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Are coordinate representations and structural descriptions mediated in neurologically dissociable visual recognition systems?

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Are coordinate representations and structural descriptions mediated in
neurologically dissociable visual recognition systems?

by

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A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

Co-Majors: Neuroscience; Psychology

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CHAPTER 1. INTRODUCTION

One of the primary goals of scientific research is to 'carve nature at its joints', and this is especially true in brain and cognitive science (Kanwisher, 2000). A fundamental principle of modern brain research is the fact that different regions of the brain are specialized for different functions (Kandel, Schwartz, & Jessell, 2000). However, the principles that underlie the 'carving' of the functional organization of the brain have remained stubbornly resistant to elucidation. As Kanwisher pointed out, proponents of one position regarding the functional organization of the brain posit that subregions of the brain are domain-specific. According to the domain-specific view, functional subregions of the brain are divided according to the *content* of the information being processed. The domain-specific view, for example, posits that distinct subregions of the brain underlie face recognition and speech recognition purely because faces are different types of entities than speech sounds, and that one region has evolved to process information regarding faces and another region has evolved to process speech.

Proponents of the other position have argued that the functional organization of the brain is domain-general. According to this position, the brain is organized according to the types of processes it carries out. That is, the nature of the content (e.g., faces vs. speech) that a specific brain region typically deals with is relevant only to the extent that different contents pose different computational problems. According to the domain-general account,

for example, face and speech recognition rely on distinct subregions of the brain purely because the information processing requirements for recognizing faces are different from those required for recognizing speech.

Understanding the functional organization of the brain regions within the extrastriate visual cortex that underlie visual recognition has become a microcosm of the problem of understanding the functional organization of the brain (Kanwisher, 2000). The reason that visual recognition serves as such a microcosm is because many lines of evidence suggest that there are dissociable neural subsystems¹ within the ventral visual pathway that use different methods for representing shape and that mediate different types of recognition tasks. The evidence (which will be discussed in the next chapter) initially seemed to suggest that one neural subsystem subserves visual face recognition and that the other neural subsystem subserves the recognition of non-face objects (e.g., Hay & Young, 1982; Yin, 1970).

Once it was discovered that dissociable neural subsystems underlie face recognition and other forms of visual object recognition, researchers turned to the question of whether the neural subsystem that subserves face recognition is domain-specific or domain-general. That is, do the neural substrates and representational processes that underlie face recognition

¹ There are three commonsensical criteria that must be satisfied for neural subsystems to be considered dissociable (Farah, 1995). First, the systems must be functionally independent, such that either can operate without the other. Second, they must be physically distinct (i.e., they must rely on different neural substrates. Third, they must process information in different ways, so that they are not merely physical duplicates of one another.

operate only on faces, or are they also recruited for some non-face recognition tasks? Furthermore, if the neural substrates that underlie face recognition are not specialized for face recognition per se, then what are the functions of each of the neural subsystems? Although a large amount of research has addressed these questions, a consensus regarding the answers to them has not been reached.

The purpose of this paper is twofold. The first purpose is to propose a theoretical framework for understanding the types of representations and recognition tasks that are mediated by the dissociable neural subsystems that underlie visual recognition. This framework will suggest a domain-general account for the types of visual recognition tasks that are mediated using these subsystems. I will argue that these subsystems are not, as some researchers have suggested (e.g., Cappa, Frugoni, Pasquali, Perani, & Zorat, 1998; Caramazza & Shelton, 1998; Chao, Martin, & Haxby, 1999b; Perani, Cappa, Bettinardi, & Bressi, 1995; Perani et al., 1999; Silveri et al., 1997), dedicated to representing and recognizing certain categories of stimuli, nor are these subsystems differentially recruited for different levels of visual categorization (e.g., Burgund & Marsolek, 1997; Burgund & Marsolek, 2000; Damasio, Damasio, & Van Hoesen, 1982; Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997; Gauthier, Behrmann, & Tarr, 1999a; Gauthier et al., 2000b; Gauthier et al., 2000c; Marsolek, 1999; Marsolek, Kosslyn, & Squire, 1992; Marsolek, Schacter, & Nicholas, 1996). Furthermore, I will argue that the level of perceptual expertise

that viewers have with a given recognition task is not the critical factor in determining which neural subsystem is recruited to perform a visual recognition task, as has been suggested by some researchers (e.g., Bruyer & Crispeels, 1992; Diamond & Carey, 1986; Gauthier & Nelson, 2001; Gauthier, Skudlarski, Gore, & Anderson, 2000a; Gauthier & Tarr, 1997; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999b; Gauthier, Williams, Tarr, & Tanaka, 1998; Tarr & Gauthier, 2000). Instead, I will argue that these neural subsystems simply mediate different types of shape-representations, and that the critical factor that determines which subsystem is used to perform a recognition task is whether the representational problems posed by the visual recognition task are better solved by one system or the other. The second purpose of this paper is to report a series of experiments designed to test this and other theoretical accounts for the functional organization of the two neural subsystems.

CHAPTER 2. EVIDENCE FOR THE EXISTENCE OF DISSOCIABLE NEURAL SUBSYSTEMS FOR FACE AND NON-FACE OBJECT RECOGNITION

As noted in the previous chapter, the evidence initially seemed to suggest that one neural subsystem had evolved for the sole purpose of recognizing faces whereas the other neural subsystem mediated non-face object recognition tasks. What led researchers to this conclusion? The strongest evidence for this conclusion came from brain-injured patients, neuroimaging studies, and visual half-field studies of cerebral lateralization, all of which suggested that the brain regions that underlie face recognition are different from the brain regions that underlie non-face object recognition. For example, some brain-injured patients, known as prosopagnosics, are impaired at recognizing faces but show intact non-face object recognition, whereas other patients show the reverse pattern of performance with intact face recognition but impaired object recognition (for a striking example, see Moscovitch, Berhman, and Winocur (1997); see Farah, 1992, for a review). Neuroimaging studies also found brain regions that respond very selectively to faces (e.g., Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Sergent, Ohta, & MacDonald, 1992). Likewise, visual half-field studies of cerebral lateralization found that recognition performance is better when faces are presented in the left visual field and thus initially to the right cerebral hemisphere than when faces are presented in the right visual field and thus

initially to the left cerebral hemisphere² (e.g., Hillger & Koenig, 1991; Leehey, Carey, Diamond, & Cahn, 1978; Levine, Banich, & Koch-Weser, 1988; Rhodes, 1993; Davidoff, 1982 and Ellis, 1983, provide reviews). In contrast, no right hemisphere advantage is typically found during basic-level object recognition, such as recognizing a stimulus as being a chair, table, or desk (Biederman & Cooper, 1991; Bryden & Rainey, 1963; Kimura & Durnford, 1974; Levine & Banich, 1982; McKeever & Jackson, 1979; Wyke & Ettliger, 1961; Young, Bion, & Ellis, 1980).

Importantly, neuroimaging studies and neurological patient data corroborate the findings of visual half-field studies in suggesting enhanced right hemisphere involvement in face recognition. Although some neuroimaging studies (e.g., Gauthier et al., 1999b; Haxby et al., 1999) have found bilateral activation in the brain regions that respond selectively to faces, other neuroimaging studies have found that differences in activation levels between faces and objects occur primarily in the right fusiform gyrus (a region that is known as the fusiform face area) (e.g., Kanwisher et al., 1997; McCarthy et al., 1997). Rossion et al. (2000) have shown that activation in the right fusiform face area corresponds to holistic/configural representations (which are thought to underlie most forms of face recognition; see Farah, Wilson, Drain, & Tanaka, 1998). In contrast, Rossion et al. (2000)

²The neuroanatomical basis of using visual half-field studies to assess cerebral lateralization will be discussed in the Overview of the Experiments chapter.

found that activation in the left fusiform gyrus corresponds to parts-based face representations, which are thought to play a minimal role in most forms of face recognition (Farah et al., 1998). Furthermore, although prosopagnosic patients often have bilateral lesions, lesions limited to the right ventral visual system can produce prosopagnosia (Damasio, Tranel, & Damasio, 1990; De Renzi, 1986; De Renzi, Perani, Carlesimo, & Silveri, 1994; Landis, Regard, Bliedle, & Kleihues, 1988; Whiteley & Warrington, 1977). The current dominant view among neuropsychologists and cognitive neuroscientists is that the right fusiform face area is specifically involved in face recognition whereas the homologous location in the left hemisphere is involved in a more general bilateral object recognition system (Rossion et al., 2000).

CHAPTER 3. THE SUBSYSTEM THAT SUBSERVES FACE

RECOGNITION: NOT JUST FOR FACES ANYMORE

Although the evidence discussed above was initially interpreted as suggesting that faces are “special” such that a specialized recognition system had evolved solely for the purpose of recognizing faces, the evidence now suggests that faces are not as special as once thought. Specifically, many researchers currently agree that the neural subsystem that subserves face recognition is not used solely to recognize faces, but rather is also used to perform some other types of recognition tasks (but see Kanwisher, 2000; Moscovitch, Winocur, & Behrmann, 1997). The evidence that face recognition is not special comes from a number of findings that the dissociations between face recognition and basic-level object recognition are not unique to faces. For example, Diamond and Carey (1986) have demonstrated that some dog experts show an inversion effect for recognizing individual dogs that is similar in magnitude to the face inversion effect. Furthermore, in addition to deficits in face recognition, prosopagnosics frequently have problems distinguishing different animals, cars, foods, flowers, and buildings (Bornstein, 1963; Cole & Perez-Cruet, 1964; Damasio et al., 1982; Newcombe, 1979; Pallis, 1955).

Recent evidence also suggests that the neural substrates that underlie face recognition can be recruited for a number of non-face recognition tasks. Gauthier and colleagues (Gauthier et al., 2000a; Gauthier & Tarr, 2002; Gauthier et al., 1999b; see Tarr and Gauthier,

2000, for a review) have conducted a number of functional magnetic imaging (fMRI) studies that demonstrate that if viewers possess sufficient expertise with a recognition task, then the task will activate brain regions that were previously thought to become fully activated only by face recognition tasks. Furthermore, it has been found that some subordinate-level recognition tasks with non-face objects can lead to patterns of brain activation similar to those seen during face recognition (Gauthier et al., 1997; Gauthier et al., 2000b). Likewise, a number of recent visual half-field studies of cerebral lateralization have found that some specific-exemplar recognition tasks are, like face recognition, mediated more efficiently in the right cerebral hemisphere (Burgund & Marsolek, 1997, 2000; Marsolek, 1999; Marsolek et al., 1992; Marsolek et al., 1996). Therefore, it appears that none of the dissociations between face recognition and basic-level object recognition that were thought to be unique to faces have been shown to be unique to faces.³

Although the neural subsystem that subserves face recognition does not seem to have evolved purely to subserve face recognition, the evidence does suggest that there are dissociable neural subsystems within the visual cortex. One neural subsystem relies on neural substrates in the right cerebral hemisphere and subserves face recognition as well as some other types of recognition tasks, and the other subsystem relies on neural substrates that

³ However, to the best of my knowledge, no research has addressed the question of whether photographic negation impacts any non-face recognition tasks that are thought to be mediated using the face subsystem to the degree that photographic negation impacts face recognition.

are bilaterally distributed (although the system might operate slightly more efficiently in the left hemisphere) and subserves most forms of basic-level object recognition. However, there is widespread disagreement regarding the types of recognition tasks that are mediated by the dissociable neural subsystems (other than the agreement that the right hemisphere subsystem mediates face recognition). The purpose of this paper is to help settle this disagreement. It will be argued that a recent hypothesis, the *coordinate relations* hypothesis (Brooks & Cooper, 2001; Cooper & Wojan, 2000), can account for the types of recognition tasks that neuroimaging studies and neurological patient data suggest are mediated by the dissociable neural subsystems. Furthermore, the results of four experiments are reported that were designed to test coordinate relations hypothesis against the other current hypotheses regarding the types of recognition tasks that are mediated by the dissociable neural subsystems.

CHAPTER 4. THE COORDINATE RELATIONS HYPOTHESIS

According to the coordinate relations hypothesis, there is a fundamental difference between the visual recognition subsystems with respect to how they represent object shape. The coordinate relations hypothesis posits that the neural subsystem that subserves most forms of basic-level object recognition relies on a structural description representation for representing shape whereas the neural subsystem that subserves face recognition relies on a coordinate relations recognition system to represent shape. Furthermore, according to the coordinate relations hypothesis, the key factor that determines which neural subsystem mediates a given recognition task is whether the computational problems of the recognition task are better solved by a structural description or a coordinate-relations representation. That is, if the computational problems of a recognition task are better solved by a structural description representation, then the task was mediated using the neural subsystem that subserves most forms of basic-level object recognition whereas if the computational problems are better solved using a coordinate-relations representation, then the task was mediated using the neural subsystem that subserves face recognition. These two methods of representing shape will now be described.

Structural description theories (e.g., Biederman, 1987; Hummel & Biederman, 1992) posit that objects are represented for the purpose of recognition as a collection of simple volumetric primitives (i.e., geons) that correspond roughly to the parts of objects.

Furthermore, structural description theories posit that the locations of visual primitives are specified in a representation using *primitive-to-primitive, categorical relations* (hereafter referred to as categorical relations). When using categorical relations to specify the location of a visual primitive, the location of the primitive is specified relative to the locations of the other visual primitives in the representation using broad categorical descriptors such as “above”, “below”, and “side-of”. The manner in which a categorical relations system could specify the spatial locations of visual primitives can be illustrated by examining the left face in Figure 1. Suppose, solely for the purposes of illustration, that the primitives used for the recognition of the face consist of the two eyes, the nose and the mouth. Using categorical relations, the location of the left eye would be represented in the following manner: the left eye is “side-of” the right eye, “above” and “side-of” the nose, and “above” and “side of” the mouth. Further, the spatial positions of each of the other primitives (i.e., the right eye, the nose and the mouth) would similarly be specified using categorical descriptors (above, below, side of) relative to the other primitives in the representation. Note that in a categorical representation, the distances between the primitives are *not* specified, only the *directions* are specified.

In contrast to structural description theories of object recognition, coordinate relations theories of object recognition (e.g., Bulthoff, 1992; Edelman & Weinshall, 1991; Ullman, 1989) do not rely on volumetric primitives that correspond to the parts of objects, but instead

typically use simpler primitives such as edges or pixels. Furthermore, coordinate relations models of object recognition rely on *primitive-to-reference point, coordinate relations* (hereafter referred to as coordinate relations) to specify the locations of visual primitives in a representation. When using coordinate relations, the precise distance of each primitive from a fixed reference point (or set of fixed reference points) is represented. An example of how a coordinate relations system could specify the spatial locations of visual primitives is illustrated by the right face in Figure 1. A coordinate relations system might represent the spatial location of the left eye in the following manner: the eye is 4 units below and 2.5 units to the right of the reference point. Note that when using coordinate relations, the precise metric locations of visual primitives are specified.

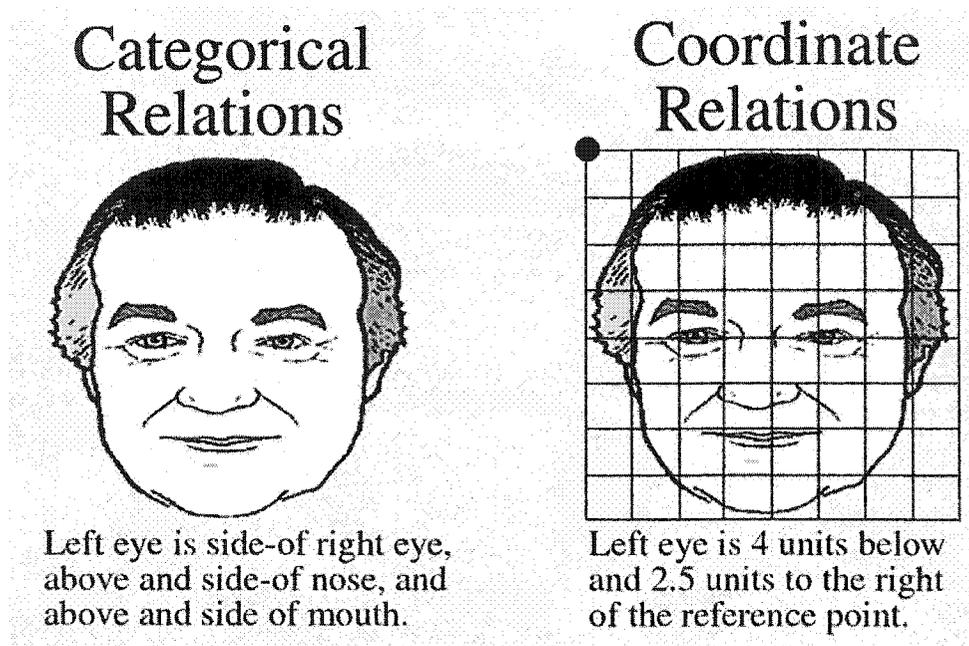


Figure 1. Illustration how the spatial position of the primitive corresponding to the eye might be coded using categorical relations (in the left face) and coordinate relations (in the right face).

Computational Advantages of Structural Description Representations

Structural description representations benefit from the fact that they can quickly place many objects with wide metric variations among their parts into the same basic-level category. For example, despite the fact that the faces in Figure 2 show wide variations in the positions, sizes, and aspect ratios of their parts, a structural description representation would generate the same representation for each of the faces (Biederman, 1987). That is, the three faces all share the same categorical relations among their parts (e.g., in all three faces, the left eye is "side of" the right eye, "above" and "side of" the nose and "above" and "side of" the mouth) so each face would activate exactly the same representation. In contrast, from the

perspective of a coordinate relations theory, all the faces in Figure 2 could activate different memory representations due to the fact that they have different metric properties. Therefore, a system that codes only categorical relations would be superior to a coordinate spatial relations system at placing all the faces in Figure 2 into the same basic-level category (i.e., "human face") quickly.

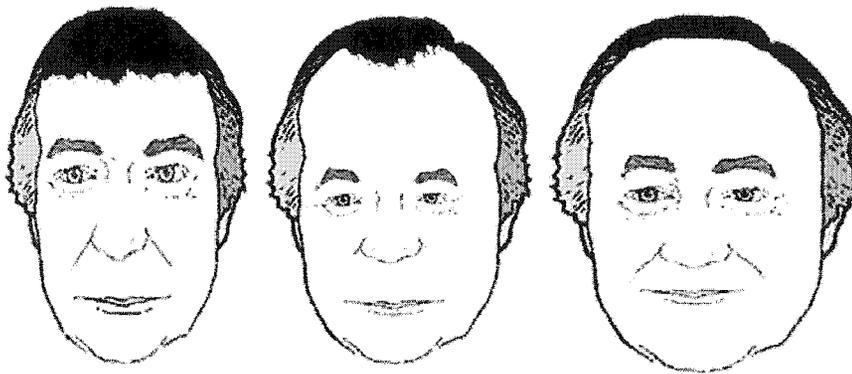


Figure 2. A recognition system using categorical spatial relations among the visual primitives would activate the same representation for all three of the faces above, despite wide variations in the size, positions, and aspect ratios of the primitives between the different faces.

Structural description representations are relatively tolerant of noise and partial occlusion of the stimulus because they do not rely on determining the precise metric properties and locations of the primitives in the visual stimulus. In contrast, because coordinate relations systems code precise metric properties of the visual input, such systems are more easily disrupted by noise and occlusion of the stimulus (Cooper & Wojan, 2000). Furthermore, structural description representations provide immediate invariance to changes

in viewpoint. For example, the left eye remains “side of” the right eye and “above and to the side of” the nose regardless of the size, position, and depth orientation (up to part occlusion) of the face. Therefore, the same representation for a face will be activated in memory regardless of the viewer's perspective on a stimulus (again, up to part occlusion). In contrast, coordinate representations specify metric information that is viewpoint dependent. The coordinates of an object's primitives will change depending on the position, distance, and orientation of the stimulus. As such, coordinate theories often posit time-consuming alignment procedures (Ullman, 1989) to normalize the size, position, and orientation of an input to some standard set of values prior to recognition. Such normalization procedures are unnecessary when using a structural description representation.

Computational Advantages of Coding Coordinate Spatial Relations

Although the preceding discussion suggests that in many circumstances a structural description representation would be computationally more efficient than a coordinate relations representation, there are certain recognition tasks at which a structural description representation would fail. As pointed out earlier, current structural description theories (Hummel & Biederman, 1992) would be unable to distinguish among the faces in Figure 2. In contrast, a coordinate representation, because it specifies metric locations of primitives, would be able to distinguish the metric differences among the faces in Figure 2 and could activate different representations for each. Thus, coordinate systems are capable of

distinguishing among stimuli, such as faces, that would activate the same structural description.

Cooper and Wojan (2000) provided empirical evidence for the existence of two recognition systems within the visual system. One of the recognition systems relies on coordinate relations to specify the locations of visual primitives and subserves face recognition, and the other recognition system relies on categorical relations (presumably using a structural description) to specify the locations of visual primitives and subserves most forms of basic-level object recognition. Cooper and Wojan (2000) hypothesized that the neural subsystem that subserves face recognition was used whenever the computational demands of a recognition task require precise metric information that is not represented in current structural description theories of object recognition but that is retained in current coordinate relations models of object recognition. Cooper and Wojan (2000) also hypothesized that the bilateral recognition system that mediates most forms of basic-level object recognition is used for any recognition task that could be performed using a structural description representation.

As an example of a recognition task that could not be performed using a structural description but that could be performed using a coordinate relations system, consider the task of distinguishing a dog (such as a collie) from a fox. Notice that the spatial relations of the eyes, nose, ears, trunk, legs, tails, and other visual primitives tend not to differ categorically

between dogs and foxes. Furthermore, notice that the shapes of the eyes, nose, ears, trunk, legs, and tails are not qualitatively different (i.e., they are not different geons) between dogs and foxes. Therefore, because dogs and foxes would activate the same representation using a structural description representation, structural description theories would have difficulty distinguishing between a dog and a fox. In contrast, a dog and a fox could be distinguished from one another using the subtle metric information that is retained in current coordinate relations theories of object recognition. Therefore, according to the coordinate relations hypothesis, because metric information is required, the neural subsystem that mediates face recognition would mediate the recognition task of distinguishing a dog from a fox.

To summarize, the coordinate relations hypothesis posits that there are two dissociable neural subsystems within the ventral visual pathway. One subsystem mediates structural description representations and subserves any recognition tasks that can be performed using a structural description and the other subsystem mediates coordinate relations representations, and mediates recognition tasks that require a coordinate relations representation.

CHAPTER 5. CURRENT ALTERNATIVES TO THE COORDINATE RELATIONS HYPOTHESIS

There are three main alternatives to the coordinate relations hypothesis that can be found in the literature. These hypotheses will now be discussed, and it will be noted how the coordinate relations hypothesis can actually account for the data that these hypotheses were designed to explain.

The category-specific neural subsystems hypothesis. One major hypothesis regarding dissociable neural subsystems for visual recognition posits that the neural subsystems are dedicated to recognizing and representing stimuli from different semantic categories. Most of the researchers supporting this hypothesis posit that one neural subsystem mediates the recognition of biological stimuli whereas the second subsystem is used to recognize non-biological stimuli (Cappa et al., 1998; Caramazza & Shelton, 1998; Chao et al., 1999b; Perani et al., 1995; Perani et al., 1999; Silveri et al., 1997).

Neuroimaging studies have shown that there are brain regions that respond selectively to biological stimuli as well as other regions that respond selectively to non-biological stimuli. For example, a recent fMRI study found that the brain regions that respond selectively to biological stimuli (animals and faces) are clustered together in the lateral fusiform gyrus whereas the brain regions that respond selectively to non-biological stimuli (houses and tools) are clustered together in the medial fusiform gyrus (Chao, Haxby, &

Martin, 1999a). Likewise, Chao, Martin, and Haxby (1999b) found that viewing faces, animals, and faceless animals lead to identical levels of activation in the fusiform gyrus and that the same fusiform regions were activated when viewing these stimuli (Chao et al., 1999b). Joseph (2001) conducted a meta-analysis on the results of neuroimaging studies of category specificity in object recognition and found that the recognition of manufactured objects activates more medial aspects of the fusiform gyrus, relative to the recognition of biological objects or to face recognition. Face recognition activates more inferior aspects of the ventral temporal cortex, relative to manufactured object recognition. Joseph's meta-analysis found that face recognition and the recognition of biological stimuli could not be dissociated from one another. These and other similar findings have led some theorists to suggest that the reason that animal recognition and face recognition both activate similar cortical regions may be due to the fact that these regions respond to some unknown set of features that animals and faces share (Chao et al., 1999a).

Cases of visual agnosia also support the hypothesis that different brain regions mediate the recognition of biological and non-biological stimuli. Some neurological patients have lost the ability to recognize biological stimuli but show intact recognition of most non-biological objects (e.g., (Hillis & Caramazza, 1991; McCarthy & Warrington, 1988; Montanes, Goldblum, & Boller, 1995; Riddoch & Humphreys, 1987; Silveri & Gainotti, 1988; Warrington & Shallice, 1984). Likewise, the most common co-occurring symptom in

prosopagnosia is a deficit in animal recognition, and it has been suggested that this deficit reflects the fact that animal and face recognition rely on similar neural substrates (Chao et al., 1999b). In contrast, other patients show the opposite pattern of dysfunction with intact recognition of biological stimuli but impaired recognition of non-biological stimuli (Hillis & Caramazza, 1991; Sacchett & Humphreys, 1992; Warrington & McCarthy, 1987; Warrington & McCarthy, 1994).

Notice that the coordinate relations hypothesis can also account for why some recognition tasks involving biological stimuli might be mediated by the system that subserves face recognition. Many animals (e.g., dogs and foxes) would tend to activate the same representation under current structural description theories of object recognition. As noted by Tarr and Bulthoff (1995), Hummel and Biederman's (1992) neural network object recognition model (which relies on categorical spatial relations), "would fail to distinguish between a cow and a horse, between a book and notepad, or between a pen and a piece of wire" (p.1507). In contrast, different animals would activate different representations under current coordinate relations models of object recognition. Therefore, the coordinate relations hypothesis predicts that many animals would be recognized using the subsystem that subserves face recognition. According to the coordinate relations hypothesis, however, it is not the fact that animals are biological stimuli per se that leads some of them to be

recognized using the face subsystem, but rather, it is the computational demands placed on the visual system when recognizing some animals.

The expert recognition hypothesis. Another influential hypothesis is that the subsystem that subserves face recognition subserves recognition tasks at which the viewer is a perceptual expert (Bruyer & Crispeels, 1992; Diamond & Carey, 1986; Gauthier & Nelson, 2001; Gauthier et al., 2000a; Gauthier & Tarr, 1997; Gauthier et al., 1999b; Gauthier et al., 1998; Tarr & Gauthier, 2000). An example of an expert recognition task is a car expert who can discriminate between a 1984 and a 1985 Corvette. Face recognition, according to this hypothesis, is simply an example of a recognition task in which virtually all viewers are perceptual experts.

One of the lines of evidence supporting the expert recognition hypothesis is that perceptual experts show a strong inversion effect for recognizing classes of objects in their area of expertise that is similar in magnitude to the face inversion effect. For example, it has been found that the costs for having dog experts recognize individual dogs that are inverted is as large as the recognition costs that adults show for recognizing inverted faces, or as stated by Diamond and Carey (1986),

No, faces are not special. The recognition of at least one other class of stimuli (dogs) is as sensitive to orientation as is recognition of faces provided that the perceivers are as expert at representing dogs as are adults at representing faces. (p. 116)

Further evidence for the expert recognition hypothesis has come from fMRI studies that have shown that perceptual expertise recruits cortical regions in the fusiform gyrus that were once thought to only be fully activated during face recognition. For example, Gauthier et al. (2000a) used fMRI to show that when car and bird experts view cars and birds, regions of the viewers' fusiform face area become activated. Furthermore, when viewers become experts at recognizing previously novel objects, regions of the viewers' fusiform face area are activated by the objects (Gauthier et al., 1999b).

Notice that many recognition tasks that require perceptual expertise could not be performed using current theories of shape recognition that rely on categorical relations. For example, all of the dogs used as stimuli in Diamond and Carey's (1986) experiments on expert recognition would activate exactly the same representation under current theories of object recognition that rely on categorical relations (e.g., Biederman, 1987). Likewise, most cars would tend to activate the same representation under current categorical relations theories of shape recognition. In contrast, coordinate theories of shape recognition would be

sensitive to the metric information that would be required to perform many expert recognition tasks. Therefore, the coordinate relations hypothesis predicts that many expert recognition tasks would be performed using the neural subsystem that mediates face recognition. However, according to the coordinate relations hypothesis, it is not expertise, per se, that leads some expert recognition tasks to be mediated by the system that subserves face recognition, but instead it is the computational demands of performing the recognition tasks.

Kanwisher (2000) has pointed out that one problem with the expert recognition hypothesis is that it cannot account for why it is that recognizing alphanumeric characters (e.g., words) do not activate face-responsive regions of the visual system. This is a problem because most viewers (as Kanwisher pointed out, especially academics!) have at least as much expertise recognizing words as they do recognizing faces. Notice that the coordinate relations hypothesis can account nicely for why expertise with visual word recognition does not lead to activation in the brain regions that respond selectively to faces. There is strong evidence suggesting that categorical (as opposed to coordinate) relations are used during visual word recognition (see Cooper & Wojan, 2000 for a discussion). Therefore, according to the coordinate relations hypothesis, words should be recognized using the neural subsystem that mediates most forms of basic-level object recognition.

The subordinate-level recognition hypothesis. Another position regarding the types of recognition tasks that are mediated by the neural subsystem that subserves face recognition is that the system mediates subordinate-level recognition tasks (e.g., Damasio et al., 1982; Gauthier et al., 1997; Gauthier et al., 1999a; Gauthier et al., 2000b; Gauthier et al., 2000c). Subordinate-level recognition tasks are tasks that require the viewer to make distinctions among different members of the same basic-level category (e.g., distinguishing different models of cars from one another). According to this hypothesis, face recognition is simply a specific example of a subordinate-level recognition task. There are a number of lines of evidence that appear to support the subordinate-level recognition hypothesis. For example, recent neuroimaging studies have shown that subordinate-level recognition tasks lead to higher levels of activation in the fusiform face area than do basic-level recognition tasks with the same stimuli (Gauthier et al., 1997). Furthermore, a recent series of visual half-field studies has shown that specific exemplar object recognition (which is a form of subordinate-level object recognition), like face recognition and unlike most forms of basic-level object recognition, operates more efficiently in the right hemisphere (Marsolek, 1999; Marsolek et al., 1992).

The subordinate-level recognition hypothesis is also consistent with the pattern of recognition deficits that are frequently observed with prosopagnosic patients. For example, Damasio (1982) pointed out that, "When face agnosics must recognize nonface entities as

unique individuals, for example, their own pets, houses or cars, their failure is generally as marked as it is for unique faces." (p.96). Damasio further noted that, "As a rule, the breakdown of recognition is most marked at the subordinate levels and spares the supraordinate levels." (p. 97).

Notice that many members of the same basic level category (e.g., most members of the basic-level category "mug") would activate the same representation in current structural description models of object recognition. However, current coordinate relations models of object recognition would be sensitive to the metric differences among members of the same basic-level category, and thus such systems could be used to distinguish among most members of the same basic-level category. Therefore, the coordinate relations hypothesis predicts that many subordinate-level recognition tasks would be mediated by the neural subsystem that subserves face recognition. However, according to the coordinate relations hypothesis, it is not the level of categorization per se that leads some subordinate-level recognition tasks to be mediated using the face subsystem, but instead, it is that many subordinate-level recognition tasks require the use of a coordinate relations recognition system.

CHAPTER 6. OVERVIEW OF THE CURRENT EXPERIMENTS

The purpose of the experiments reported in this paper was to test the coordinate relations hypothesis against the competing hypotheses regarding the types of recognition tasks that are mediated using the neurologically dissociable recognition systems. All of the experiments in this paper used cerebral lateralization as a marker to indicate which neural subsystem is used to perform a given visual task. As discussed earlier, there is a preponderance of evidence that suggests that the neural subsystem that subserves face recognition operates either exclusively or at least more efficiently in the right cerebral hemisphere. Therefore, if a recognition task is mediated by the neural subsystem that subserves face recognition, then there should be a right hemisphere advantage for performing that recognition task. In contrast, if a recognition task is mediated by the neural subsystem that mediates most forms of basic-level object recognition, then there should either be a left hemisphere advantage for the task, or there should be no hemispheric advantage for performing the task.

Recall that many species of animal cannot be distinguished using a structural description representation. Therefore, the coordinate relations hypothesis predicts that many animals would be recognized at the basic-level using the neural subsystem that subserves face recognition. Experiment 1 tested whether some animals are indeed recognized at the basic-level using the neural subsystem that subserves face recognition (as predicted by the

coordinate relations hypothesis). Notice that it would also be consistent with the category-specific neural subsystems hypothesis if animals are recognized using the neural subsystem that subserves face recognition because the category-specific hypothesis posits that biological stimuli are recognized using the same subsystem (i.e., faces and animals are both biological stimuli). However, such a finding would be inconsistent with the expert recognition and subordinate-level recognition hypotheses because basic-level animal recognition is not an example of a subordinate-level recognition task, and the subjects that will participate in the experiments are not animal experts.

Experiment 2 provided a critical test of whether it is category membership (i.e., whether stimuli are biological) or the computational demands of a recognition task (i.e., whether the recognition task can be performed using a structural description) that determines which neural subsystem mediates a recognition task. Subjects in Experiment 2 performed a physical discrimination task in which during some trials they physically discriminated objects that would activate different structural description representations and on other trials they physically discriminated objects that would activate the same structural description representation. The coordinate relations hypothesis predicts no right hemisphere advantage for the trials in which the objects can be discriminated using a structural description representation but that there should be a right hemisphere advantage for the trials in which the objects cannot be discriminated using a structural description representation. All of the

objects in Experiment 2 belonged to the same semantic category (i.e., they were all inanimate objects), and as such, any difference in cerebral lateralization for performing the two types of physical discrimination tasks cannot be attributed to semantic category membership. Furthermore, the level of categorization was the same for both types of physical discrimination tasks, and as such, any difference in cerebral lateralization for performing the two types of physical discrimination tasks cannot be attributed to levels of categorization. Likewise, there was no difference in the level of perceptual expertise that the subjects had with the two types of physical discrimination tasks, and as such, any difference in cerebral lateralization for performing the two types of physical discrimination tasks cannot be attributed to the effects of perceptual expertise. The coordinate relations hypothesis is the only current hypothesis that predicts different patterns of cerebral lateralization for the two types of physical discrimination tasks in Experiment 2.

Experiments 3 and 4 provided further tests of the coordinate relations hypothesis. Experiment 3 tested the effects of inversion on the right hemisphere neural subsystem in an attempt to provide converging evidence that the right hemisphere neural subsystem can indeed mediate the recognition of non-biological stimuli. Experiment 4 tested whether priming in the neural subsystems depends on whether a prime shares the same structural description as a primed object.

CHAPTER 7. THE NEURONATOMICAL BASIS OF VISUAL HALF-FIELD

STUDIES OF CEREBRAL LATERALIZATION

The experiments reported here tested for cerebral lateralization of visual recognition functions by employing the divided visual half-field method. Therefore, the neuroanatomical basis of using the divided visual half-field studies to test for cerebral lateralization will briefly be described before discussing the experiments.

Due to the anatomical organization of the visual system, information presented in the left visual field is projected initially to the right cerebral hemisphere whereas information presented in the right visual field is projected initially to the left cerebral hemisphere (see Figure 3). During a visual half-field study, stimuli are projected in either the left or right visual field for less than 200 milliseconds. Due to the fact that it takes the superior colliculus more than 200 milliseconds to generate an eye saccade, information projected less than 200 milliseconds in only one visual field is projected initially only to the contralateral hemisphere of the brain (Springer & Deutsch, 1998).

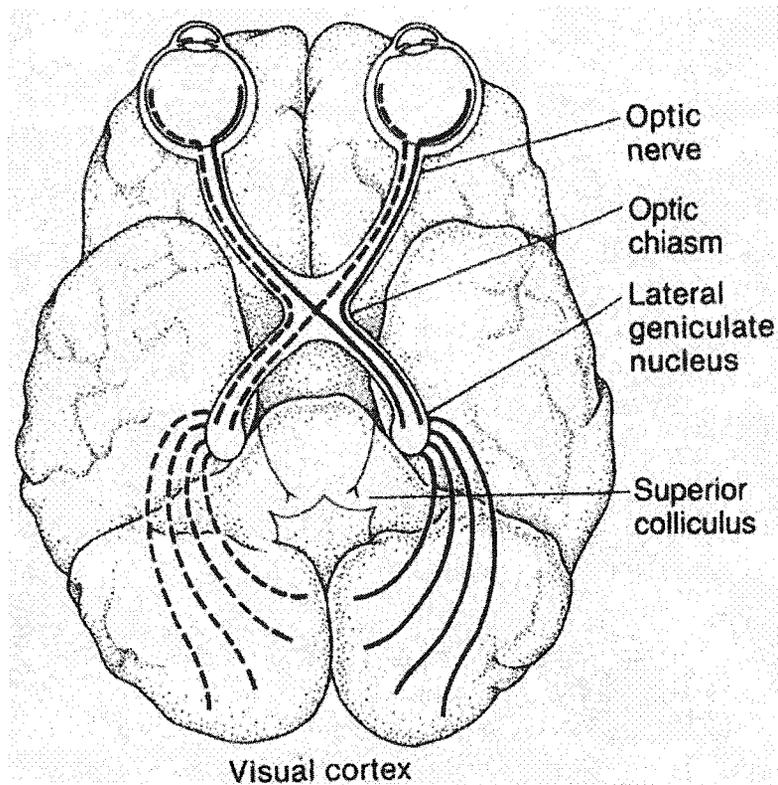


Figure 3. The human geniculo-striate visual pathway. The neural projections originating from both right hemiretinas project to the right visual cortex whereas the neural projections originating from both left hemiretinas project to the left visual cortex. Light from the left visual field falls on the right hemiretinas whereas light from the right visual field falls on the left hemiretinas. Therefore, information regarding stimuli in the left visual field is projected to the right visual cortex whereas information regarding stimuli in the right visual field is projected to the left visual cortex. Although not illustrated here, the fovea (central vision) projects bilaterally to both cerebral hemispheres. (Adapted from Springer & Deutsch, 1998)

In a visual half-field study of cerebral lateralization, the visual information projected directly to one hemisphere must be shunted across commissures (such as the corpus callosum, which is shown in Figure 4) in order to be processed by the other cerebral hemisphere. As a result, the subsystems in the cerebral hemisphere of direct presentation

receive higher quality information and receive it earlier than subsystems in the other cerebral hemisphere. Therefore, if a neural subsystem operates exclusively or more efficiently in one cerebral hemisphere (i.e., if the hemisphere is specialized for the task), then performance when using that subsystem should be higher when the information needed for the task is projected directly to that hemisphere.

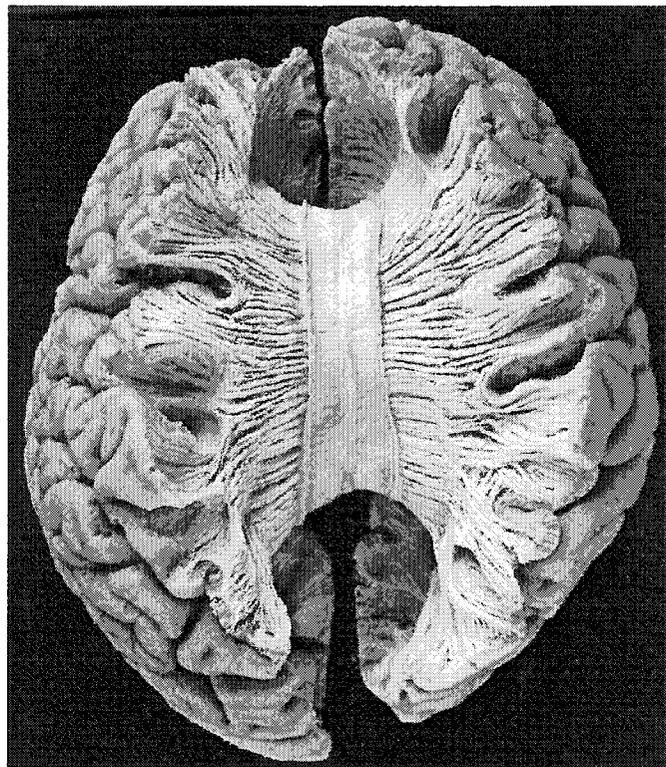


Figure 4. Ventral view of a human brain that has had the tissue ventral to the corpus callosum removed. As such, the corpus callosum is clearly visible. The fibers of the corpus callosum are the major substrates for relaying information between the cerebral hemispheres. (Adapted from Kandel et al., 2000)

CHAPTER 8. EXPERIMENT 1: CEREBRAL LATERALIZATION FOR
RECOGNIZING UPRIGHT AND INVERTED ANIMALS

Cooper and Brooks (Brooks & Cooper, under submission; Cooper & Brooks, in press) conducted a series of visual half-field studies of cerebral lateralization in which they found a right hemisphere advantage for basic-level animal recognition whereas there was no right hemisphere advantage for the basic-level recognition of non-animal objects (e.g., chairs). It was argued that the results of those experiments provide evidence that animals are recognized using a coordinate representation, probably using the same neural subsystem that mediates face recognition.

If the right hemisphere advantage that was found for animal recognition reflects the fact that the animals are recognized using the face subsystem, then this falsifies the expert recognition and the subordinate-level recognition hypotheses (which are arguably the two most popular hypotheses regarding the types of recognition tasks mediated by the face subsystem). However, it is always possible that the right hemisphere advantage that was found for animal recognition is not indicative of a coordinate representation relying on the same neural substrates as face recognition, but instead reflects some other mechanism that operates more efficiently in the right hemisphere. For example, maybe the animals showed a right hemisphere advantage because they required more attention to be recognized, and certain attentional mechanisms show a right hemisphere advantage. Or maybe surface-

texture is represented more efficiently in the right hemisphere, and animal recognition relies more on surface-texture than non-animal object recognition. The purpose of Experiment 1 was to attempt to provide converging and more definitive evidence that animals are indeed recognized using the neural subsystem that subserves face recognition.

It turns out that the neural subsystem that subserves face recognition only operates on upright stimuli (see Valentine, 1988, for a review). In fact, it is thought that face recognition is so profoundly affected by inversion because the normal neural substrates and representational strategies that are employed during face recognition only operate on upright faces, and therefore, inverted faces must be recognized using the bilateral object recognition system (de Gelder & Rouw, 2000; Farah, Tanaka, & Drain, 1995; Rossion et al., 1999). Due to the fact that the neural subsystem that subserves face recognition only operates on upright faces, inverting faces eliminates the right hemisphere advantage for face recognition (e.g., Hillger & Koenig, 1991; Leehey et al., 1978; Levine et al., 1988; Rhodes, 1993). Experiment 1 tested whether the right hemisphere advantage for animal recognition, like the right hemisphere advantage for face recognition, is eliminated when animals are inverted.

Notice that inversion only disrupts the spatial relations of visual primitives. Inversion does not disrupt surface texture, spatial frequency components, or other stimulus factors in the animals. Furthermore, inversion will presumably render animals more difficult to recognize. Therefore, if the right hemisphere advantage found in our previous experiments is

due to surface texture, task difficulty, attentional demands, or some other confounding factor between animals and non-animal objects, then there should be a right hemisphere advantage for recognizing upright and inverted animals (because any confounding factor was present in both upright and inverted animals). If, on the other hand, the right hemisphere advantage that was found in our previous experiments is indicative of the neural machinery and coordinate representational processes of face recognition, then inverting animals should eliminate the right hemisphere advantage for animal recognition, which would falsify the subordinate-level and expert recognition hypotheses.

Method

Subjects

The subjects were 128 right-handed male⁴ undergraduate students from the subject pool at Iowa State University naïve to the purpose of the experiment. Hand preference was determined by use of the Edinburgh Handedness Inventory (Oldfield, 1971) in which subjects indicate on a five point scale (Always Right, Sometimes Right, Either Hand, Sometimes Left, Always Left) the hand used when performing a variety of motor tasks including writing, drawing and throwing. Subjects were all native English speakers who

⁴ Most experiments designed to investigate cerebral lateralization utilize only right-handed males. The reason for excluding females and left-handed males from participation is because there is a relation between sex, handedness, and cerebral lateralization. Specifically, the brains of right-handed males tend to be the most lateralized whereas the brains of left-handed males and females are sometimes more functionally symmetrical or even show a reversed pattern of lateralization. Therefore, it is easier to find hemispheric asymmetries when using right-handed male subjects. For an extensive discussion about the relation between sex, handedness, and cerebral lateralization, see Springer and Deutsch (1998).

reported normal or corrected to normal vision and received course credit for their participation.

Apparatus

The experiment was controlled by a Macintosh Quadra 800 computer using Picture Perception Lab software (Kholmeyer, 1992). Subjects responded by naming the stimuli into a microphone. Stimuli were presented on an Apple 17-inch color monitor with a resolution of 832 x 624 pixels and a vertical refresh rate of 75 Hz.

Stimuli for the experiment consisted of color photographs of 36 animals. Animals chosen for use in the experiment were all animals that shared their three largest geons and relations with another animal from a different basic-level category (for example, a dog and a fox each share the same largest three geons and relations). This criterion excludes animals like elephants that have a unique geon structure. To be included in the experiment, the animals had to have a clear upright orientation. The photographs of animals were chosen to maximize the number of parts visible, and to be the most prototypical examples of the animals that could be found. The pictures were scanned so that their maximum extent would fit just inside a 227 X 227 pixel box. Given the conditions of the experimental presentation, the stimuli fit in a box with 4° X 4° of visual angle. Examples of the animals may be seen in Figure 5. From each of the 36 animal photographs, a mirror image version of each animal was also created. The mirror images are needed to ensure that the distance from foveal

vision of the features used for animal recognition was balanced for visual field presentation across the experiment. Furthermore, for each of the original 36 photographs of animals and each corresponding mirror-image version of each animal, an inverted version was created by rotating each photograph in the picture-plane by 180°.

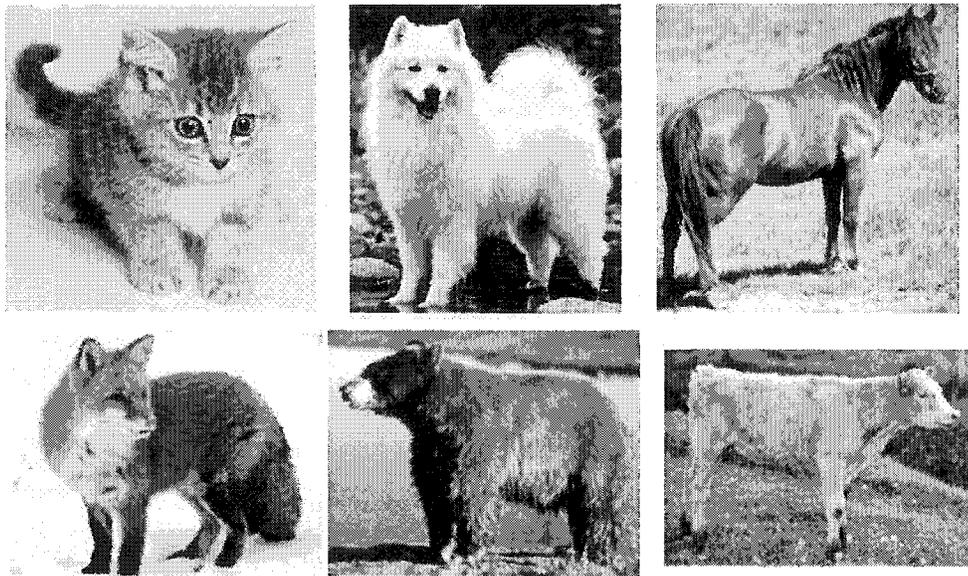


Figure 5. Examples of six of the animals that were used in Experiment 1. The photographs used in the actual experiment were in color.

Procedure

Presentation of the stimuli in the experiment was self-paced. Subjects clicked a mouse button to begin each trial. After clicking the mouse button, a fixation cue was presented on the screen for 504 msec, followed by one of the stimuli for 192 msec. The 192 msec presentation of the images is too brief to make a second eye fixation. The closest edge of the image was 2.4° of visual angle to the left or right of where the cue was presented.

All 36 animals were presented once for each subject during the experiment. Stimulus presentation was balanced such that across a set of eight subjects, the standard version, the mirror-reversed version, the inverted standard version, and the inverted mirror-reversed version of each animal was presented to the right and to the left of fixation once and only once. Thus, for each subject, there were nine stimuli each in the inverted and upright conditions presented to each hemisphere. The order in which the stimuli were presented was chosen randomly with half the subjects seeing the stimuli in forward order and half in reverse.

Subjects were presented with eight practice trials prior to the experiment using the same presentation conditions used during the actual experiment. The practice stimuli consisted of photographs of eight animals. None of the practice stimuli were presented in the experiment proper.

Results

The mean response times from Experiment 1 are shown in Figure 6. Response times and error rates were subjected to a within subjects factorial Analysis of Variance (ANOVA) with orientation (upright vs. inverted) and hemisphere (right vs. left) as the variables in the analysis.

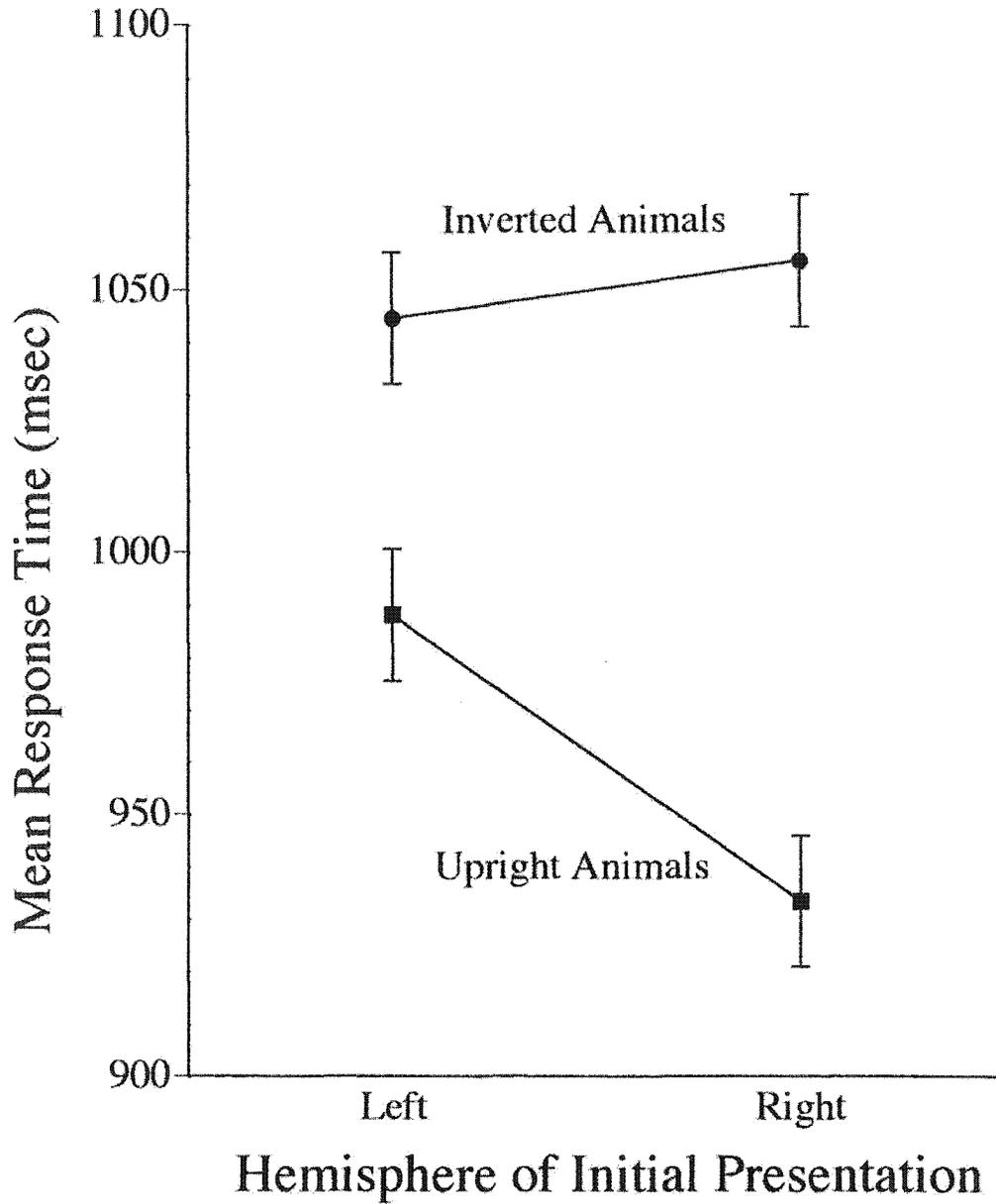


Figure 6. Response time data from Experiment 1. Error bars represent the standard error of the mean (see Loftus & Loftus, 1988).

Response Time Data. There was a reliable main effect of orientation, $F(1, 127) = 60.23$, $p < .0001$, $MSE = 23270.44$. Overall, response times were faster for recognizing the

upright animals (mean RT = 960 ms) than for recognizing the inverted animals (mean RT = 1049). There was not a main effect of hemisphere, $F(1, 127) = 3.381$, $p > .07$, $MSE = 18408$. There was a reliable interaction between orientation and hemisphere, $F(1, 127) = 4.57$, $p < .04$, $MSE = 30159$. Contrasts revealed a reliable LVF/RH advantage for recognizing upright animals, $F(1, 127) = 6.39$, $p < .013$, $MSE = 30160.65$ whereas no hemispheric effects were found for recognizing the inverted animals, $F(1, 127) = 0.245$, $p > .62$, $MSE = 30201.85$.

Error data. The error data from Experiment 1 can be seen in Table 1. Error data showed a reliable main effect of orientation, $F(1, 127) = 73.62$, $p < .0001$, $MSE = .015$. Subjects made more errors recognizing the inverted animals (mean = 31.2%) than when recognizing the upright animals (mean = 18.7%). Neither the hemisphere main effect, $F(1, 127) = 0.011$, $p > .91$, $MSE = .018$ nor the Orientation x Hemisphere interaction, $F(1, 127) = 0.283$, $p > .59$, $MSE = .039$ were statistically reliable, although trends in the error data were in the same direction as in the response time data.

Table 1

Error data from Experiment 1

Hemisphere	Upright Animals		Inverted Animals	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Right	18.2%	1.2	31.6%	1.6
Left	19.2%	1.2	30.9%	1.9

Discussion

The results from Experiment 1 demonstrate that there is a right hemisphere advantage for recognizing upright animals and that inverting animals eliminates the right hemisphere advantage for basic-level animal recognition (just as inverting faces eliminates the right hemisphere advantage for face recognition). All of the non-visual components of generating a response remain the same for upright and inverted animal recognition. Therefore, the results of Experiment 1 provide evidence that the right hemisphere advantage for animal recognition reflects the fact that the right cerebral hemisphere is superior to the left at mediating the visual representations that subserve animal recognition. Notice that inversion only disrupts the spatial relations of primitives, and therefore, the results of Experiment 1 also suggest that the right hemisphere advantage for recognizing upright animals is due to the method by which spatial relations are coded during animal recognition (as posited by the coordinate-relations hypothesis).

The purpose of Experiment 1 was to provide converging evidence that the same neural subsystem that subserves face recognition is used to recognize animals. It is always possible, however, that animals and faces are recognized by neurologically-distinct recognition systems that both just happen to operate more efficiently in the right cerebral hemisphere and that both just happen to be disrupted by inversion such that they no longer subserve the recognition of faces or animals. However, this possibility seems very unlikely

given the fact that the most commonly co-occurring symptom in prosopagnosia is a deficit in animal recognition and given the neuroimaging evidence suggesting similar neural representations for animal and face recognition discussed throughout this paper. Without convincing data to suggest otherwise, it is more parsimonious to posit that one system mediates the recognition of animals and faces than it is to posit separate systems for the two tasks.

CHAPTER 9. EXPERIMENT 2: CEREBRAL LATERALIZATION FOR PHYSICALLY DISCRIMINATING METRIC VS. GEON-CHANGED OBJECTS

The results of Experiment 1 are inconsistent with the subordinate level and expert recognition hypotheses and consistent with the category-specific recognition and coordinate relations hypotheses. The purpose of Experiment 2 was to test the coordinate relations hypothesis against the category-specific recognition hypothesis. Furthermore, Experiment 2 directly tested the central tenet of the coordinate relations hypothesis. Specifically, that the essential factor that determines which neural subsystem subserves a recognition task is whether the computational demands of the task are better solved using coordinate relations or a structural description representation.

Subjects in Experiment 2 performed physical discriminations using line drawings of common inanimate objects (see Figure 7). During each trial of the experiment, subjects were presented with a pair of objects (that belong to the same basic-level category) separated by a mask, and their task for each trial was to decide if the pair of objects were physically identical. On the trials in which the objects were not physically identical, some of the objects could be discriminated from one another using a structural description (e.g., objects a and b in Figure 7) whereas other objects could not be discriminated using a structural description representation (e.g., objects a and c in Figure 7). The objects that could be discriminated from one another using a structural description differed from each other by one geon, but the

aspect ratio of the corresponding geons did not differ for the objects that comprise these pairs. The objects that could not be discriminated using a structural description shared the same structural description, but the aspect ratio of one of the geons was different between the objects comprising the pair. Therefore, the visual system would have to rely purely on the metric properties of these objects in order to physically discriminate them.

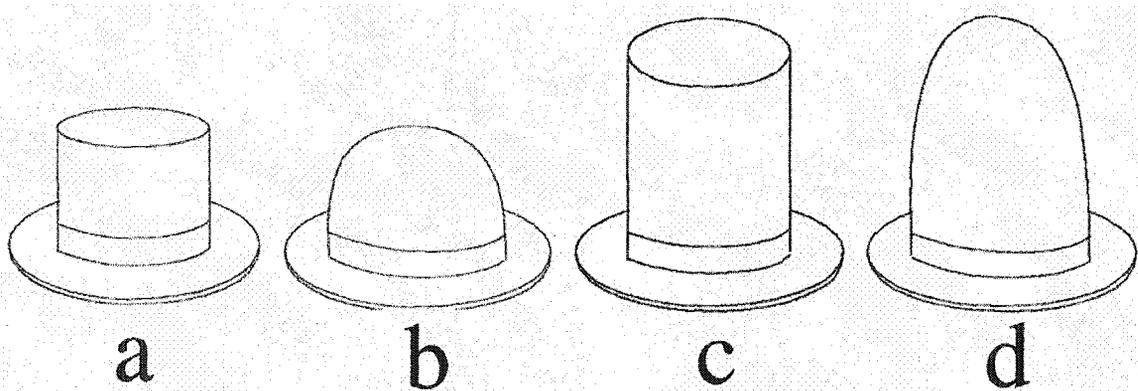


Figure 7. Examples of the different exemplars of objects comprising the basic-level category "hat" in Experiment 2. Objects a and b as well as objects c and d do not share the same geon structural description whereas objects a and c, as well as objects b and d have different metric properties but share the same geon structural description.

The first object within a trial was presented in foveal vision whereas the second object within a trial was presented directly to one of the cerebral hemispheres (i.e., it was presented in the left or right visual field). The coordinate relations hypothesis predicts that there should be a right hemisphere advantage for physically discriminating the objects that share the same structural description but differ only by their metric properties and that there

should not be a right hemisphere advantage when physically discriminating objects that have different structural descriptions. The current alternatives to the coordinate relations hypothesis do not predict different hemispheric asymmetries depending on whether the stimuli can be distinguished using a structural description.

Recall from earlier that the main reason theorists have posited the use of structural descriptions is that when such representations are able to mediate a recognition task, structural descriptions are, in general, computationally more efficient than coordinate relations (Hummel & Biederman, 1992). Therefore, the coordinate relations hypothesis is the only hypothesis that makes the additional prediction that performance for physically discriminating the objects that can be discriminated using a structural description should be better than performance for discriminating objects that cannot be discriminated using a structural description.

Method

Subjects

The subjects were 64 right-handed male undergraduate students from the subject pool at Iowa State University naïve to the purpose of the experiment. Hand preference was determined by use of the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were all native English speakers who reported normal or corrected to normal vision and received course credit for their participation.

Apparatus

The apparatus used for Experiment 2 was the same as used in Experiment 1 except that instead of naming stimuli into a microphone, subjects responded using a two button response box attached to a National Instruments NB-DIO-24 interface board that gave ± 0.5 ms response time accuracy. The stimuli for the experiment consisted of line drawings of simple two-part objects taken from the stimulus set used by Cooper and Biederman (1993). Thirty-two basic-level object categories were used in the experiment (e.g., hat, truck, house). There were four different exemplars from each basic-level object category. Two pairs of exemplars within a basic-level category differed from each other by one geon, but the aspect ratio of the corresponding geons did not differ for the objects that comprise such pairs. These object pairs comprised the *geon-changed objects* (see Figure 7, note that objects a and b comprise one pair of geon-changed objects and that objects c and d comprise the other pair of geon-changed objects). Two other pairs of exemplars within a basic-level category shared the same geon structural description, but the aspect ratio of one of the geons was different between the objects comprising such a pair. These were the *metric-changed objects* (see Figure 7, note that objects a and c comprise one pair of metric-changed objects and that objects b and d comprise the other pair of metric-changed objects). Importantly, Cooper and Biederman constructed the objects such that in a *simultaneous* same-different match task, the

geon-changed objects were as physically different from one another as the metric changed objects are physically different from one another.

A mirror image version of each of the objects was also created to ensure that the distance from foveal vision of the object features was balanced for visual field presentations across the experiment. The line drawings were sized to the same extent as the animals in Experiment 1.

A pattern mask was also used in Experiment 2. The pattern mask was created by copying edge segments from the line drawings that were used during the practice trials, and pasting the edge segments onto one-half of the pattern mask. Then the half of the pattern mask that contains the line segments was copied, mirror-reversed, and pasted back onto the other side of the pattern mask. This method of constructing the pattern mask ensured that it was right-left symmetrical and ensured that the mask was not more disruptive in one visual field than the other. Furthermore, there was a second cue imbedded in the center of the pattern mask.

Procedure

Presentation of the stimuli in the experiment was self-paced. Subjects clicked a mouse button to begin each trial. After clicking the mouse button, a fixation cue was presented in the center of the screen for 504 msec, followed by the first stimulus, which was also centered for 200 msec, followed by the pattern mask for 756 msec, followed by the

second stimulus (which always belonged to the same basic-level category as the first stimulus) for 148 msec. The cue embedded in the pattern mask was located in the center of the screen. The second object was lateralized such that the closest edge of the image was 2.4° of visual angle to the left or right of where the cues were presented. There were three different types of stimulus sequence combinations shown in the experiment. Specifically, the first and second objects within a trial were either physically identical (see example a in Figure 8), a metric-changed pair (see example b in Figure 8), or a geon-changed pair (see example c in Figure 8). Subjects were instructed to focus their eyes on the cue after pressing the mouse button, then to look at the first object that followed the cue, then to focus their eyes onto the cue imbedded in the pattern mask until the pattern mask disappeared, then to look at the second object. Subjects were instructed to press the button on the response box labeled "same" if the objects that appeared on the screen within a trial were physically identical and to push the button labeled "different" if the objects that appeared on the screen within a trial were not physically identical.

There were 32 basic-level stimulus classes used in the experiment, with four exemplars in each class (e.g., the four exemplars of the hat in Figure 7). Therefore, there were 128 total objects. Each object appeared four times as the first stimulus for each subject. There were two identical trials, one geon changed trial and one metric change trial for each of the 128 objects, yielding a total of 512 trials for each subject. Thus, for each subject there

were 128 stimuli each in the metric and geon changed conditions. For the even numbered subjects, the right button on the response box was the "same" button and for the odd numbered subjects, the right button on the response box was the "different" button. Half of the subjects in the experiment saw mirror-reversed versions of the objects. Across a group of four subjects, each possible pairing of two objects appeared equally often in the right and left visual fields.

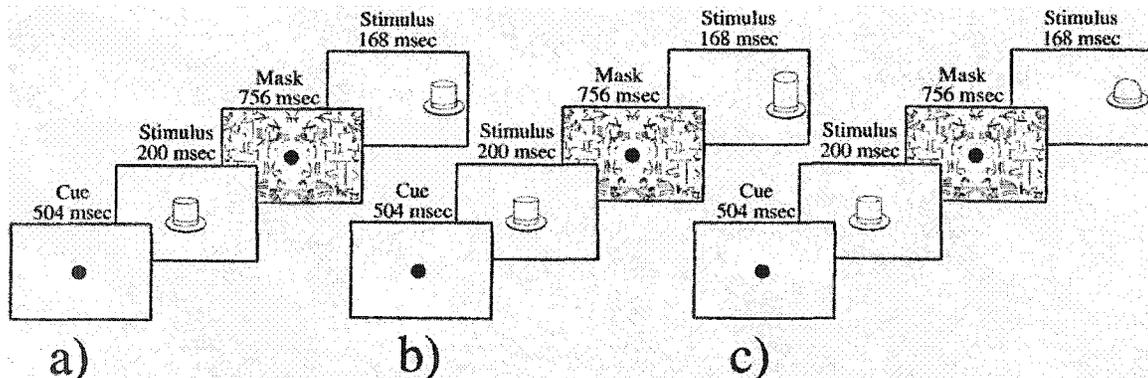


Figure 8. The three different combinations of stimuli that were shown during Experiment 3.

Subjects were presented with 24 practice trials prior to the experiment using the same presentation conditions used during the actual experiment. None of the practice stimuli were presented in the experiment proper.

Results

The mean response times from Experiment 2 are shown in Figure 9. Response times and error rates were subjected to a within subjects factorial ANOVA with Hemisphere of

Initial Presentation (Right vs. Left) and Trial Type (Metric Change vs. Geon Change) as factors in the analysis.

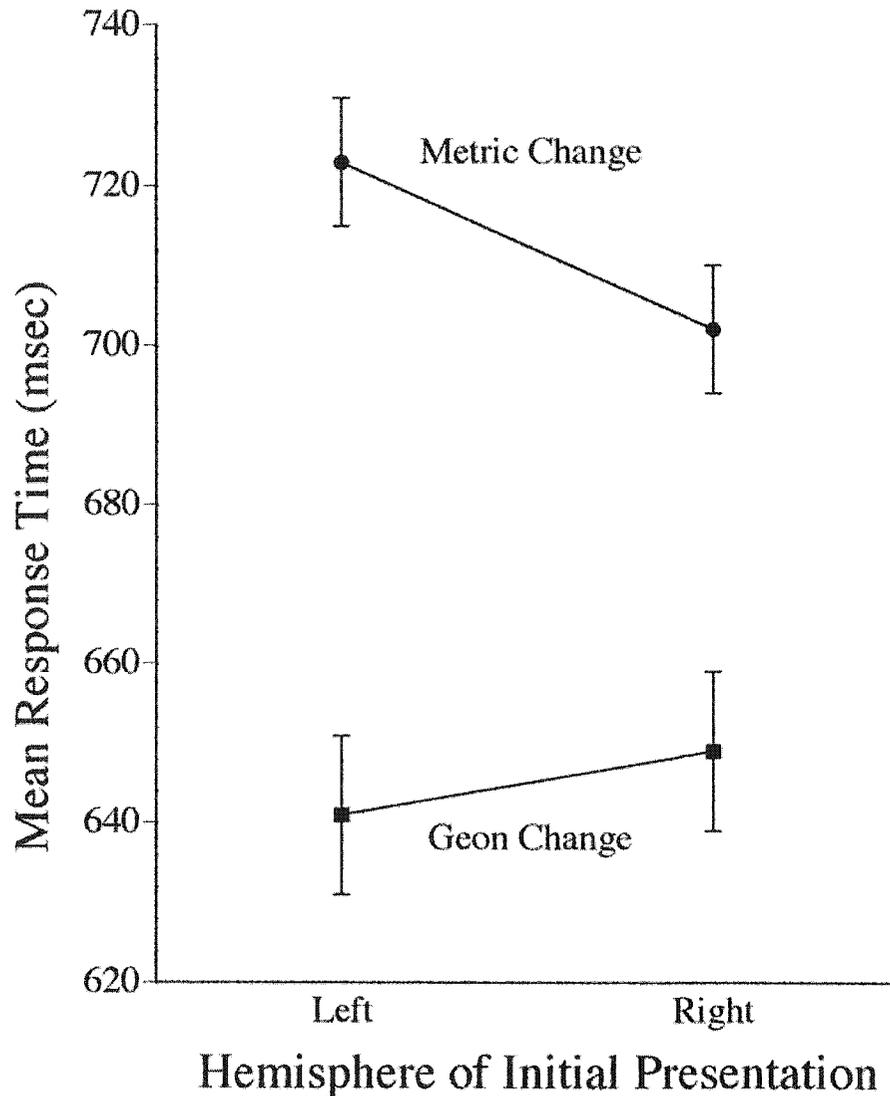


Figure 9. Response time data from Experiment 2. Error bars represent the standard error of the mean.

Response Time Data. There was a reliable main effect of Type of Change, $F(1, 31) = 34.01$, $p < .0001$, $MSE = 4324$. Overall, response times were faster for the geon change trials (mean RT = 645 ms) than for the metric change trials (mean RT = 713). There was not a

main effect of hemisphere, $F(1, 31) = 0.62$, $p > .43$, $MSE = 2284$. There was a reliable interaction between type of change and hemisphere, $F(1, 31) = 6.7$, $p < .014$, $MSE = 948$. Planned contrasts revealed a reliable LVF/RH advantage for the metric change trials, $F(1, 31) = 7.3$, $p < .0113$, $MSE = 947$ whereas no hemispheric effects were found for the geon change trials, $F(1, 31) = 0.9$, $p > .34$, $MSE = 948$.

Error data. The error data from Experiment 2 can be seen in Table 2. There was a reliable main effect of Type of Change, $F(1, 31) = 165.9$, $p < .0001$, $MSE = 0.06$. Overall, error rates were lower for the geon change trials (mean error rate = 9.4) than for the metric change trials (mean error rates = 27.5). No other trends in error data approached statistical reliability (all $F_s < 0.8$; all p -values $> .36$).

Table 2

Error data from Experiment 2

Hemisphere	<u>Geon Change</u>		<u>Metric Change</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Right	8.6%	0.9	27.7%	1.6
Left	10.2%	1.1	27.2%	1.6

Discussion

The pattern of results from Experiment 2 are precisely the pattern predicted by the coordinate relations hypothesis and cannot be accounted for by the current alternatives to the coordinate relations hypothesis. The coordinate relations hypothesis predicts a right hemisphere advantage when the task is to physically discriminate objects that share the same

structural description but that have different metric properties. Consistent with this prediction, Experiment 2 found a right hemisphere advantage for the Metric Change condition. The coordinate relations hypothesis predicts there should not be a right hemisphere advantage when the task is to physically discriminate objects whenever the objects that are discriminated do not share the same structural description. Consistent with this prediction, Experiment 2 found no evidence of a right hemisphere advantage for the geon change trials. The coordinate relations hypothesis predicts that overall, performance should be better for recognition tasks that can be mediated using a structural description representation than for tasks that require a coordinate representation. Consistent with this prediction, Experiment 2 found that overall, performance was better for the geon change trials than for the metric change trials.

The results of Experiment 2 suggest a fundamental difference in how shape is represented in the neural subsystems. Experiment 2 found that the right hemisphere neural subsystem operates more efficiently than the bilateral system at mediating a recognition task that required discriminating between objects that share the same structural description but that differ metrically from one another. In contrast, the right hemisphere neural subsystem was not more efficient than the bilateral neural subsystem at mediating a recognition task that required discriminating between objects that do not share the same structural description. The results, therefore, suggest that the right hemisphere neural subsystem mediates a

coordinate representation whereas the bilateral neural subsystem mediates a structural description representation. In summary, the results of Experiment 2 corroborate the coordinate relations hypothesis and are inconsistent with all other current hypotheses regarding the types of recognition tasks and representations mediated by the dissociable neural subsystems.

CHAPTER 10. EXPERIMENT 3: THE EFFECTS OF INVERSION ON
PHYSICALLY-DISCRIMINATING METRIC CHANGED OBJECTS

The results of Experiment 2 corroborate the coordinate relations hypothesis and are inconsistent with all other hypotheses regarding the functions of the dissociable neural subsystems. However, there is always the possibility that the right hemisphere advantage for the metric change condition is not indicative of the right hemisphere neural subsystem that subserves face recognition, but instead reflects some other factor or right hemisphere computational mechanisms that is used for the physical discrimination task. For example, it could be the case that task difficulty alone was responsible for the different patterns of cerebral lateralization for the two conditions. That is, maybe the same representational strategy was used by the visual system for both conditions, but only the metric change condition was sufficiently difficult to be diagnostic of cerebral asymmetries associated with the representational strategy.

The purpose of Experiment 3 was to attempt to provide converging and more definitive evidence that the right hemisphere advantage in the metric change condition in Experiment 2 is indeed indicative of the right hemisphere neural subsystem that subserves face recognition. Experiment 3 was similar to Experiment 2 except that all of the trials in Experiment 3 were either identical or metric change trials. Furthermore, half the trials in

Experiment 3 showed the second object inverted (i.e., rotated 180° in the picture plane) relative to the orientation of the first object.

Recall that the right hemisphere neural subsystem only operates on upright stimuli. Therefore, if the right hemisphere advantage for the metric change trials is indicative of the neural subsystem that subserves face recognition, then there should only be a right hemisphere advantage for the trials in which the objects are shown at the same orientation. In contrast, if the right hemisphere advantage reflects some other factor or right hemisphere mechanism, then there should be a right hemisphere advantage for metric change trials regardless of the orientation of the objects⁵.

Method

Subjects

The subjects were 64 right-handed male undergraduate students from the subject pool at Iowa State University naïve to the purpose of the experiment. Hand preference was determined by use of the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were all native English speakers who reported normal or corrected to normal vision and received course credit for their participation.

⁵ Notice that this is the same logic that was used in Experiment 1 to test whether the right hemisphere advantage for animal recognition is indicative of the neural subsystem that subserves face recognition.

Apparatus

The apparatus used in Experiment 3 was the same as used in Experiment 2

Procedure

With the exception of the changes listed below, the procedure used during Experiment 3 was the same as used in Experiment 2. First, there were no geon change trials in Experiment 3. Second, half of the objects shown in Experiment 3 were shown upside-down. There were four combinations of orientation possible between the first and second objects, and each of these possible combinations appeared equally often for each subject and across subjects in the experiment: The first and second object could both be upright, the first and second object could both be inverted (these two conditions will collectively be referred to as the Same Orientation Condition), the first object could be upright and the second object could be inverted, or vice versa (these two conditions will be collectively referred to as the Different Orientation Condition). Across a group of 16 subjects, each possible pairing of two objects appeared equally often in the right and left visual fields and equally often inverted and upright. The order of stimuli was chosen randomly with half the subjects seeing the stimuli in forward order and half the subjects seeing the stimuli in reverse.

Results

The mean response times from Experiment 3 are shown in Figure 10. Response times and error rates were subjected to a within subjects factorial ANOVA with Hemisphere of

Initial Presentation (Right vs. Left) and Orientation (Same vs. Different) as factors in the analysis.

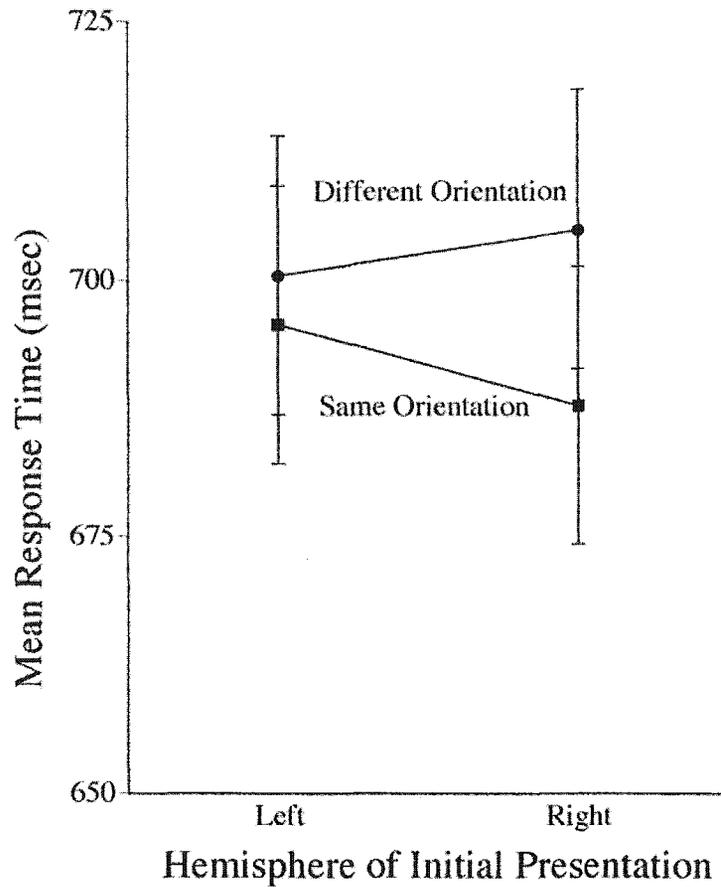


Figure 10. Response time data from Experiment 3. Error bars represent the standard error of the mean (Loftus & Loftus, 1988).

Response Time Data. The effect of orientation was marginally reliable, $F(1, 63) = 3.97$, $p = .0506$, $MSE = 1928$. The mean response time for the same orientation trials was 691 ms whereas the mean response time for the different orientation trials was 703 ms. No other

trends in the response time data approached statistical reliability (all $F_s < 1.5$; all p -values $> .23$).

Error data. The error data from Experiment 3 can be seen in Table 2. No trends in the error data approached statistical reliability (all $F_s < 0.4$; all p -values $> .52$).

Table 3
Error data from Experiment 3

Hemisphere	<u>Same Orientation</u>		<u>Different Orientation</u>	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Right	28.6%	1.4	28.9%	1.1
Left	28.8%	1.2	28.1%	1.2

Discussion

The purpose of Experiment 3 was to test whether showing one of the objects within the metric change trials at a different orientation than the other object eliminates the right hemisphere advantage for physically discriminating the metric change objects. The results of Experiment 3 found no evidence of a right hemisphere advantage for the metric change condition when the two objects within a trial were shown at different orientations. However, Experiment 3 also failed to find a right hemisphere advantage for the metric change trials in which the objects were shown at the same orientation. Therefore, the results of Experiment 3 failed to replicate the results of Experiment 2. Perhaps most surprisingly, the main effect of orientation was only marginally reliable in Experiment 3. Most studies of the effects of

planar orientation on visual recognition performance find large effects of orientation (Jolicoeur, 1985, 1990, 1992).

The fact that main effect of orientation was only marginally reliable suggests that subjects might not have been relying on their normal representational strategies during Experiment 3. Albeit speculative, I can think of at least two possible reasons why the results of Experiment 3 failed to replicate the results of Experiment 2. Both of these reasons suggest that subjects might not have been relying on their normal visual object representations to perform the physical discrimination task in Experiment 2

Notice that it is possible to perform the physical discrimination task even without recognizing the objects in the experiment. (For example, the experiment could have used nonsense objects that would have been de-facto unrecognizable). It could be the case that subjects do not have stored representations of the objects when inverted, and therefore, tended to use a strategy in the experiment that did not use their stored object representations throughout the experiment.

Furthermore, notice that in Experiment 3 (unlike in Experiment 2) it would have been possible to rely solely on judging the size of the objects in order to perform physical discrimination task⁶. If subjects adopted the strategy using size for both the upright and

⁶ That is, in Experiment 2, objects could be the same size but not be physically identical whereas in Experiment 3, all of the objects that were not physically identical were also different sizes.

inverted conditions, then it would be expected that both conditions would show similar laterality effects.

If subjects in Experiment 2 were relying on normal representational strategies whereas subjects in Experiment 3 were not relying on normal representational strategies, then the results of Experiment 2 and not Experiment 3 should be considered diagnostic of shape representation in the neural subsystems.

Could it be the case that subjects began the experiment relying on their normal representational strategies and during the course of the experiment adopted an alternative representational strategy that was insensitive to the orientation (i.e., whether the objects were the same or different orientation within a trial)? In order to examine this possibility, a subsequent item analysis divided the experiment in half based on trials number. The item analysis then tested for an interaction between the trial number and orientation. The interaction between trial number and orientation did not approach statistical reliability, $F(1, 63) = 0.068, p > .79$. Therefore, it does not appear that an orientation had different effects in the first and second half of the experiment.

Another possibility is that Experiment 3 lacked the statistical power to find any effects. A subsequent analysis was conducted to calculate the smallest response time difference between the right and left hemisphere in the same orientation condition that would be reliable given the experimental data. The results of this analysis demonstrated that an

effect of 15 ms would have been found to be statistically reliable at an alpha level of .05. A 14 ms effect in a test of cerebral lateralization would be quite small. Therefore, it does not appear that the experiment lacked statistical power. In any case, the results of Experiment 3 appear inconclusive.

CHAPTER 11. EXPERIMENT 4: THE EFFECTS OF METRIC VS. GEON CHANGES
ON VISUAL PRIMING IN THE NEURAL SUBSYSTEMS

Some of the strongest evidence against the coordinate relations hypothesis has come from a series of experiments conducted by Burgund and Marsolek (2000). Specifically, Burgund and Marsolek have provided evidence (which will be discussed in the next few paragraphs) that the neural subsystem that mediates basic-level object recognition does not rely on a structural description representation. Recall that one of the central tenets of the coordinate relations hypothesis is that the system that subserves most forms of basic-level object recognition mediates structural description representations.

Subjects in Burgund and Marsolek (2000) named objects in foveal vision during the first block of trials and then named the same objects during a second block. In the second block, the objects were presented very briefly to the left or right hemispheres. The objects shown in the second block of trials were either identical views of the objects shown during the first block or the objects were rotated in depth relative to the first block. Importantly, some of the depth-rotated objects were rotated so that the same geons and categorical relations could be seen that were shown during the first block. In contrast, other rotated objects were rotated such that completely different geons were visible between the first and second block of trials. Burgund and Marsolek found more priming in the right hemisphere for objects that were shown from the same viewpoint than for objects rotated in depth.

Furthermore, Burgund and Marsolek found the same amount of priming in the left hemisphere regardless of whether the objects were identical or were rotated in depth between the trials. Most importantly for the coordinate relations hypothesis, Burgund and Marsolek found no difference in the amount of priming in the left hemisphere for the rotated objects that had the same geons and categorical relations present between the blocks and the rotated objects that had completely different geons present between the blocks. Burgund and Marsolek interpreted this last result as showing that the neural subsystem that mediates basic-level object recognition does not code geons or categorical relations, and therefore that the subsystem that mediates basic-level object recognition does not rely on a structural description.

There are a number of reasons to question Burgund and Marsolek's (2000) interpretation of their results. First, Biederman and Cooper (1991a) found reduced priming for different exemplar objects in both visual fields while Burgund and Marsolek only found reduced priming in the right hemisphere). Second, Burgund and Marsolek used a within subject design for all of the variables in their experiment except for the same vs. different geon visible variable, which was a between subjects variable. Therefore, all of the conditions in which they found differences in priming were much more statistically powerful than the condition in which they tested whether there was reduced priming for objects that have different geons between blocks. Third, Burgund and Marsolek only used error percentage as

their dependent measure. It may be that there was reduced priming for objects that had unique geons between the blocks, but the reduced priming only was exhibited in response times that were not collected.

The purpose of Experiment 4 was to conduct a priming study similar to Burgund and Marsolek's (2000) study. In Experiment 4, subjects recognized, in two blocks of trials, the same objects that were used in Experiments 2 and 3. The objects in the first block were shown in central vision. Following the first block of trials, subjects again recognized objects that belong to the same basic-level category as those shown during the first block, but the objects in the second block fell into one of three conditions relative to the objects in the first block (see Figure 11). The second block objects in the *identical* condition were identical in every way to the corresponding objects presented during the first block of trials. The objects in the *metric change* condition were the metric changed versions of the objects that were presented during the first block of trials. Finally, the objects in the *geon change* condition were the geon changed versions of the objects that were presented during the first block of trials. Furthermore, the objects in the second block of trials was presented initially to the right or left hemisphere.

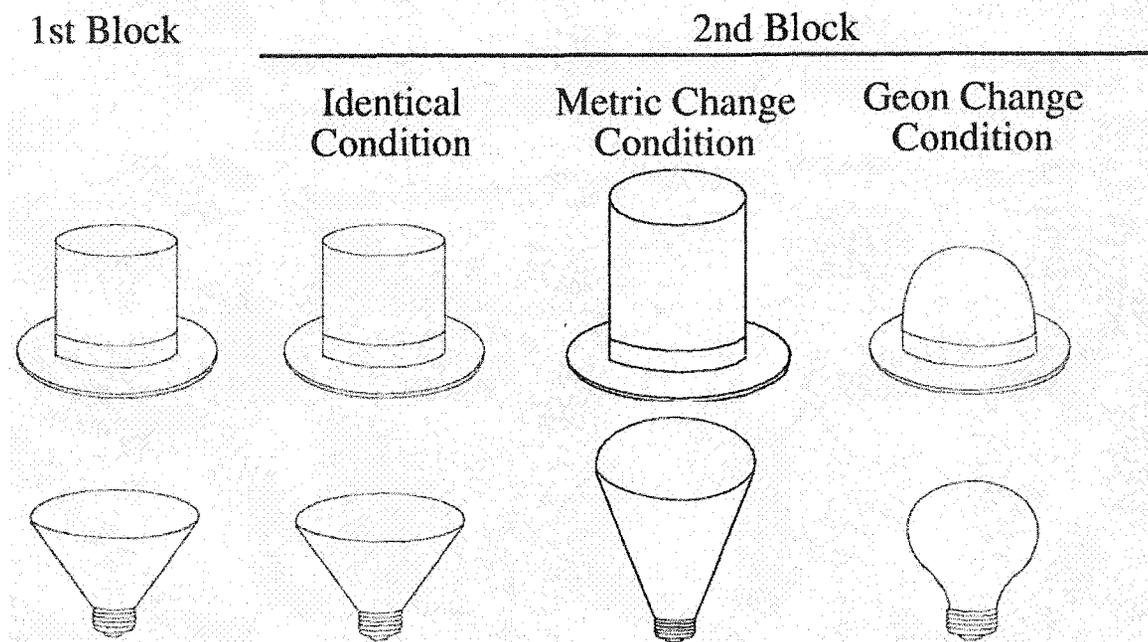


Figure 11. Illustration of the conditions used in Experiment 4. Note that objects presented during the second block of trials were either a) identical to the object presented during the first block of trials, b) metric changed versions of the objects presented during the first block of trials, or c) geon changed versions of the objects presented during the first block of trials.

Due to the fact that all of the recognition tasks in Experiment 4 were basic-level recognition tasks that can be mediated using a structural description representation, the coordinate relations hypothesis predicts no effect of hemisphere of initial presentation for any of the conditions in the experiment. Burgund and Marsolek's theory (2000) posits that the right hemisphere neural subsystem is specialized for recognizing specific exemplars of objects stored in memory. Therefore, because the objects in the Identical condition are identical to the objects (i.e., they are specific exemplars) shown in the first block, Burgund and Marsolek's theory predicts a right hemisphere advantage for the Identical condition.

Most importantly, the coordinate relations hypothesis predicts that there should be more priming in the metric change condition than in the geon change condition. This prediction follows because a structural description representation would be insensitive to the metric differences between the objects in the first and second blocks whereas a structural description representation would be sensitive to geon changes between the blocks.

Notice that any reduction in priming in the current experiment between the identical condition and the other conditions in the experiment must reflect a reduction in *visual* priming (rather than general practice effects or conceptual priming) because the only variables that differ between these conditions are visual. However, the design of the current experiment will not allow the absolute amount of visual or non-visual priming that might occur in the experiment to be measured. This is because the absolute amount of priming in a study is measured as the decrease in response times for stimuli that have been presented in both blocks relative to stimuli that have been presented only in the second block. In the current study, all of the stimuli were presented in both blocks (although different *versions* of the stimuli were presented between the blocks).

However, the coordinate relations hypothesis makes no predictions regarding the absolute amount of priming that should occur in the current study, and so the absolute amount of priming is of no interest for the current project. Many other experiments (e.g., Biederman & Cooper, 1991a; Biederman & Cooper, 1991b; Biederman & Cooper, 1992;

Brooks, Rosielle, & Cooper, 2002; Bruce & Valentine, 1985) have investigated the absolute amount of priming in experiments of this sort. There is, however, one potential problem with not measuring the absolute amount of priming in the current study. If there is no reduction in priming between the identical condition and the other conditions in the experiment, then it is not possible to distinguish between two interpretations for the lack of a reduction in priming. First, the lack of difference in priming between the conditions could occur because the representations mediating visual recognition are invariant to the stimulus transformations employed in the study. Second, the lack of a difference in priming could occur because there literally was no visual priming in the study, and therefore, the study would not be diagnostic of the visual representations mediating recognition. However, because the experiment employed a small set of stimuli in which the metric changes have been psychophysically equated with the geon changes, the risk of not measuring the absolute amount of priming is outweighed by the costs of sacrificing the use of some of the stimuli for the purpose of measuring the absolute amount of priming. If a condition was employed in which objects were not included in both blocks of trials, then there would be a substantial loss of data points that could test for a differences in priming between the identical condition, metric change condition, and geon change conditions.

Method

Subjects

The subjects were 96 right-handed male undergraduate students from the subject pool at Iowa State University naïve to the purpose of the experiment. Hand preference was determined by use of the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were all native English speakers who reported normal or corrected to normal vision and received course credit for their participation.

Apparatus

The apparatus used in Experiment 4 was the same as used in Experiment 2 with the following exceptions. First, the microphone was used instead of the button box for collecting responses from the subject. Second, there were 36 basic-level stimulus classes in Experiment 4. Third, the mask was not employed during Experiment 4.

Procedure

Each subject was presented with two blocks of trials. The first block was the priming block and the second block was the primed block. The presentation sequence for each trial was as follows: First, a fixation cue was presented for 504 ms, followed by one of the stimuli for 336 ms (first block of trials) or 168 ms (second block of trials). Following the procedure used by Biederman and Cooper (1992) and Brooks, Rosielle, and Cooper (2002), the stimuli in the first block were shown for longer than those in the second block in order to allow for

substantial activation of the first block stimuli representations so that they would be effective primes for the second block stimuli. During the first block of trials, the stimuli were presented in central vision (i.e., where the cue was presented). During the second block of trials, the stimuli were lateralized such that the closest edge of the image was 2.4° of visual angle to the left or right of where the cues was presented. Each subject's task for both blocks of trials was to name the stimuli at the basic-level into the microphone as quickly and accurately as possible.

For the trials in the second block for each subject: six were identical to those in the first block, six were metric changed versions of objects from the first block, and six were geon-changed versions of the objects shown in the first block. Examples of the conditions can be seen in Figure 11.

For each subject, half of the stimuli in each of the second-block conditions were presented directly to the right hemisphere and half of the stimuli in the second block conditions were presented directly to the left hemisphere. Across subjects, each object was presented equally often in all conditions and equally often across the cerebral hemispheres. Further, across subjects, each of the three versions of each object (i.e., a standard, a metric change, and a geon-change version of each object) appeared equally often as the stimulus in the first block and in the second block. Subjects were told before the beginning of the second block that they would see the same objects they saw during the first block, but that

sometimes the objects would be different versions of the objects they saw during the first block of trials. In addition, subjects saw the objects in a different, randomly generated order during the first and second blocks. Approximately six minutes intervened on average between the presentations of a particular object from the first to the second block.

Subjects were presented with eight practice trials prior to the experiment using the same presentation conditions used during the actual experiment. None of the practice stimuli were presented in the experiment proper.

Results

The mean response time for the first block of trials was 1016 ms. The mean response times from the second block conditions are shown in Figure 12. Response times and error rates from the second block conditions were subjected to a within subjects factorial ANOVA with Type of Prime (Identical vs. Metric Change vs. Geon Change) and Hemisphere of Initial Presentation (Right vs. Left) as factors in the analysis.

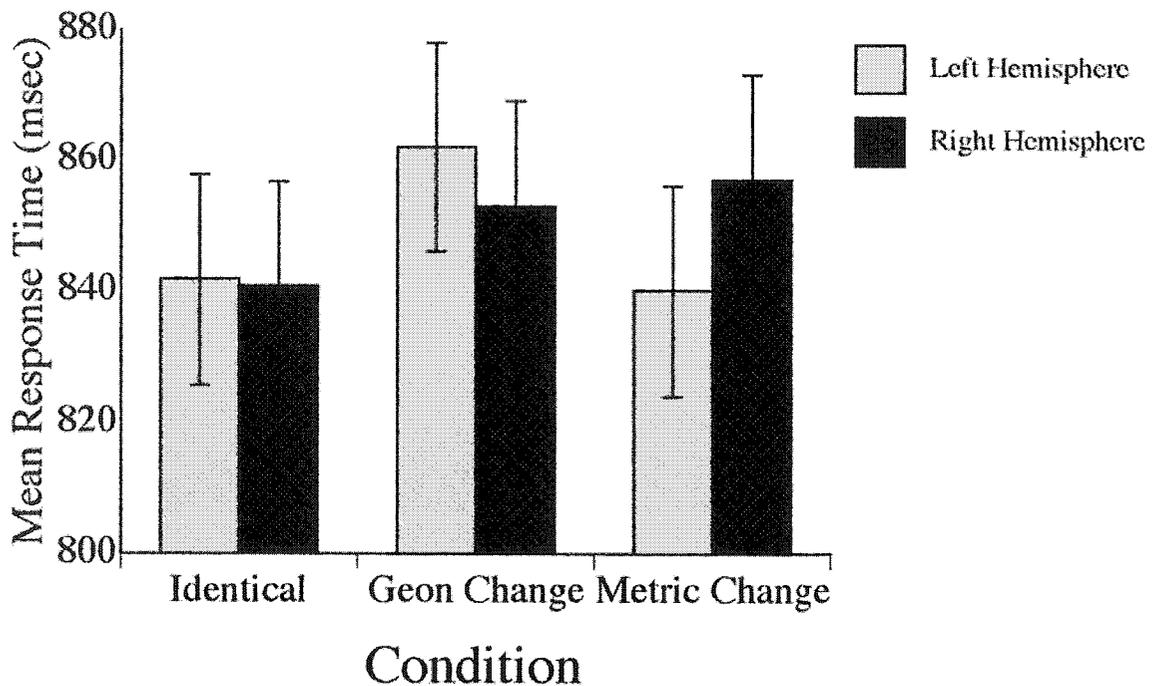


Figure 12. Response times from the three different types of trials from the second block of Experiment 4

Response Time Data. There was no effect of Type of Prime, $F(2, 95) = 0.64$, $p > .52$, $MSE = 2402$. There was also no effect of Hemisphere of Initial Presentation, $F(2, 95) =$

0.56, $p > .45$, $MSE = 25826$. Furthermore, there was no interaction between Type of Prime and Hemisphere of Initial Presentation, $F(2, 95) = 0.25$, $p > .77$, $MSE = 18186$.

Error data. The error data from Experiment 4 can be seen in Table 4. There was no effect of Type of Prime, $F(2, 95) = 1.099$, $p > .10$, $MSE = 0.008$. There was also no effect of Hemisphere of Initial Presentation, $F(2, 95) = 0.01$, $p > .92$, $MSE = 0.006$. Furthermore, there was no interaction between Type of Prime and Hemisphere of Initial Presentation, $F(2, 95) = 1.291$, $p > .27$, $MSE = 0.007$.

Table 4.

Error data from Experiment 4

Hemisphere	Identical		Geon Change		Metric Change	
	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>	<u>M</u>	<u>SE</u>
Right	3.6%	0.9	5.7%	1.2	5.2%	1.2
Left	4.5 %	1.1	5.0%	1.1	5.2%	1.1

Discussion

The purpose of Experiment 4 was to test the effects of metric and geon changes between blocks on priming in the neural subsystems. Unfortunately, the experiment failed to find any statistically reliable effects. One possibility for the lack of statistically reliable effects is that, even with 96 subjects, the experiment lacked the statistical power to be diagnostic of any of the questions it was designed to address. As such, a subsequent analysis was conducted to calculate the smallest response time difference between the geon change

and metric change conditions that would be reliable given the experimental data. The results of this analysis demonstrated that an effect of 60 ms between the geon and metric change conditions would have been found to be statistically reliable at an alpha level of .05. A 60 ms effect in a priming study would be exceptionally large. As such, it does appear that the experiment lacked statistical power.

There were a number of differences in the method between Burgund and Marsolek (2000) and the current experiment. Therefore, each of these differences could be responsible for failing to replicate results of Burgund and Marsolek and/or for the lack of statistical power.

First, Burgund and Marsolek presented eight objects in each condition per subject whereas the current experiment only presented three objects in each condition per subject. The additional trials per condition in Burgund and Marsolek probably reduced the within subject variability in their data. Therefore, Burgund and Marsolek's design was probably a more power within subject design than the current study.

Second, Burgund and Marsolek (2000) presented objects for 17 ms in the second block whereas objects were presented for 168 ms in the second block of the current experiment. It could be the case that the longer presentation times in the current experiment resulted in a ceiling effect in the error data. (Recall that Burgund and Marsolek only found effects in error data.) Consistent with this possibility, Burgund and Marsolek's lowest error

rate in any of their conditions was approximately 20% whereas the highest error rate in the current experiment was only 5.2%.

Third, Burgund and Marsolek (2000) presented objects for three seconds in the first block whereas objects were presented for only 336 ms in the first block of the current experiment. It could be the case that the longer presentation times used by Burgund and Marsolek allowed for much greater priming of the metric properties of objects than in the current experiment.

As discussed in the Introduction to Experiment 4, there were a number of reasons why Experiment 4 was not designed to be an exact replication (with different stimuli) of Burgund and Marsolek (2000). However, because the current experiment failed to replicate any of Burgund and Marsolek's findings, it might be worth considering an exact replication of Burgund and Marsolek in the future.

CHAPTER 12. GENERAL DISCUSSION

The purpose of this dissertation was to describe a framework (the coordinate relations hypothesis) for understanding the types of shape representations and recognition tasks that are mediated in dissociable neural subsystems, and to test this theoretical framework. Due to the fact that the recognition system that mediates face recognition operates either exclusively or more efficiently in the right cerebral hemisphere, the current experiments used a right hemisphere recognition advantage as a marker to indicate whether or not various recognition tasks are mediated using the system that subserves face recognition. If a recognition task is mediated using the neural subsystem that subserves face recognition, then the recognition task should show a right hemisphere recognition advantage. In contrast, the lack of a right hemisphere recognition advantage for a recognition task provides evidence that the task is not mediated using the system that subserves face recognition. Furthermore, if a recognition task is mediated using the neural subsystem that subserves face recognition, then inverting the stimuli should eliminate the right hemisphere advantage for the recognition task (just as inversion eliminates the right hemisphere advantage for face recognition).

The purpose of Experiment 1 was to provide further evidence that the right hemisphere advantage for basic-level animal recognition is due to the neural and representational mechanisms that underlie face recognition. The results from Experiment 1 demonstrate that there is a right hemisphere advantage for recognizing upright animals, but

that inverting animals eliminates the right hemisphere advantage for basic-level animal recognition. Furthermore, inversion only disrupts the spatial relations of primitives (all other visual aspects of the stimuli are left unaltered), and therefore, the results of Experiment 1 suggest that the right hemisphere advantage for recognizing upright animals is due to the coding of spatial relations (as posited by the coordinate-relations hypothesis). The results from Experiment 1 provide converging evidence with neuroimaging studies and neurological patient data that animals are recognized using the neural subsystem that subserves face recognition. The finding that animals are recognized using the right hemisphere neural subsystem that subserves face recognition is incongruent with the expert recognition and subordinate-level recognition hypotheses. The only current hypotheses that can account for the results of Experiment 1 are the coordinate relations and category specific recognition hypotheses.

The purpose of Experiment 2 was to test the coordinate relations hypothesis against the category specific recognition hypothesis, and to provide further evidence that perceptual expertise and the level at which visual stimuli are categorized are not critical factors determining which neural subsystem is used for a recognition task. Furthermore, Experiment 2 was designed to demonstrate that the critical factor that determines whether a recognition task is mediated by the right hemisphere neural subsystem is whether the recognition task requires a metrically precise coordinate representation. The results of Experiment 2 showed

that there is a right hemisphere advantage the task is to physically discriminate objects that differ only in their metric properties but that there is not a right hemisphere advantage for objects that can be discriminated using a structural description. The results of Experiment 2 therefore suggest that a critical factor determining which neural subsystem mediates a recognition task is whether the task can be mediated using a structural description representation or requires a metrically precise representation.

The results of Experiment 2 are also incongruent with all of the hypotheses regarding the neural subsystems except for the coordinate relations hypothesis. The results of Experiment 2 are incongruent with the category specific recognition hypothesis because the results suggest that the right hemisphere neural subsystem is used for physically discriminating non-biological objects provided the objects share the same structural description. None of the subjects in Experiment 2 were experts at performing the visual discriminations in the experiment. Therefore, the results of Experiment 2 are incongruent with the expert recognition hypothesis because the results suggest that the right hemisphere neural subsystem is recruited for some recognition tasks the viewer is not an expert at performing. Lastly, the results of Experiment 2 suggest that level of visual categorization is not a critical factor that determines which neural subsystem subserves a recognition task. In Experiment 2, the level of visual categorization was held constant across conditions, but only

the metric change condition showed the right hemisphere advantage indicative of the neural subsystem that subserves face recognition.

Experiments 3 and 4 were designed to provide further evidence for the coordinate relations hypothesis. Experiment 3 tested whether showing the metric change objects at different orientations eliminates the right hemisphere advantage for the metric change trials. Experiment 4 was designed to investigate the effects of metric vs. geon changes in priming. Unfortunately, the results of Experiments 3 and 4 were inconclusive (possibly due to a lack of statistical power in the experiments).

Although the results of Experiments 3 and 4 were inconclusive, Experiments 1 and 2 provide strong evidence for the coordinate relations hypothesis and are inconsistent with the other hypotheses regarding the neural subsystems. Therefore, the remainder of this dissertation will discuss the coordinate relations hypothesis in relation to issues within the fields of visual cognition and visual neuroscience.

Coordinate Relations vs. Holistic Representations

One of the most common suggestions that can be found in the literature regarding representational differences between face recognition and most forms of basic-level object recognition is that face recognition (unlike most forms of basic-level object recognition) relies on holistic or configural representations (e.g., Farah et al., 1998; Rhodes, 1993; Rhodes, Brake, Taylor, & Tan, 1989; Tanaka & Farah, 1993). Although the concept of a

holistic representation is somewhat poorly defined, it is generally agreed that holistic representations do not decompose shapes into parts to a significant degree (Farah et al., 1998). The concept of a configural representation is likewise somewhat poorly defined, but is generally agreed to mean that the spatial relations among the parts of an object are represented (Rhodes et al., 1989). Furthermore, it is thought that the right hemisphere neural substrates that subserve face recognition are involved in mediating holistic or configural representations (which explains why there is a right hemisphere advantage for face recognition) (e.g., Rhodes, 1993; Rossion et al., 2000). However, up to this point in this dissertation, I have not discussed holistic representations. Am I implicitly claiming that the right hemisphere neural subsystem does not mediate holistic or configural representations? The answer to that question is "not necessarily." All holistic representations are necessarily coordinate representations. Holistic representations are necessarily coordinate representations because holistic representations do not represent the visual features of a stimulus independently of one another or of their *coordinate* locations in a representation (Hummel, 2000). Therefore, when researchers claim that face recognition relies on a holistic representation, they are de facto claiming that face recognition relies on a coordinate representation.

Is Perceptual Expertise Completely Irrelevant?

Currently, the most commonly cited hypothesis regarding the function of the neural subsystem that subserves face recognition is the expert recognition hypothesis. Furthermore, the evidence (most of which is discussed in this paper) implicating perceptual expertise as a factor that can, under certain circumstances, cause the recruitment of the neural substrates that underlie face recognition is significant and mounting (Bruyer & Crispeels, 1992; Diamond & Carey, 1986; Gauthier & Nelson, 2001; Gauthier et al., 2000a; Gauthier & Tarr, 1997; Gauthier & Tarr, 2002; Gauthier et al., 1999b; Gauthier et al., 1998; Tarr & Cheng, 2003; Tarr & Gauthier, 2000). The position advanced in this paper is not that perceptual expertise has nothing to do with whether a recognition task is mediated using the neural subsystem that subserves face recognition. The position in this paper is simply that expertise is neither a necessary nor a sufficient condition for the neural subsystem that subserves face recognition to perform a recognition task. However, one possibility is that if viewers obtain sufficient expertise with certain types of recognition tasks, they will rely on coordinate representations when performing the task, and that therefore, they will rely on their neural subsystem that subserves face recognition. In fact, one of the appealing features of the coordinate relations hypothesis is that it *offers an explanation* regarding how shape representations might differ for experts and non-experts. That is, as viewers gain perceptual expertise with a visual task, their visual systems might be constructing fine-grained

coordinate representations that are used for the recognition task. Likewise, the coordinate relations hypothesis offers an explanation for why perceptual expertise with some types of recognition tasks (e.g., letter and text recognition) does not recruit brain regions that subserve face recognition. Because letters can be easily distinguished using categorical relations, there is no need to build fine-grained coordinate representations for reading. However, notice that all of the examples of expert recognition tasks that have been found to activate the neural substrates involved with face recognition (e.g., distinguishing different cars, dogs, and birds) are examples of recognition tasks that could not be performed using a structural description.

What are the Appropriate Stimuli in Object Recognition Experiments?

A lively debate has raged between proponents of structural description and coordinate relations theories of object recognition about what sorts of experimental stimuli and recognition tasks are appropriate for studying object recognition (Biederman, 2000; Biederman & Bar, 1999; Biederman & Gerhardstein, 1993; Biederman & Gerhardstein, 1995; Tarr, Bülthoff, Zabinski, & Blanz, 1997; Tarr & Bulthoff, 1995; Tarr, Williams, Hayward, & Gauthier, 1998). Experiments that have provided evidence for structural description theories have tended to use objects that activate different geons and categorical relations (e.g., Biederman & Gerhardstein, 1993). In contrast, experiments providing evidence for coordinate relations theories have often used sets of stimuli that would activate the same geons and relations. (e.g., Bulthoff & Edelman, 1992; Tarr & Pinker, 1989). Each

side has argued that the stimuli it uses are the most appropriate ones for studying object recognition processes.

The coordinate relations hypothesis might be helpful in resolving this debate. The coordinate relations hypothesis posits that both the structural description and coordinate relations representations exist and are represented in dissociable neural subsystems. Therefore, whether a set of stimuli is recognized using one system or the other depends on whether the recognition task with the stimulus set can be performed using a structural description representation or requires a coordinate relations representation. If a set of stimuli taps the subsystem that mediates structural descriptions, then there should not be a right hemisphere advantage for the recognition task. In contrast, if a set of stimuli is recognized using coordinate relations, then there should be a right hemisphere advantage for the recognition task, and inverting the stimuli should eliminate the right hemisphere advantage for the recognition task. Future research should examine the possibility that different sets of stimuli are tapping the two different neural subsystems.

Coordinate Relations and Category-Specific Brain Regions

One of the most exciting recent discoveries in the cognitive neuroscience of vision is the finding that different cortical regions within the ventral visual system are activated by visual tasks involving stimuli from different semantic categories (Chao et al., 1999a; Chao et al., 1999b; Haxby et al., 2001; Haxby, Ishai, Chao, Ungerleider, & Martin, 2000; Ishai,

Ungerleider, Martin, & Haxby, 2000). For example, it has been found that within the more medial regions of the fusiform gyrus, there are regions that respond more strongly to tools and houses and that within the more lateral regions of the fusiform gyrus, there are regions that responded more strongly to faces and animals (Chao et al., 1999a).

There is currently a large amount of research being performed to investigate the principles that underlie the category-specific organization of the visual system. (Chao et al., 1999a; Chao et al., 1999b; Haxby et al., 2001; Haxby et al., 2000; Ishai et al., 2000). Chao, Haxby, and Martin (1999a) suggested that the organization of the ventral visual system might be determined by object features that cluster together in the cortex, and that the nature of these features remains to be determined. However, notice that the coordinate relations hypothesis offers a natural account for why the regions that respond to houses and tools are clustered together and why the regions that respond to faces and animals are clustered together. Face and animal recognition are both tasks that rely on coordinate relations, and thus faces and animals would be expected to activate similar anatomical regions. In contrast, recognizing houses and tools can be performed using categorical relations, and thus houses and tools would be expected to activate similar anatomical regions. Therefore, it might be the case that the modules in the ventral visual system are anatomically organized according to whether the stimuli represented within the modules tend to be recognized using a representation that relies on coordinate relations. Specifically, maybe the lateral regions of

the fusiform gyrus are used for representing objects that tend to be recognized using coordinate relations whereas the medial regions of the fusiform gyrus are used for representing objects that tend to be recognized using structural description representations. In conclusion, the evidence for the coordinate relations hypothesis presented in this paper suggests a domain-general functional organization of the brain regions that underlie visual recognition. That is, the regions of the visual system that underlie visual recognition appear to be organized according to the computational problems posed by a recognition task rather than by the semantic category of the stimuli being recognized or by the level at which visual stimuli are categorized.

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