

Categorization in Neuroscience: Brain Response to Objects and Events

Catherine Hanson and Stephen J. Hanson

Rutgers University, Newark, NJ, United States

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Abstract

Neuroscientific methods have become an increasingly important influence on the study of cognitive processing. In this chapter, we look at how the study of patient populations in addition to neuroimaging techniques have been used to address basic questions about category knowledge. How does the brain represent category knowledge? What information is acquired during category learning? Why do people parse action streams into discrete events? We examine how neuroscience has shaped the way we ask and answer questions about category learning and representation. There may not be agreement about the answers, but neuroscientific methods have helped to make investigating the questions more interesting.

9.1 INTRODUCTION

Whether we are recognizing a friend or making a cup of coffee, the seemingly effortless and instantaneous ability to transform sensory information into meaningful concepts determines the success with which we interact with the world. However, the seeming ease with which we engage common concepts belies the complexity of the underlying brain processing that makes categorization possible. At what point in the processing of sensory information is the category decision made? Work with nonhuman subjects suggests that categorization may be traced to individual neurons. In their seminal work, [Hubel and Wiesel \(1962\)](#) implanted electrodes into the visual cortex of cats and found that some neurons would respond to certain types of visual input but not to others. That is, like cells in the retina of the eye, neurons in the visual cortex of the cat appeared to be dedicated to specific types of visual input. Unlike the retinal cells, the neurons of the visual cortex responded to more complex patterns involving shape and orientation. Based on their observations, Hubel and Wiesel argued that neurons in the visual cortex were hierarchically organized into simple and complex cells, and the complex cells were constructed from more elementary ones.

The view of visual cortex as hierarchically organized was formalized by [Barlow \(1972\)](#) in a paper outlining the tenets of a neuron doctrine of perception. This model of perception at the neural level has dominated neuroscience studies of perception to this day. The underlying premise of the neuron doctrine is that neurons at higher brain areas are assumed to become more selective, so that “the overall direction or aim of information processing in higher sensory centers is to represent the input as completely as possible by activity in as few neurons as possible” (p. 382).

Thus, as information is propagated through the system, neurons are assumed to respond to progressively more complex and invariant features. Accordingly, it should be possible to identify neurons specialized for particular objects, e.g., faces. One of the first studies to demonstrate

face-responsive cells was conducted with Macaque monkeys (Gross, Rocha–Miranda, & Bender, 1972). Recording activity of single neurons in response to visual stimulation, Gross et al. found individual cells that responded maximally to face stimuli and even detected a neuron that responded maximally to a monkey hand. These specialized cells were found in the inferior temporal cortex of the monkey, which is thought to correspond, in humans, to the medial temporal lobe (MTL). Later in this chapter, we discuss data from human research that suggests the presence of face-specific brain response and its implications for category processing.

One major criticism of the neuron doctrine is that, contrary to the theory, large parts of the brain can be damaged without correspondingly large changes in behavior (Lashley, 1929). This property of the brain, which is known as *cerebral mass action*, and a second property, *equipotentiality* (the ability of a brain area to take on the function of a damaged area), suggest that brain function is not localized. Rather, these properties suggest that brain function is distributed across neuronal populations that are clustered into networks and circuits and are recruited opportunistically as various perceptual and cognitive tasks arise.

This debate between proponents of localized and distributed processing has become particularly salient in the neuroscience literature related to categorization. As we shall see, support for both sides has been collected, although recent efforts seem to favor a distributed representation of category information over ones positing localized representation. Our goal in this chapter, however, is not to argue for one view over the other, but rather to present representative research that was performed using neuroscientific techniques to study categorization.

One neuroscientific approach that has been used successfully relies on the study of patient populations. Researchers have long been interested in neurological impairments because of what they could reveal about normal cognition. Knowing that certain lesions in specific brain areas lead to fairly predictable cognitive deficits provides the means of studying the link between brain function and cognitive function. If a lesion in a given brain area produces a language deficit, it is highly likely that that area is important to normal language processing. Moreover, if that lesion does not affect other cognitive processes, it reveals something about the independence of cognitive functions.

Over the past 10–15 years, interest in brain function and its relation to cognitive function has led to a dramatic increase in the use of tools and techniques such as event-related potential (ERP), positron-emission tomography (PET), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) that had long been the exclusive domain of medical practitioners. By adopting the tools of neuroscience, cognitive psychologists are now able to directly (or as directly as

feasible) observe the brain as it works on various cognitive tasks. Although the methodologies associated with neuroscience are not without pitfalls (see [Gabrieli, 1998](#)), cognitive neuroscientists have come very close to looking inside the black box.

The focus of this chapter is on the work that has applied the techniques of cognitive neuroscience to the study of category processing. Specifically, we examine what studies using a neuroscience approach have contributed to the understanding of how categories are learned and represented. Our review is not meant to be exhaustive, but rather to provide some examples of how neuroscientific approaches have contributed to our understanding about the processing of category knowledge in the brain.

Our discussion focuses on two types of knowledge about the world; namely, objects and actions. Most work on categorization concerns how object categories are represented and learned, and we devote the first part of this chapter to this research. A large component of human experience, however, involves the interpretation and representation of action, so we next look at how the brain processes real-world events such as *going to the theater* or *having dinner*. Finally, we offer some suggestions about future investigations.

9.2 REPRESENTING OBJECT CATEGORIES IN THE BRAIN

The cognitive neuroscientific approaches to category representation can be divided roughly into two camps. In one camp are those researchers who believe that there exist category-specific structures in the brain (e.g., [Kanwisher, McDermott, & Chun, 1997](#)). In the other camp are those who believe that category knowledge is based on distributed feature topologies (e.g., [Haxby, Ishai, Chao, Ungerleider, & Martin, 2000](#)). A different approach is taken by [Gauthier \(2000\)](#), who sees brain structures as being linked to how category information is processed rather than to any specific category content. We review what each of these positions has contributed to our understanding of categorization.

9.2.1 Category-Specific Representation

One way in which the brain may represent categories is to dedicate a set of neurons to the task. That is, the brain could allocate particular areas to individual categories, so that whenever a category exemplar was encountered, the area of the brain dedicated to this would be activated. Moreover, brain areas dedicated to a particular category would be

unresponsive when exemplars of a different category were encountered. Thus, the brain area that responded to category A would not respond to category B, and vice versa. Moreover, if category information was selectively represented in particular brain structures, damage to those structures should disrupt knowledge associated with those categories.

Category-specific disorder, a disorder in which patients demonstrate a selective dysfunction in retrieving category exemplars or features, has been associated with brain damage resulting from a wide range of etiologies including herpes simplex encephalitis, brain abscess, anoxia, stroke, head injury, or dementia of Alzheimer type (DAT). The most common form of category-specific disorder involves animate objects, inanimate biological objects, and artifacts (Capitani, Laiacona, Mahon, & Caramazza, 2003).

Category-specific disorder often affects one type of category while sparing another. Much of the extant work in this area has found that a patient suffering from category-specific disorder will have difficulty with either the category of animate objects or that of artifacts. Rarely does a patient have difficulty with both categories. Research with patients has found that damage to areas in the inferotemporal cortex, the mesial temporolimbic structures, and the temporal pole (Gainotti, 2000) disrupts access to knowledge about living things. In contrast, knowledge about artifacts seems to be most often associated with damage in the frontoparietal areas (Gainotti, Silveri, Daniele, & Giustolisi, 1995; Saffran & Schwartz, 1994) and in the posterior left middle temporal gyrus (Martin & Chao, 2001; Phillips, Noppeney, Humphreys, & Price, 2002). Fig. 9.1 shows a picture of a brain with these areas of interest labeled.

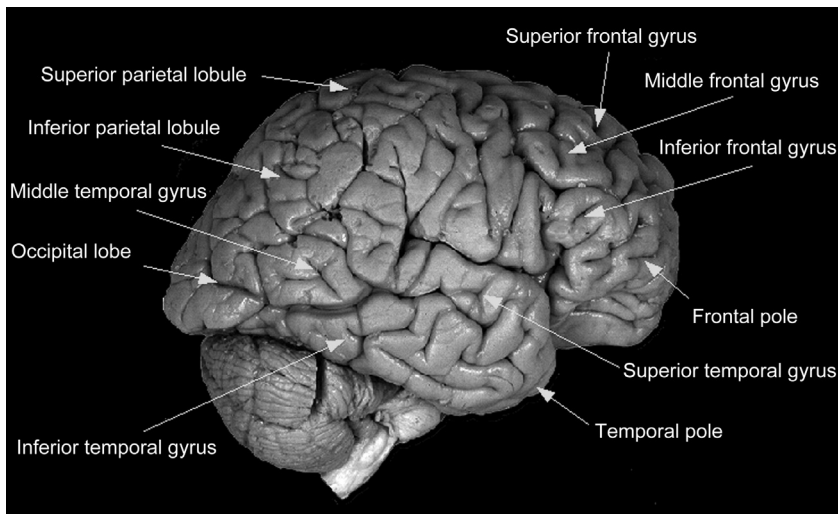


FIGURE 9.1 Human brain with labels indicating important cortical areas.

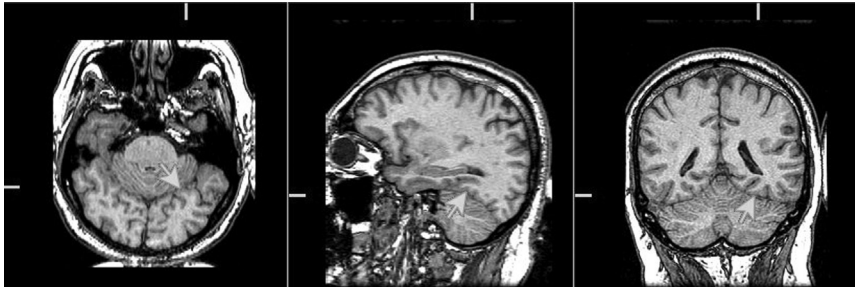


FIGURE 9.2 Fusiform gyrus shown in MRI images of axial, sagittal, and coronal views of the brain.

Functional neuroimaging work looking at normal brain activation has revealed a similar pattern of results. In patient studies using PET, researchers have found that knowledge about artifacts is associated with the left posterior middle temporal area (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Martin, Wiggs, Ungerleider, & Haxby, 1996; Moore & Price, 1999; Mummery, Patterson, Hodges, & Wise, 1996; Mummery, Patterson, Hodges, & Price, 1998; Perani et al., 1995) and knowledge about animals is associated with activation in visual association areas (Martin et al., 1996; Perani et al., 1999). Similar results have been found by researchers using single-photon emission computed tomography (SPECT) (Cardebat, Demonet, Celsis, & Puel, 1996), ERP (Rossion et al., 2003) and MEG (Tarkiainen, Cornelissen, & Salmelin, 2002).

Some researchers have taken this view further, arguing that categories as specific as faces (Kanwisher et al., 1997; Puce, Allison, Gore, & McCarthy, 1995) or buildings (Aguirre, Zarahn, & D'Esposito, 1998) can be shown to activate well-defined areas of the brain. Evidence for activation of category-specific brain areas rests largely on correlations between neural response and specific stimuli. For example, the fusiform face area (FFA) is so designated because it tends to respond maximally when faces are presented. Fig. 9.2 shows the location of the fusiform gyrus.

Similarly, the parahippocampal place area responds strongly to places. Fig. 9.3 shows the location of the parahippocampal gyrus in the brain.

However, several researchers have questioned the existence of category-specific areas (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999, 2000; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999; Ishai, Ungerleider, Martin, & Haxby, 2000). They offer alternative explanations of brain activation in response to category exemplars based

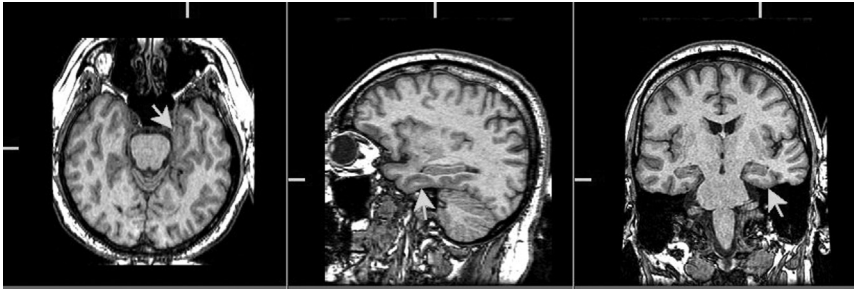


FIGURE 9.3 Parahippocampal gyrus shown in MRI images of axial, sagittal, and coronal views of the brain.

on distributed feature networks or processing demands. We next present work that supports the existence of distributed feature networks.

9.2.2 Feature-Specific Representation

There is a growing body of work that suggests that categories may be represented by different feature-based neural systems in the brain, rather than by category-specific structures. In a review of the literature, [Martin and Chao \(2001: 196\)](#) suggest that:

ventral occipito-temporal cortex may be best viewed not as a mosaic of discrete category-specific areas, but rather as a lumpy feature-space, representing stored information about features of object-form shared by members of a category

This “lumpy feature-space” can be thought of as a feature-map ([Gauthier, 2000](#)) or object-form topology ([Haxby et al., 2000](#)).

Much of the evidence against category-specific brain structures comes from work showing that the response of these areas is not restricted to specific categories alone (e.g., [Blonder et al., 2004](#); [Haxby et al., 2001](#)). [Chao, Haxby, and Martin \(1999\)](#) found that the lateral fusiform gyrus and the right posterior-superior temporal sulcus responded to animals, faceless animals, and human faces.

Recent findings in our lab ([Hanson, Matsuka, & Haxby, 2004](#)), in which we used a neural net classifier to model brain activation patterns, do not support the notion of category-specific brain structures. We used a voxel-wise sensitivity analysis to look at category-related responses in the ventral temporal (VT) lobe. Our results indicate that the same VT lobe voxels contributed to the classification of multiple categories, which does not support a category-specific model. Instead, we argue for a combinatorial coding of category features in VT.

The advantage of a distributed representation of features approach is that it can account for activation of the same brain structure when exemplars from different categories are present. On the other hand, this approach is not good at explaining why a brain structure that responds when certain objects are present does not similarly respond when other objects that have similar features are present (Gauthier, 2000). Objects that share similar features should be expected to elicit similar activation in the same brain structure, but this is not always the case (Epstein & Kanwisher, 1998).

A third account of category representation in the brain, the process-map model (Gauthier, 2000), takes an entirely different approach. In this model, neither categories nor features *per se* are represented, but instead brain structures are seen as computationally specialized for category-related processing. We look at this approach next.

9.2.3 Process-Specific Representation

Gauthier (2000) argues that brain response to category information is based not on category *content*, but rather on category *process*. In her words (2000: 1–2), “extrastriate cortex contains areas that are best suited for different computations.” Category exemplars elicit brain activation based on how the information is to be used (e.g., level of categorization) as well as on prior experience. Consequently, the process-map reflects experience and processing goals.

In a direct challenge to the category-specific approach, Gauthier (2000) argues that brain response to faces may seem to differ from that for objects, because faces are processed at a more specific level of categorization than are most objects. Moreover, she argues, within-category discrimination may be more relevant for faces than for other objects, leading to a greater expertise in selecting critical features.

To examine the effect of expertise on FFA, Gauthier et al. (1999) trained study subjects in a category comprising of artificially generated exemplars, which she called “greebles.” She used fMRI to scan subjects first before they had any experience with the greebles, then at three different times during the learning phase, and finally, twice after they reached a learning criterion. Gauthier then examined the region of interest (ROI) previously associated with face processing, the middle and anterior fusiform gyri. She found the expected response in the presence of faces. She also found, however, changes in brain response as the study participants’ experience with greebles increased. Gauthier concludes that the fusiform gyrus, rather than being a category-specific structure of the brain associated with faces, is the site of fine-level category discrimination that changes as a function of experience.

Evidence for the fusiform gyrus being activated during fine-level category discrimination was also found by Tyler et al. (2004).

9.2.4 Summary

The studies of category representation that we have reviewed in this section provide three potential accounts of how category knowledge is represented in the brain. Although they are very different, they are not mutually exclusive. It is certainly feasible that areas of the brain might respond differentially to different objects, even if category knowledge is represented by a distributed feature topology (Martin & Chao, 2001). Moreover, any model of category representation must account for learning and within-category discrimination, and it is quite possible that the distributed feature topology underlying category representation varies as a function of the processing demands needed for a given task (Tyler et al., 2004). There is also the possibility that category representations may differ across the two brain hemispheres, with the left hemisphere representation being more category-specific and the right hemisphere representation being more similar to a feature topology (Deacon et al., 2004).

While a definitive account of category representation remains to be determined, the direction that research needs to take about the neural substrate of category representation is becoming clearer. In the next section we look at studies that focus on how categories are learned. The questions are different but the goal of understanding the role of the brain in category knowledge is similar.

9.3 ACQUIRING CATEGORY KNOWLEDGE

Objects and entities may be grouped together, i.e., form a category, for many reasons. A category such as *red objects* is a relatively simple category whose members include red things. The red things may be small or large, animate or inanimate, soft or hard, noisy or quiet, etc. It is only necessary that the members share the property of redness. A different kind of category, e.g., the category *game*, cannot be easily defined by a set of necessary and sufficient features. A game may be played by one or by many, it may or may not be played outdoors, and scoring may or may not be required, etc.

Categories such as *red objects* are known as well-defined categories, because they are completely defined by necessary and sufficient features. On the other hand, categories such as *game* are known as ill-defined categories, because they are not readily defined by necessary

and/or sufficient features. Thus, learning a rule that includes the features necessary for category membership may be sufficient to correctly categorize members and nonmembers of a well-defined category. If a concept is ill-defined and does not have necessary and sufficient features, however, the basis of its representation is not as clear cut.

Categories that cannot be learned on the basis of a rule may be learned through similarity judgments between the to-be-categorized object and exemplars that have already been identified. This can be accomplished in two ways. First, a similarity judgment can be made by comparing one or more exemplars with the to-be-categorized object. Second, a similarity judgment can be made by comparing some central tendency or prototype generated from experience with exemplars to the to-be-categorized object.

Earlier, we examined how category information might be represented in the brain. In this section, we look at how the brain responds when categories are being learned. Concept learning involves learning what it is that binds exemplars of a category together. Our consideration of brain response during concept learning will focus on a traditional distinction made by cognitive psychologists between explicit, analytic processing and implicit, nonanalytic processing.

Explicit, analytic processing is associated with learning based on rules that specify the necessary and sufficient features required for category membership (Bruner, Goodnow, & Austin, 1956). Analytic processing occurs most often with well-defined stimuli, in which category membership depends on specific features shared by all members of the category. Exemplars of categories that are rule-based do not differ in the degree to which they are typical of a category inasmuch as they differ in the degree to which all members must share the necessary features.

Implicit, nonanalytic processing involves similarity-based comparisons between the to-be-categorized object and a representation of the candidate category. The representation that is used in the similarity judgment may be either known members of the candidate category or a derived prototype of the category. Similarity judgments based on exemplars rely on the similarity between a to-be-categorized object and the exemplars of a candidate category. Thus, one may learn about dogs by noting the similarity between a newly encountered dog and a particular dog such as the poodle next door, or the family basset hound.

Alternatively, similarity judgments during category learning may rely on a prototype. A prototype is generated through experience with individual exemplars, yet is different from any given exemplar. The generation of a prototype occurs without conscious effort and often, is not easily described in words. Category structure based on a prototype is most similar to family resemblance (FR) (Rosch & Mervis, 1975), in which some members are more typical than others.

Do analytic and nonanalytic processing reflect different neural structures? Work with individuals with brain damage has provided some indication that different neural structures underlie different types of category processing. Damage to the MTL structures that include hippocampus and amygdala is associated with anterograde amnesia, a dysfunction characterized by the inability to explicitly access newly acquired information. Individuals with anterograde amnesia are capable of learning new information, but lack the ability to consciously or explicitly access it. Consequently, medial temporal (MT) brain structures have been associated with declarative memory processes, those responsible for processing factual, explicitly available information.

In contrast to declarative knowledge, procedural knowledge such as that involved in skill learning does not require explicit or conscious retrieval. Although patients with anteretrograde amnesia cannot access information for tasks that require explicit processing, they can learn new sensorimotor skills such as mirror tracing (Milner, 1962) or rotary pursuit (Corkin, 1968). Patients who are most impaired in sensorimotor skill learning are those with diseases that affect basal ganglia, especially Huntington's disease (HD) and Parkinson's disease (PD).

This difference between analytic and nonanalytic processing is also found when brain-impaired individuals engage in probabilistic classification tasks. Patients with amnesia tend to show normal learning during the early but not later learning stages of classification problems (Knowlton, Squire, & Gluck, 1994). However, HD and PD patients tend to be impaired throughout this learning process (Knowlton, Mangels, & Squire (1996). Thus, it appears that MTL and basal ganglia support different aspects of processing during probabilistic classification.

Further support of the localization of two kinds of category processing was obtained by Myers et al. (2003). In this study, patients with MT amnesia and patients with PD were first exposed to pairings in which two stimuli A1 and A2 were both associated with a third stimulus X1. They were then shown pairings of A1 with a new stimulus X2. Myers et al. aimed to determine whether or not presentation of the stimulus A2 would lead the study participants to pair that stimulus with X2, thereby demonstrating that they had equated A1 and A2. The investigators predicted that they would observe a double dissociation in learning performance between study participants suffering from hippocampal atrophy and those suffering from PD. This was confirmed. They conclude that basal ganglia are responsible for simple associative learning early on and the hippocampus is responsible for the ability to transfer knowledge to new exemplars. The finding that patients with amnesia have difficulty with more complex associations is consistent with the results of an earlier study by Kolodny (1994) who found that individuals with amnesia were able to learn simple, perceptually based

categories, but had difficulty with more complex stimuli. Neuroimaging studies with healthy individuals support this distinction between the structures that underlie analytic and nonanalytic processes during a categorization task. [Smith, Patalano, and Jonides \(1998\)](#) scanned experimental participants with PET while they performed either an exemplar- or a rule-based categorization task. They found frontal activation of the dorsolateral prefrontal cortex and areas of the frontal cortex to be uniquely associated with the rule-based task while the exemplar-based task uniquely activated the left visual cortex (Brodmann area 18) and the left cerebellum.

Support for distinct brain structures underlying analytic and nonanalytic processing has also been found in fMRI studies. [Poldrack et al. \(2001\)](#) found activation of MTL to be negatively correlated with activity in basal ganglia during a category learning task. They argue that MTL may be most involved whenever flexible accessibility to knowledge is needed, whereas striatum (a subset of basal ganglia that includes the caudate, the putamen, and the nucleus accumbens) supports fast, automatic responses. Drawing on both animal and human research, [Poldrack and Packard \(2003\)](#) conclude that MTL and basal ganglia function as independent memory systems that are capable of interacting with one another.

[Lieberman, Chang, Chiao, Bookheimer, and Knowlton \(2004\)](#) also found a dissociation between MTL and caudate in an fMRI study of artificial grammar learning. In the Lieberman et al. study, MTL was associated with “chunk strength,” a measure of the similarity between test and training items, and the caudate was associated with “rule adherence,” or grammaticality. By manipulating both the chunk strength and rule adherence of items independently, Lieberman et al. were able to assess the contribution of the MTL and the caudate to learning, and to determine the interaction between nonanalytic (chunk strength) and analytic (rule adherence) processes. They found that the MTL and the caudate were negatively correlated, as was reported in the [Poldrack et al. \(2001\)](#) study.

Similar dissociations using the artificial grammar learning paradigm have been found between the MTL and the prefrontal cortex (PFC) in healthy adults ([Opitz & Friederici, 2003, 2004](#)) as well as in patient populations ([Ullman et al., 1997](#)). Taken together, these studies suggest that grammar learning progresses from similarity-based processing in the MTL to more complex processing in the PFC.

A direct investigation of analytic and nonanalytic processes and the associated neural structures involved was performed by [Tracy et al. \(2003\)](#). They instructed participants to classify pseudowords on the basis of a criterion attribute (CA) or on the basis of FR. CA processing was found to be associated with the right anterior temporal and the

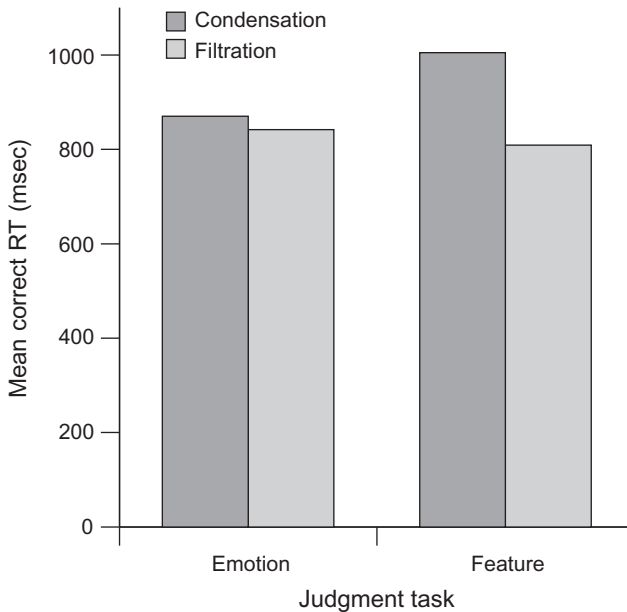


FIGURE 9.4 Left-hand barplot shows the correct reaction time (RT) from overall subjects. Note modulation of condensation by priming condition.

inferior frontal regions of the brain, whereas FR processing activated the medial cerebellar and the left extrastriate areas.

In our laboratory, we found that study participants who are biased toward a configural orientation (making a judgement about expressed emotion) will perform differently on integral (condensation) and separable (filtration) categorization tasks than will those who are biased toward a featural orientation (making a judgement about facial features) (Hanson, Hanson, & Schweighardt, 2004). Specifically, we found that feature level processing significantly impeded a subsequent categorization task based on integral features but not one based on separable features (see Fig. 9.4).

We imaged experimental participants with fMRI as they performed the category task and found parahippocampal gyrus and posterior cingulate to be active during categorization when the task was inconsistent with the initial orientation (see Fig. 9.5).

9.3.1 Summary

The evidence from both patient studies and neuroimaging studies of healthy individuals suggest that analytic and nonanalytic category

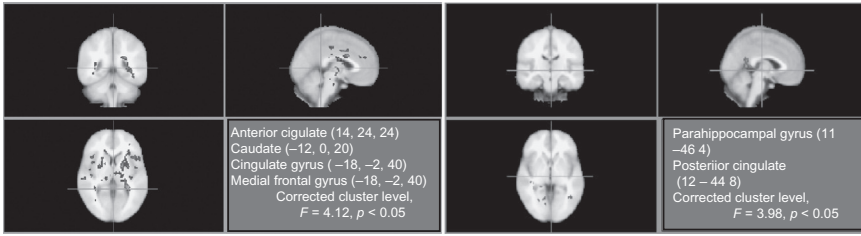


FIGURE 9.5 Main effects of BOLD (left) showing significant activation in caudate, anterior cingulate, medial frontal gyrus, and anterior cingulate over 40 subjects during three blocks of categorization decisions in the condensation task. Interaction effect (right) between priming and task over 40 subjects during three blocks of categorization decision in both condensation and filtration task. Significant BOLD activation is shown in both posterior cingulate and parahippocampal gyrus.

learning engage different neural structures. Similarity-based categorization is very likely accomplished in the MTL, whereas rule-based categorization apparently engages the basal ganglia. Complex rule learning, such as that involved in learning artificial grammars, may also involve the PFC.

The PFC may also play a major role in the categorization of action units or events. Although much of the cognitive neuroscience work on categorization has focused on object categorization, interest in how the brain parses action streams into discrete and meaningful units is increasing. We next look at some of the research in this field.

9.4 CATEGORIZING ACTIONS AND EVENTS

Our discussion of categories thus far has focused on object categories. Yet, a very important type of category knowledge concerns the way individuals categorize the dynamic information associated with actions and activities. We recognize someone *driving a car*, we arrange to *have lunch with a friend*, and we relate our hopes about *moving to a new house*. Whereas object categories lend themselves to representations based on perceptual or functional qualities, the perceptual attributes associated with events such as *making a phone call* are not as well-defined. The person making the call, the type of telephone being used, the time of the day, the location, the duration of the call, and the target of the call are not constrained in the same way that the attributes of *apple* or *table* are.

9.4.1 The Nature of Event Knowledge

When people remember *vacationing in Provence* and tell each other about *what happened at work*, they are imposing a categorical structure

on what is essentially unstructured, continuous activity. Without the shorthand afforded by event categories, it would be an impossibly tedious task to recount the actions involved in a single morning; the time needed to recount performed actions would approach the duration of the actions themselves. Even the seemingly endless recounting of some favorite memory by a too verbose friend does not approach the duration of the actual experience of the events.

It is this element of time that distinguishes event categories from object categories. Whereas objects occupy space, events occupy time. Recognition of objects is immediate under most circumstances, but recognition of events must evolve in time. Perhaps most tellingly, temporal order can change the meaning of events, whereas spatial order rarely affects the meaning of objects.

Despite these differences, event categories share many basic features of category representation with object categories. Like many object categories, event categories have a typicality structure. *Reading a menu* is a fairly typical exemplar of the class of actions involved in going to a restaurant, whereas a waiter *singing to the customers* is not. It is this typicality structure that allows the listener to infer the events *being seated*, *reading a menu*, *ordering food*, *paying a bill* when the speaker relates that *she went out to dinner*.

Similarly, event categories, like object categories, have a partonomical structure (Miller & Johnson-Laird, 1976; Tversky, 1990; Tversky & Hemenway, 1984; Zacks & Tversky, 2001). That is to say, an event is composed of other events. In much the same way that a table is made up of a surface and legs, the event *setting the table* involves *carrying* plates and utensils to the table and *arranging* them appropriately. *Setting the table* itself may belong to other events such as *throwing a party* or *feeding the family*. Objects, unlike events, also have a taxonomic structure, so that category members inherit the properties of the superordinate category. Partonomies do not propagate the properties of a superordinate to subordinate levels. Although *buying a ticket* is part of *going to the theater*, the features of *going to the theater* are not propagated to *buying a ticket* in the way that the features of an animal (such as breathing and eating) are propagated to members of the animal category. If a mouse is an animal, it breathes and eats. In contrast, how one *attends a theater performance* reveals little about how one *buys a ticket*.

Although there are many different ways to buy a ticket (at the theater, through the mail, from the Internet), the event itself, *buying a ticket*, is a highly probable component of *attending the theater*. Thus, expectations about event categories are primarily functional, rather than perceptual. If you are asked to retrieve an apple from the kitchen, you have certain expectations about the size, color, and shape associated with the apple category that allow you to choose an apple when you see it rather than selecting an orange or banana. Expectations about

events are not bound by the same kind of perceptual constraint. So, how do we categorize dynamic action sequences into distinct events?

We have argued elsewhere (Hanson & Hanson, 1996) that the perception of events is a cyclical process in which memory focuses attention, attention selects information from the environment, and attended information influences the activation of memory. Using a recurrent neural network to simulate human event judgments, we were able to demonstrate that this kind of perceptual cycle (Neisser, 1976) is a viable account of how people categorize events. Moreover, the expectations (memories) that guide attention include a temporal element. In other words, the duration of an event is one of its critical features and is used to segment action streams into individual events.

9.4.2 When Categorization of Action Fails

Although we take for granted our ability to interpret and produce mundane events such as *making coffee* or *mailing a letter*, failure to comprehend or perform simple action sequences can have a debilitating effect on daily life. The inability to imitate or perform an action sequence on demand, despite intact sensory and motor ability, is labeled apraxia. A broad distinction can be made between conceptual (or ideational) apraxia and production (or ideomotor) apraxia (Liepmann, 1920). That is, the source of impairment may rest in the action representation (conceptual) or in the execution of action (production).

Evidence for different neural circuits underlying conceptual and production apraxia is limited, although some indication of distinct systems has been obtained. For example, Rapcsak, Ochipa, Anderson, and Poizner (1995) studied a patient with a progressive bilateral limb apraxia who complained of severe spatiotemporal problems related to skilled limb movement that were confirmed by clinical assessment and a three-dimensional computerized graphic analysis of her movements. Despite severe impairment in the ability to produce action, the patient's conceptual knowledge of action seemed relatively intact. Neuroimaging by MRI revealed atrophy of the posterior-superior parietal lobes, with relatively normal frontal, temporal, and occipital areas. Scanning with SPECT found extensive posterior cortical dysfunction involving the temporoparietal area, which on the left side extended into the inferior parietal lobule. Conceptual apraxia often accompanies damage to the left posterior parietal and/or the premotor cortex.

In a review of lesion studies and neuroimaging work, Johnson-Frey (2004) concludes that the different types of impairment seen in conceptual and performance apraxia stem from functionally specialized neural systems underlying semantic knowledge and procedural knowledge.

Specifically, he provides an account involving distributed neural systems in the left temporal, parietal, and frontal areas. Based on a variety of studies, he suggests that parietal areas are involved primarily with action performance, temporal areas with action knowledge, and frontal areas with both production and representation of action.

Much of the work on apraxia focuses on a subcategory of action knowledge concerned with skilled performance and tool use. Tool use, however, is only one aspect of how people use action categories. People continually parse a stream of activity into meaningful units. The ability to parse action sequences into meaningful units underlies our ability to make sense of the world and to communicate with others.

Patients with schizophrenia are another population who demonstrate difficulty with action categorization. A primary symptom of schizophrenia is the incorrect attribution of self-generated action to external sources. This misattribution often leads to delusions in which the individual believes others are controlling his or her thoughts and/or actions. There is some evidence that this dysfunction is related to the inability of schizophrenic individuals to differentiate intention from recognition of action (Daprati et al., 1997) or to represent predicted consequences of action (Frith, Blakemore, & Wolpert, 2000). The latter authors suggest that a disconnection between frontal brain areas that initiate action and parietal areas that represent body state is responsible for the misattribution of self-generated action. They note that in healthy individuals, brain activity in the frontal areas is inversely proportional to that in the posterior areas, but in schizophrenic individuals activity in the frontal and posterior areas are independent. Frith et al. suggest that this disconnection between the anterior and posterior cortex indicates that the response to self-generated actions are not suppressed in schizophrenic individuals, unlike in healthy individuals.

Schizophrenic patients also demonstrate difficulty in retrieving action knowledge (Zalla, Posada, Franck, Georgieff, & Sirigu, 2001) and parsing action streams (Lyons, 1956; Zalla, Verlut, Franck, Puzenat, & Sirigu, 2004). Zalla et al. (2001) found that schizophrenic patients, even more than patients with frontal lobe afflictions, had trouble sequencing actions and prioritizing actions related to a goal. Zalla et al. (2004) asked schizophrenic patients and healthy controls to parse action sequences into small and large units. Compared to the control subjects, the schizophrenic subjects had difficulty detecting large action units; this difficulty was positively correlated with higher levels of disorganization in these subjects. Zalla et al. also found that schizophrenic patients remembered the action information differently than did healthy subjects. Schizophrenic patients were more likely to recall actions without regard to temporal order, to personalize the characters in videos, and to confabulate.

Unlike schizophrenic individuals, healthy individuals rarely have difficulty distinguishing between self-generated and other-generated action. This is particularly notable given the growing evidence that similar neural systems underlie observation, mental simulation, and imitation of actions (see the review by [Decety & Chaminade, 2003](#)). The PFC, anterior cingulate, premotor cortex, inferior parietal lobule, ventrolateral thalamus, and caudate appear to be involved in the representation of self-generated action as well as action performed by others. Distinguishing self-generated action from that generated by an external agent appears to be accomplished in the inferior parietal cortex and the right PFC ([Decety & Chaminade, 2003](#)).

9.4.3 The Perception of Events

Healthy individuals effortlessly parse action streams into discrete units (events) and moreover, demonstrate a high degree of consensus in judgments of event boundaries ([Hanson & Hirst, 1989](#); [Newton, Engquist, & Bois, 1977](#)). We use events to understand, remember, and communicate what would otherwise be an overwhelming and chaotic deluge of stimulation. Although considerable effort has been spent studying how object categories are represented and learned, much less attention has been allocated to understanding how the brain makes sense of the what William James calls the “blooming, buzzing confusion” that is everyday experience.

How does the brain categorize information that extends both in time and space? This was the question posed by [Zacks et al. \(2001\)](#), who used fMRI to scan the brains of healthy subjects while they watched short videos of common activities such as *making the bed* and *doing the dishes*. Looking at brain activity during event transitions, they found activation in the bilateral posterior cortex and the right frontal cortex, with prominent activity located in the occipital/temporal junction, at the middle temporal/ventral 5 (MT/V5 complex) also known as the extrastriate motion complex. The MT/V5 area is associated with processing biological motion and human action, and the right frontal area is associated with active shifts of attention and eye movements.

A subsequent study of event perception by [Speer, Swallow, and Zacks \(2003\)](#) used fMRI in an ROI analysis of the MT/V5 complex and the frontal eye field (FEF). These areas were chosen because the MT/V5 is known to respond to visual motion and the FEF is known to orient eyes to a visual stimulus through guided saccadic and smooth pursuit eye movements. Speer et al. reasoned that if motion changes contribute to the perception of event boundaries, then activity in these areas should correlate with judgments about event transition points. They

conclude that event perception is related to the detection of visual changes, but leave open the question of whether MT/V5 and FEF are driven directly by bottom-up (stimulus-based) activation or modulated by top-down (knowledge-based) processes.

Some evidence for top-down processing during event perception (Sitnikova, Kuperberg, & Holcomb, 2003) has been found using ERP. Sitnikova et al. had subjects watch short videos of common events such as *shaving* or *cooking*. The key manipulation was whether an appropriate or inappropriate object was used in the sequence (e.g., whether a razor or a rolling pin was used in the shaving sequence). They found that a strong negative ERP (N400) accompanied the appearance of the critical object, and they interpret this result as indicating that a strong temporal relation exists between object identification and scene comprehension during event perception.

Indirect evidence for top-down processing during event perception has also been found in recent work by Wood, Romero, Makale, and Grafman (2003). They used fMRI to look at brain activity in healthy subjects as they categorized words and phrases associated with social and nonsocial structured event complexes (SECs). SECs are familiar event sequences that others have labeled as “scripts” or “schemas.” The fMRI data revealed differences in activation patterns between social and non-social conditions in the PFC, which Wood et al. interpreted as evidence for category-specific representations in the PFC.

In a recent study in our laboratory (Hanson & Hanson, 2005), we manipulated bottom-up and top-down factors directly during an event perception task. We scanned the brains of study subjects with fMRI while they watched either highly familiar, common events such as *drinking coffee*, or a novel cartoon depicting a geometric shape moving around other geometric shapes. Fig. 9.6 shows the temporal

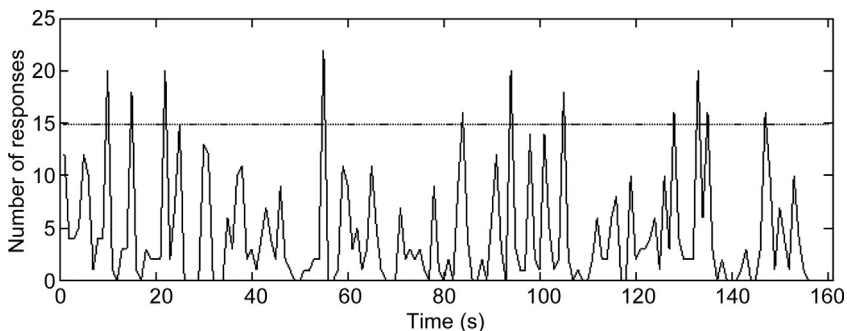


FIGURE 9.6 Temporal response density (TRD) for subjects watching a video of a student studying. The points above the threshold (15 responses) represent significant agreement across subjects.

response density (TRD) for the real-world familiar event; the 99% confidence limit is shown by a frequency response near 15. At this threshold most subjects identified 11 independent event change points in the video sequence.

Using these TRD event points we constructed a contrast between event change points and nonevent change points. Fig. 9.7 shows the analysis of an fMRI scan of the brain of a subject parsing a real-world familiar sequence. Typical areas of activity that are found include the

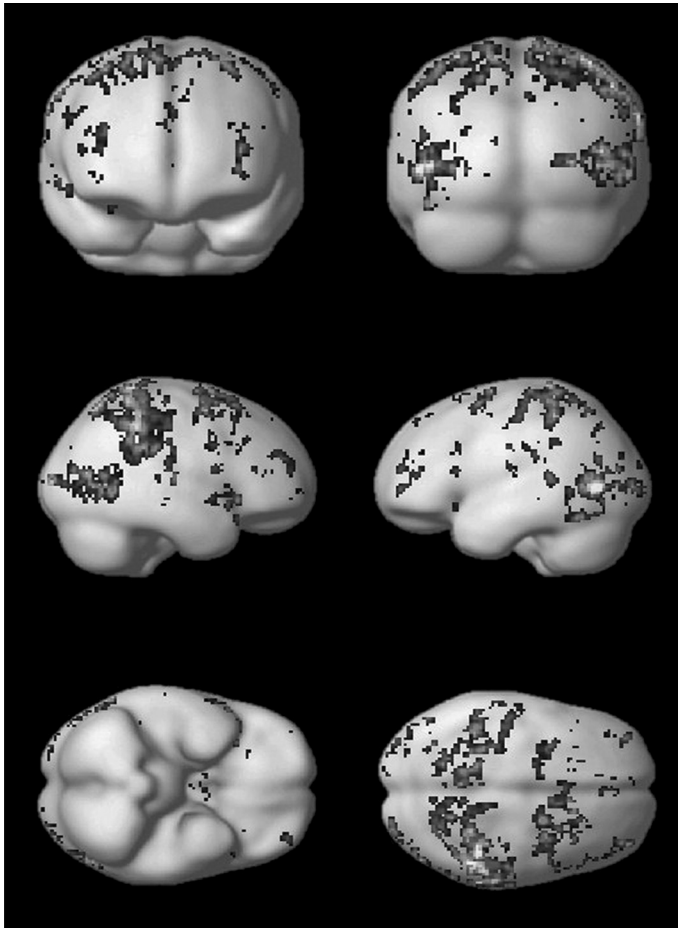


FIGURE 9.7 Contrast between event change points determined by significant temporal response density (TRD) points and nonevent points. Typical areas that appear engaged are the anterior cingulate, the inferior frontal gyri, the middle frontal gyri, the precuneus, the parietal lobule, and the dorsal lateral prefrontal cortex. These are voxel activities that are used for further clustering and graph analysis.

bilateral prefrontal areas, the anterior cingulate, and other related attentional areas.

We cluster the areas using a mode-density clustering algorithm that tends toward sparse cluster structure and determines $\langle x, y, z \rangle$ centroid voxels for each ROI. These centroids are then used to calculate covariance between ROIs to determine their interactivity by finding the best-fitting graph using LISEREL. Fig. 9.8A–C are best-fit graphs for performing a visual oddball task (detection task with tonic background), parsing a simple geometric stimulus, and parsing a real-world familiar task, respectively. Note that the oddball task contains some constituent ROIs (the inferior frontal and the middle frontal gyri) that also appear in the event–parsing tasks. This might suggest that various areas are recruited as constituents in a larger computational network.

9.4.4 Summary

Studies of event perception, such as those we have reviewed here, provide a unique opportunity to observe the dynamic interaction of brain areas during the performance of a real-world cognitive task. Parsing action streams into discrete, meaningful units involves the recognition of not only object boundaries, but also action boundaries. Because events take place in time, sequence information is important. Studies of patients with apraxia and patients with schizophrenia suggest that the frontal lobe plays an important role in processing sequence information. In addition, the neuroimaging studies implicate both MT/V5 and prefrontal areas as being involved in event perception.

9.5 CONCLUSION

Categorization is a fundamental cognitive skill. Due to the use of cognitive neuroscience methods, our understanding about both the representation and processing of category information has been greatly advanced. It is clear that category learning and representation requires interaction between a number of brain areas that are constitute processes of other complex cognitive functions like language, executive function, and attention. Future understanding of basic cognitive processes will probably engage both object and event representations to determine the nature of fundamental brain processes underlying these common complex categorization functions.

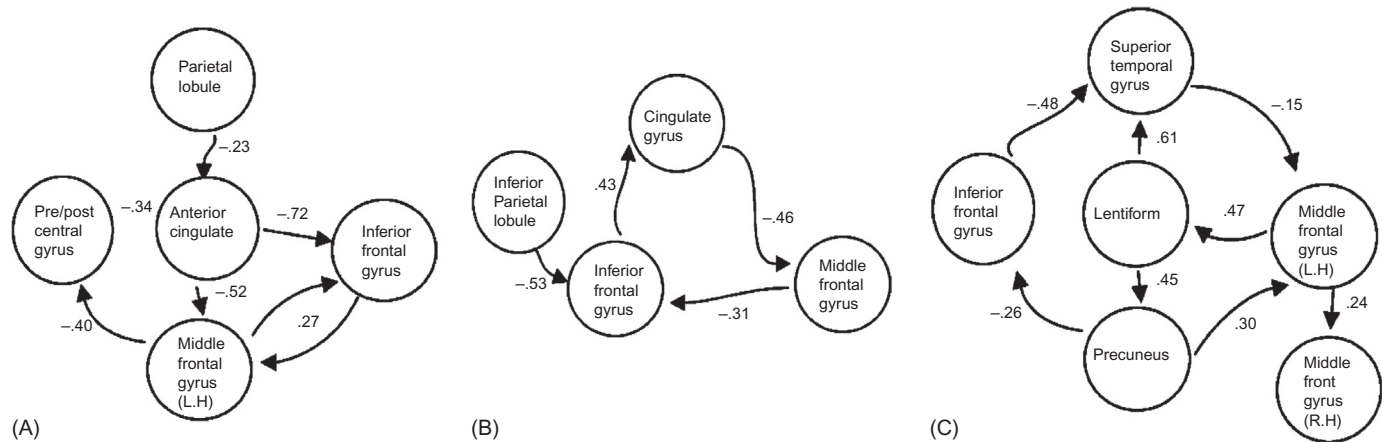


FIGURE 9.8 (A). Graphical fit to covariance ROIs for subjects doing visual oddball detection task. (B). Graphical fit to covariance ROIs for subjects parsing a simple geometric stimulus video. (C). Graphical fit to covariance for subjects parsing a real-world familiar video.

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