations? Are receivers of translations inevitably predisposed to domesticate translations in their own cognitive reception of texts (whether oral or written) because of the hierarchical and componential structuration of memory itself related to concepts and categories activated by the translation? If a translator were intent on expanding the categorical thinking of a target audience and making translations — as well as specific features of other cultures — memorable (that is, integrated into explicit long-term memory), what sort of translation strategies might be adopted in light of current research in neuroscience on long-term implicit and explicit memory? These are among the many questions pertaining to memory that stand at the intersection of translation studies and neuroscience.

6. Plasticity of the brain

It used to be thought that adult brains could not grow new neurons or change to any great extent, but it is now known that human brains are more flexible than was once assumed. This new concept of the flexibility of the brain is known as "plasticity". Research in the last two decades has shown that the brains of adult animals and humans alike can and do grow new neurons and that areas of the brain can also be reallocated for new uses if old functions are no longer needed. The concept of plasticity has become somewhat trendy in academic circles but it is often used in ways that are different from its meanings in neuroscience. Plasticity is much more than the superb ability of human beings to be flexible and to learn new things: as already intimated, in neuroscience the concept of plasticity signifies the ability of the brain to reallocate parts of the brain to new uses when the old ones cease to be needed, as well as the physical alteration of neurons and neural networks or the growth of new neurons. Plasticity in neuroscience is a physical feature of the brain ranging from the micro levels of the synapse and the neuron to the macro levels of the networking of the brain as a whole. In scientific discourse plasticity takes time: it is not merely a function of transfer from short-term to long-term memory or the ability of the brain to learn and adapt quickly. Plasticity involves brain changes that are physical and many such changes do not happen in a short time but may require months or more. The cognitive flexibility designated by the term *plasticity* in neuroscience is enormously significant in terms of any assessment of the abilities of human beings to change and develop cognitively. Evidence of the brain's ability to grow and change is particularly welcome, because neuroscience has also found clear evidence of physiological alterations associated with aging that make it more difficult for people to learn and remember as they grow older. Moreover, as we will see below, there is evidence that some limitations on the adaptability of memory networks occurs in the brain in early adulthood. It is possible that these various limitations can be offset in part by the brain's plasticity.

We have seen that long-term memories are hard-wired in the brain. Until recently this hard-wiring was largely attributed to changes in neural patternings associated with the synapses between neurons. It is known, for example, that when neurons on both sides of a synapse are simultaneously stimulated, the connection between those two neurons is preferentially strengthened and a fixed association between the two neurons is often created (Kandel 2006). More recent work has focused on physical changes related to neural networks that involve the so-called white matter of the brain, namely the myelin coating of the fibers of axons that serve as the signaling channels connecting neurons in vastly different regions of the brain (see Fields 2008). One essential of neural networks is the connection and coordination of numerous signals from different parts of the brain so that many components of sensory input and memory can simultaneously coalesce into a single thought, perception, or memory. A specific job of the myelin coating on the axons is to regulate the speed of stimuli from different parts of the brain, so that all relevant signals network simultaneously. Because distances in the brain can vary considerably (in terms of molecular distances), some signals must be sped up and others slowed down; the thickness of the myelin coating on axons in relation to the diameter of the fiber is instrumental in determining the speed of neural signals (Fields 2008: 54–57). Once the myelin coating of a fiber is established, the changes that axons can undergo become more limited: it is much more difficult for an axon to grow new branches and trim others in response to experience (Fields 2008: 57), thus initiating the formation of a new connection with another neural pathway or eliminating such a connection. Interestingly, the neurons in the higher brain centers of human beings — the forebrain of the cortex — only receive their full myelin coating in an individual's early adulthood (usually the mid twenties), suggesting that at the end of adolescence, many brain pathways become more fixed and less malleable and adaptable (Fields 2008: 56–57). Though this greater fixity may have something to do with the better judgment of mature people rather than adolescents, the research on myelination is somewhat discouraging regarding the plasticity of the brain, particularly as people age.

A third major discovery of neuroscience that pertains to the concept of the brain's flexibility in the largest sense is the presence in the brain of so-called mirror neurons.[15] Though mirror neurons are not normally included under the rubric of plasticity per se, they are central in the ability of human beings to learn and to understand things that are new and unfamiliar, hence to change. Mirror neurons are widespread throughout the brain; these neurons fire both when an individual performs a simple goal-directed motor sequence and when the individual sees another person perform the same act. Sets of mirror neurons encode templates for specific actions, allowing individuals to perform actions and to understand the same acts when observed (Rizzolatti et al. 2006: 56).

Experiments have shown that mirror neurons also enable humans and some primates to understand the intentions and emotions of others. The ability to comprehend such things through a direct mapping mechanism in the brain strongly facilitates social life, providing a neural basis for some of the interpersonal relations on which more complex social behaviors are built and locating basic motor acts within a semantic network that does not require complex cognitive machinery to comprehend the behavior of others (cf. Rizzolatti et al. 2006: 59). Current research is investigating the role of mirror neurons in observation-based learning, imitation, and language acquisition and use. Mirror neurons may provide an explanation for two aspects of communication: parity (the message is the same for the sender as for the recipient) and direct comprehension (no previous agreement

— on arbitrary symbols, for example — is required for individuals to understand each other).[16]

The discovery of the system of mirror neurons provides an optimistic perspective on the plasticity of the brain and may constitute some of the most promising research in neuroscience for the purposes of translation studies. Mirror neurons are good news for translators, because unlike myelination which makes neurons less flexible over time, mirror neurons continue to function throughout a person's lifetime. Mirror neurons allow human beings to learn by observing others and they enable immediate comprehension of many of the acts of other people and the meaning of those actions, independent of other knowledge. Not only do mirror neurons seem to be a factor in empathy and understanding of others, they may be related to self-awareness, introspection, and self-reflexivity (Ramachandran quoted in Colapinto 2009: 87). All these functions of mirror neurons are related to understanding other cultures, whether directly through experience or perhaps indirectly through representation.[17] Obviously the functions of mirror neurons contribute to the abilities of good translators and also probably to the qualities of sympathetic readers of translations, speaking to the ability of people to understand cultural difference and newness. Discoveries about the role of mirror neurons in language acquisition and language use will have particular significance for translation studies.

7. Implications for translation studies related to the plasticity of the brain

We have seen that various aspects of the way that memories are coded in the brain have implications for why the concepts of a person's native culture become deeply ingrained and hard to challenge; thus the hard-wiring of neural circuitry has implications for cultural translation in particular. Neuroscience suggests the difficulty entailed in enlarging concepts and categories when learning, teaching, or writing about another set of cultural conceptualizations. The plasticity of the brain is an important factor in being able to shift the cultural frameworks within which neurological patterning was established. New neurons can grow, new networks can be developed, and areas of the brain can be reallocated for new purposes.

At the same time research on plasticity indicates that category, conceptual, and networking change is not simply a matter of exerting the will so as to learn new things or of exercising goodwill so as to accept difference. Physical changes in neurons and shifts in neural networks are part of memory, associations, concept formation, and category perceptions, all of which factor into translation — particularly translation of culture and cultural difference. Many of these changes operate at a nonconscious level. They affect the receivers of translations as much or more than translators themselves. These unconscious elements do not simply disappear when we want them to and they are not necessarily amenable to conscious alteration. Research on myelination is important for indicating that all signals related to a neural pathway must be temporally coordinated to be effective: it may be possible to know all elements of a new situation but be unable to actualize that knowledge effectively or fully at a relevant juncture either as a translator or a receiver of a translation because all the factors necessary for understanding and empathizing may not be simultaneously accessible or coordinated. Where myelination suggests limits on plasticity, mirror neurons by contrast seem to facilitate the process of learning new cultural dispositions and practices, of understanding others, of translating culture bodily as well as cognitively, and perhaps also of being receptive to cultural difference presented in the representations of translations.

8. Conclusions

Translation studies is a broad field that brings together many diverse issues and many theoretical perspectives. No one person can or should expect to address all the concerns raised by translation or to master all the skills deployed in its investigation. Nonetheless, in "Connecting the Two Infinite Orders: Research Methods in Translation Studies" (2002), I argue that both micro and macro approaches are equally important for the field as a whole: macro approaches such as those offered by sociocritiques, ideological investigations, literary analyses, and systems studies are as important as the micro analyses of linguistics, for example. Moreover, in Chapter 4 of *Enlarging Translation*, I suggest that the methodologies of scholarship in translation studies resulting in durable conclusions are essentially similar, whether a scholar is making a sociocultural argument or a linguistic one, whether a scholar conducts an experiment on translators or analyzes a translated text. At first consideration, the contributions that neuroscience can offer to translation studies seem to constitute another approach to translation operating at the micro level. As indicated in this article, however, the neuroscience of translation will have significant implications for understanding translation at the macro level as well. Clearly not everyone interested in translation need be immersed in neuroscience, but it is an area that should be tracked in the field of translation studies as a whole, if only because the neuroscience of translation is one of the most important known unknowns of the discipline.

Some of the most exciting advances in translation studies in the near future will result from its intersections with neuroscience. In such joint endeavors, it will be important to remain aware of the links between micro and macro research: to engage in investigations of translation at the micro level of the brain but to see as well the implications for the macro levels of translations as texts, as mediations between cultures, and as ideological interventions, as well as the implications for many other macro level topics that have flourished in translation studies. Some scholars may initially think that the investigations of neuroscience at the level of molecular biology are irrelevant to these larger concerns of the discipline of translation studies, the processes of translation, the products or translation, or the practical training of translators. As I have pointed out earlier (2002), however, this is as shortsighted as it would have been for telescope enthusiasts in the seventeenth century to have rejected the findings of the microscope.

The three topics discussed in this article — perception, memory, and plasticity — are only a few of the many areas being explored in neuroscience that have implications pertinent to questions that have already been raised in the field of translation studies. There is much more in neuroscience research of theoretical and pragmatic interest for translation scholars and practitioners. A great deal of the relevant research in neuroscience will also have implications for translator training. Moreover, as new technologies develop in neuroscience, those advances will allow translation studies scholars themselves to propose and perhaps participate in neuroscience teams undertaking specific experiments that relate both to the micro levels of translation and that have implications for the macro levels.

Some translation scholars have already begun to work on the neuroscience of translation in places as diverse as England, Slovakia, Switzerland, Spain, and Turkey, using techniques such as neuroimaging. The questions raised in these experiments range widely from questions about the performance of interpreters to investigations of differentials in neuroimages when a translator is translating into a first or second language. All this is to the good: it is just a matter of time until neuroscientists and molecular biologists focus their attention on mediations between languages, including translation. Translation studies itself should have scholars at the table when investigations of these known unknowns of translation are undertaken.

Notes

1. In the remainder of this essay I will include interpreting under the rubric of translation, which I see as a process that can be both audio-oral and textual.

2. On cognitive science approaches to translation, see, for example, Danks et al. (1997), Shreve (2009), and sources cited. Related work on cognitive and psycholinguistic approaches to bilingualism are found, for example, in de Groot and Kroll (1997); in addition some research on bilingualism has already begun to incorporate developments in neuroscience, notably the work of Paradis (2004, 2009).

3. Most of my citations in this essay are to sources of this type. For more in-depth technical discussions, see the sources cited in the accounts written for general audiences and in my forthcoming book *Neuroscience and Translation*.

4. See related findings in Ellis (2006: 183–86).

5. Wixted and Squire (2011) discuss the integration of a wide variety of experiential aspects including visual, spatial, temporal, tactile, emotional, and auditory elements in the formation of integrated memory traces.

6. Note that in this essay the terms *unconscious* and *nonconscious* are used interchangeably in reference to implicit versus explicit memory, discussed below, rather than in any psychoanalytic sense.

7. A more technical account of the impoverishment of actual perceptual data in favor of data from memory is found in Raichle 2010. See also Holcombe 2009.

8. Other examples of nonconscious perception are found in Gladwell (2005).

9. Note that Paradis (2004, 2009) argues that automated linguistic processes (such as grammar) are essentially unavailable to conscious inspection. One can only overlay them with explicit knowledge of "rules". The same might be argued about many nonconscious perceptual processes and learning associated with them.

10. See the diagram in Kandel (2006: 130) for how the two types of long-term memory are stored and for their distinct pathways in the brain, with the pathway of implicit or procedural memory bypassing the hippocampus.

11. Kandel (2006) has written a memoir that also serves as an introduction to the neuroscience of memory for general readers or scholars in fields outside neuroscience.

12. Compare, for example, the discussions of hierarchical and componential analyses of language asymmetries in Nida (1964: 73–87).

13. Kandel (2006: 264–65) discusses such memories.

14. Similar questions are asked and the debates on the issues are discussed in de Groot and Kroll (1997: 7–10, 145–200).

15. Rizzolatti et al. (2006) presents an overview of mirror neurons.

16. See Rizzolatti et al. (2006: 61).

17. The latter seems promising in light of the use of videos in experiments about mirror neurons, for videos are a form of representation. The importance of this point seems to elude Rizzolatti et al. (2006). It indicates that representations of various other types, including translations, may have the power to trigger mirror neurons just as physical observations of live human beings do.

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Author's address

Maria Tymoczko
Comparative Literature
University of Massachusetts Amherst
AMHERST
MA, 01003, USA

tymoczko@complit.umass.edu