

2012

Configural, holistic, and coordinate processing: The same or different?

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Configural, holistic, and coordinate processing: The same or different?

by

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A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Majors: Psychology; Neuroscience

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2012

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ABSTRACT

Configural, coordinate, and holistic representations have all been proposed to explain why face recognition is more disrupted by inversion than other stimuli. The current study attempted to determine the nature of the representation that causes the face inversion effect. Experiments 1 and 2 compared the planar rotation functions for face, animal, and object recognition in order to determine whether the rotation function for faces was qualitatively different than the rotation functions for animals and objects. Experiment 3 examined the inversion effects produced by manipulating the number of features present in a face. Experiment 4 tested whether face like inversion effects could be found for houses that, like faces, shared the same structural description. The results of Experiments 1 and 2 showed that the planar rotation function for faces is qualitatively different (steeper) than the rotation functions for animals and objects. Experiment 3 found inversion effects for features of faces removed from the context of a whole face that grew larger as the number of features in the face increased. Experiment 4 found inversion effects for house stimuli that also increased as the number of features to be coded increased. The current set of experiments suggests that the face inversion effect is due to the precision required for the discrimination of objects, the amount of visual information to be coded by a coordinate representation, and the amount experience one has with forming a coordinate representation of an object from a particular orientation.

INTRODUCTION

In the past three decades scientists have made considerable progress in understanding the human species in a number of areas: geneticists have mapped the human genome, molecular biologists have made considerable progress in understanding various cancers and diseases, and the advances of computer technology have provided researchers with the ability to record, model, and analyze data in ways that would not have been possible thirty years ago. Despite the considerable progress scientists have made, scientists still do not completely understand how the neural processes underlying human perception and cognition are performed. Currently vision scientists do not agree on the number of specialized processes required to perform various types of object recognition. One area of considerable debate is whether or not two or more visual recognition systems are required to perform different types of object recognition. The current paper will review the evidence for different types of object recognition processing systems, discuss theories as to what those processing systems represent, and experimentally test the validity of the visual recognition systems posited by researchers.

Behavioral Dissociations

A number of behavioral studies suggest that basic-level object recognition differs from face recognition. "Basic-level" refers to the categorization level at which people tend to classify a presented object (Rosch, Mervis, Johnson, & Boyes-Braem, 1976; Rosch & Mervis, 1981). For example, if one were to present a picture of a glass to individuals and asked them to name the object,

they would say, “glass”. Behavioral experiments have found that humans have great difficulty recognizing faces, but not objects, that have been inverted. This phenomenon is called *the face inversion effect* (Valentine, 1988; Yin, 1969; 1970). Further evidence of differences between face and basic-level object recognition is that photographic negatives of faces are more difficult to recognize than normal photographs of faces, however, researchers do not find significant impairments in recognition of photographic negatives of objects (Galper, 1970; Galper & Hochberg, 1971). Finally, researchers using *the preferential looking paradigm* (Fantz, 1958, 1965) have found that infants will look at faces longer than non-face objects (Maurer & Barrera, 1981).

Neurophysiological Dissociations

In addition to the extensive behavioral evidence suggesting differences between face and basic-level object recognition, a number of researchers have examined whether dissociations could also be observed in the nervous system. Researchers have found dissociations between face and basic-level object recognition using brain damaged patients, event-related potentials (ERPs), single unit recordings, neuroimaging, and laterality studies. The next sections will discuss each of these paradigms in further detail.

Agnosia & Prosopagnosia

Researchers have found that certain lesions to the brain can produce different types of visual recognition deficits (for review, see Farah, 2004). In particular, researchers have reported a distinct population of brain-damaged patients called *visual form agnosics* (Benson & Greenberg, 1969) who are

impaired in basic-level object recognition. Another distinct population of brain-damaged patients called *prosopagnosics* (Bodamer, 1947) are impaired in face recognition, but retain the ability to perform most forms of object recognition.

Visual Form Agnosia is a deficit in which brain damaged patients retain elementary visual functions (e.g., they have relatively normal visual acuity, depth perception, motion perception, and color vision), but are impaired in their ability to recognize, copy, match, and discriminate basic-level objects (Farah, 2004). Visual form agnosia typically results from carbon monoxide poisoning (Milner et al., 1991), mercury poisoning (Landis, Graves, Benson, & Hebbon, 1982), or blunt force trauma (Gelb & Goldstein, 1918) that produces brain damage to posterior regions of the cerebral cortex resulting in bilateral damage to the occipital lobes and proximal regions.

Prosopagnosia is a deficit in which brain-damaged patients retain the ability to recognize basic-level objects, but are impaired in their ability to recognize faces (for review, see Mayer & Rossion, 2007). Prosopagnosia often results from bilateral temporo-occipital lesions (Damasio, Damasio, & Van Hoesen, 1982), although prosopagnosia can also result from unilateral damage to the right temporo-occipital cortex (De Renzi, 1986a;1986b; Wada & Yamamoto, 2001). Prosopagnosia is typically caused by posterior cerebral artery infarcts (Brand, Steinke, Thie, Pessin, & Caplan, 2000) and head trauma (Mayer & Rossion, 2007).

Research suggests that object agnosia and prosopagnosia are relatively dissociable. For example, researchers have reported object agnosics that retain

the ability to recognize faces (Humphreys & Rumiati, 1998; Moscovitch, Winocur, & Behrmann, 1997; Rumiati, Humphreys, Riddoch, & Bateman, 1994), and other researchers have described of some prosopagnosics who are impaired in face recognition, but can perform most forms of object recognition (De Renzi, 1986; Farah, Levinson, & Klein, 1995; McNeil & Warrington, 1993; Sergent & Signoret, 1992). Although prosopagnosics can perform basic-level object recognition, many prosopagnosics exhibit significant deficits when discriminating objects that are visually similar. For example, prosopagnosics often have difficulty discriminating different four legged animals, currencies, plants, and buildings sharing the same general features (Farah, 2004; Mayer & Rossion, 2007).

A number of researchers have developed theories to explain the other sorts of recognition tasks (beyond face recognition) that are impaired in prosopagnosia. Some researchers have proposed that the deficits observed in prosopagnosics reflect a general deficit in the ability to differentiate biological visual stimuli (Cappa, Frugoni, Pasquali, Perani, & Zorat, 1998; Caramazza & Shelton, 1998; Chao, Martin, & Haxby, 1999). Support for the biological hypothesis is provided by the fact that the most frequently co-occurring symptoms in prosopagnosia is difficulty discriminating different animals (Bornstein, Stroka, & Munitz, 1969).

Although prosopagnosics do have difficulty in visually recognizing certain classes of biological stimuli, the biological hypothesis does not fully explain the sorts of visual impairments seen in prosopagnosics. For example, Damasio, Damasio, and Van Hoesen (1982) reported that the prosopagnosics they tested

could always discriminate biological stimuli that had unique structural descriptions (e.g., they could discriminate visually similar objects, such as a owl from a horse). Furthermore, Damasio et al. noted that the prosopagnosics they tested displayed impairments in recognition of non-biological stimuli such as differentiating different cars. Damasio et al. posited that the deficits observed in prosopagnosia are more accurately portrayed as an impairment in the ability to recognize and differentiate different visual stimuli that require distinguishing between two members of the same basic-level category (i.e., *subordinate level recognition*: discriminating objects within the same basic-level category). One limitation to this *subordinate recognition hypothesis* is that prosopagnosics often have difficulty recognizing visual stimuli that do not belong to the same subordinate class. For example, prosopagnosics have difficulty discriminating different four legged animals that do not belong to the same basic-level category (e.g., discriminating a horse from a donkey; Mayer & Rossion, 2007).

More recently, researchers have posited that the deficits observed in prosopagnosia reflect impairments in tasks at which the individual has acquired visual expertise for a given class of objects (Diamond & Carey, 1986; Gauthier, Sudlarski, Gore, & Anderson, 2000; Gauthier & Tarr, 1997). Rather than positing that face recognition is “special”, *the expert recognition hypothesis* posits that participants use the face recognition system, which is impaired in prosopagnosics, when discriminating visual objects within a class for which the individual has acquired expertise. “Greeble” studies have provided some of the most convincing data for the expert recognition hypothesis (Gauthier et al., 2000;

Gauthier & Tarr, 1997; Richler, Bukach, & Gauthier, 2009). Greebles are novel homogeneous visual stimuli that have been used to show that non-face stimuli can exhibit similar patterns of results in research paradigms that have been used to demonstrate that face recognition is unique. A limitation of the expertise recognition hypothesis is that prosopagnosics are often impaired at visual tasks in which they would not be considered an expert in (e.g., some prosopagnosics are impaired in differentiating different plants, but were not in any way “plant experts”; Damasio et al., 1982).

None of the aforementioned theories can explain why prosopagnosics are commonly impaired in the recognition of visually similar non-face stimuli. One common theme from the literature on prosopagnosics is that they have difficulty in discriminating and recognizing visual stimuli that share common structural descriptions (Biederman, 1987). In theories positing a structural description, the relations among the parts of an object are coded using broad categories rather than specific values, such as the relative position (above, “below”, and “side of”), size (“larger than”, “smaller than”, and “equal to”) and orientation of the relations to one another (“parallel to”, “perpendicular to”, and “oblique to”). Casner and Cooper (2006) proposed that the recognition system impaired in prosopagnosics is used to discriminate objects sharing the same structural description. Support for this hypothesis is provided by researchers who have found that prosopagnosics they have tested are largely impaired in recognition tasks in which the structural descriptions of the objects to be compared do not differ (Barton, Cherkasova, Press, Intriligator, & O’Connor, 2004; Levine & Calvanio,

1989).

In summary, although researchers agree that the deficits observed in object agnosia and prosopagnosia differ qualitatively, researchers have not reached an agreement as to what the differences reflect.

ERP Studies

In the past few decades, researchers using *event-related potentials* (ERPs) have presented a number of studies that suggest that the temporal processing of face recognition differs from that of basic-level object recognition. ERPs are a measure of brain activity acquired by averaging multiple *electroencephalography* (EEG) responses when performing a particular task or when presented with a stimulus of interest. An ERP component is an identifiable part of the larger ERP wave that is presumed to represent a particular stage of neurophysiological processing. Researchers have found at least three separate ERP components that occur during tasks involving face processing that are absent or attenuated during tasks involving basic-level objects.

The P1 component

The P1 is a positive visual ERP component that appears to be generated from the striate and extrastriate cortex approximately 100-120 ms following the presentation of visual stimuli (Gonzales, Clark, Fan, Luck, & Hillyard, 1994). Itier and Taylor (2002) found that the amplitude of the P1 component was significantly larger when participants viewed face rather than non-face stimuli. Although the functional significance of the P1 component in face processing remains unclear, researchers have generated various hypotheses as to what the P1 differences

found between faces and non-face objects represent. Itier and Taylor (2002) proposed that the P1 component may reflect an early global response to faces—possibly representing faces holistically. Rossion et al. (1999) observed that the P1 component's amplitude was larger when participants performed a face recognition task than when they performed a gender discrimination task and suggested that the observed difference reflected task difficulty. Lastly, Doi, Sawada, and Masataka (2007) proposed that the observed differences between faces and non-face stimuli might reflect the initial processing of eye-gaze. *The VPP and the N170 components*

The vertex positive potential (VPP) and N170 components have been two of the most studied face processing components. Jeffreys (1989) compared participants' ERP responses to face and non-face stimuli and found that faces elicited a more positive deflection than non-faces approximately 150-200 ms after stimulus onset at central midline electrodes of the scalp that he named the VPP. More recently, researchers recording at electrodes over the occipito-temporal regions of the scalp have reported a negative wave that begins around 170 ms after the visual presentation of a face that was absent (or attenuated) for visually presented non-face stimuli (Bentin, Allison, Puce, Perez, & McCarthy, 1996; George, Evans, Fiori, Davidoff & Renault, 1996). Several researchers have proposed that the vertex positive potential and the N170 could arise from the same neural generator and that they are merely opposite sides of the same dipole (George et al., 1996; Itier & Taylor, 2002; Joyce & Rossion, 2005; Luck, 2005; Rossion et al., 1999).

Converging evidence suggests that the N170 component reflects structural encoding of faces (such as computing the location of each visual primitive in a face relative to one another) rather than the recognition of individual faces. For example, a number of studies have failed to find differences between familiar and unfamiliar faces in N170 amplitude and/or latency (Eimer, 2000; Rossion et al., 1999). A recent study found hemispheric differences between configural-change face tasks (discriminating two faces in which one part differs in length) and featural-change face tasks (discriminating faces in which the identity of one feature has changed; Scott & Nelson, 2006). Scott and Nelson reported that the N170 amplitude for configural-change tasks was greater in the right hemisphere, whereas the N170 for featural change tasks was greater in the left hemisphere. Given these results it is possible that the N170 observed in each cerebral hemisphere reflects different forms of face processing.

In contrast to researchers who posit the selectivity of the N170 to facial stimuli, Thierry, Martin, Downing, and Pegna (2007) posit that the N170 is an artifact of differences in *interstimulus perceptual variance* (ISPV) between faces and non-face stimuli. What Thierry et al. meant by ISPV is that if all the face stimuli from the previous ERP studies were averaged, the resulting image would still be recognizable as a face. However, if the non-face stimuli from the previous ERP studies were averaged, the resulting image would not be recognizable as any particular object. Thus, the faces in previous studies were more visually similar than the non-face objects. Thierry et al. found that the amplitude of the N170 component was reduced when the ISPV was high (i.e., the

objects are visually dissimilar) compared to when it was low (i.e., the objects are visually similar) for both pictures of faces and non-face objects. However, the N170 amplitude was greatest for low ISPV face stimuli. The finding that low ISPV would increase the amplitude of the N170, is consistent with Cooper and Brook's (2004) proposal that the face recognition system is used for differentiating visual stimuli that share structural descriptions because stimuli that share structural descriptions will have very low ISPV under Thierry et al.'s definition.

Researchers have found that the amplitude and latency of the N170 can be modulated by expertise (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Tanaka & Curran, 2001; Gauthier, Curran, Curby, & Collins, 2003; Busey & Vanderkolk, 2005; Rossion, Collins, Goffaux, & Curran, 2007). Tanaka and Curran (2001) found the N170 component was earlier when bird and dog experts performed a categorization task of objects within their domain of expertise relative to outside their domain of expertise. These results suggest that expertise for classes of objects sharing structural descriptions (i.e., birds and dogs) can produce N170 components similar to the N170 observed for faces.

Taken collectively, the ERP literature on face processing shows that there are differences in certain ERP components for face and non-face stimuli.

Single Unit Recordings

Studies using single unit recordings (i.e., recording the electrical activity of individual neurons) in macaques have found that certain regions of the macaque brain contain neurons that fire more to faces than to non-face stimuli (for a

review, see Rolls, 2007). Baylis, Rolls, and Leonard (1987) recorded from more than 2600 neurons in architecturally defined visual areas of macaques and found that as many as 20% of neurons in the *superior temporal sulcus* (STS) and TE (analogous to the inferior temporal cortex in humans; Orban, Van Essen, & Vanduffel, 2004) were more selective to faces than to non-face stimuli.

Interestingly, Baylis et al. (1987) reported that the face selective neurons were widely distributed amongst neurons that were not face selective throughout the temporal cortex of macaques. Considerable research has found that neurons that respond more selectively to facial expression are more likely to be found in the STS (Desimone, 1991; Hasselmo, Rolls, & Baylis, 1989), whereas neurons that respond selectively to an individual face were more likely to be found in TE (Hasselmo et al., 1989; Rolls, 2000).

Although regions of TE contain neurons that are selective to faces, researchers have also used single unit recordings to demonstrate that regions of TE contain neurons that selectively respond to certain forms of complex objects rather than to faces, single shapes, or visual gratings (Gross, 1992; Tanaka, 1993; for review see Tanaka, 1996). For example, Tanaka (1993) found that area TE of the inferotemporal cortex of macaques displayed some degree of columnar organization for complex object features (i.e., columns of cells responding to similar shapes are found close to one another). The columnar organization found by Tanaka was not as pronounced as that observed by Hubel and Wiesel (1959) in layer 4 of the primary visual cortex. Consistent with Baylis et al. (1987), not all of the neurons recorded by Tanaka (1993) within a given

area of TE were selective for a particular complex object. Research has shown that as one moves anteriorly through IT, the cells require increasingly more complex stimuli to activate them (Gross, 1992; Tanaka, 1993).

Some of the face selective and the non-face selective cells in TE show viewpoint dependence while others show at least some degree of viewpoint invariance. Specifically, researchers have found that some cells will fire to several different depth or planar rotations of the same face (Hasselmo, Rolls, Baylis, & Nalwa, 1989) or non-face object (Booth & Rolls, 1998; Logothetis & Sheinberg, 1996).

Researchers, recording from a number of face selective neurons in TE, have demonstrated that the pattern of neural firing from the face selective neurons differs reliably from one individually presented face to another (Rolls, 2000). Furthermore, the firing pattern of these cells allowed researchers to reliably differentiate which face was presented (for review see Rolls, 2007). Extensive research examining the firing properties of neurons in TE suggests that visual representations are the product of the differential firing properties of many neurons rather than the firing properties of a single neuron (Gross, 1992; Rolls, 2000; Rolls, 2007). Rolls (2007) states that based on the response properties of the face selective and non-face selective cells in TE, there is no reason to suppose that the coding of faces is qualitatively different than the coding of non-face stimuli.

Neuroimaging Studies

A number of studies using *functional magnetic resonance imaging* (fMRI)

techniques have presented data that suggest that different regions of the brain are more active for some types of visual recognition tasks than others. fMRI is an imaging technique that relies on the differences in magnetic properties between oxygenated hemoglobin and deoxygenated hemoglobin to determine which regions of the brain are absorbing greater quantities of oxygen during a particular task (Poldrack, Mumford, & Nichols, 2011). In theory, the areas of the brain that have greater quantities of deoxygenated hemoglobin have absorbed more oxygen as a result of that particular task's demands (i.e., those areas were more activated).

Face-selective Superior Temporal Sulcus (fSTS)

Consistent with single unit recordings from the superior temporal sulcus of macaques (Desimone, 1991; Perrett et al., 1991), researchers using fMRI in humans have found a region of the superior temporal sulcus that is more active for face than non-face stimuli that has been named the *face-selective superior temporal sulcus* (fSTS; see Figure 1 for location; Allison, Puce, & McCarthy, 2000; Hoffman & Haxby, 2000). The fSTS appears to be more involved in the perception of eye-gaze and facial expression than in the recognition of faces (Allison et al., 2000; Hoffman & Haxby, 2000). In fact, a recent study reported that the fSTS was activated by the directional information from eye gaze but not from the physical properties of the eyes (e.g., the shape of the eyes; Materna, Dicke, & Theier, 2008).

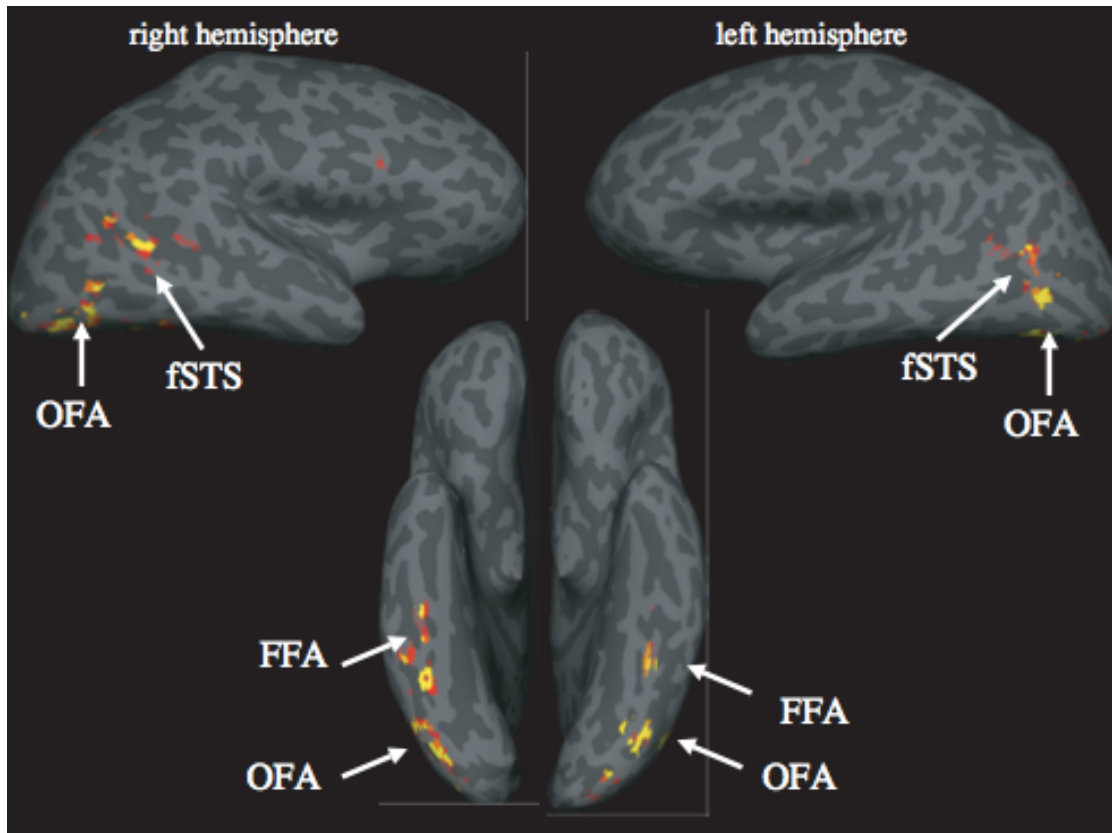


Figure 1. A display of the three face selective areas of the cerebral cortex observed in fMRI studies (taken from Kanwisher & Yovel, 2006). As previously noted, the right hemisphere displays greater activation in the occipital face area (OFA) and FFA than the left hemisphere.

Fusiform Face Area

Kanwisher, McDermott, and Chun (1997), using fMRI, reported a region in the fusiform gyrus that displayed greater activity during passive viewing when subjects viewed faces than when viewing non-face objects that Kanwisher et al. named the region the *fusiform face area* (FFA; see Figure 1 for location).

Sergent, Ohta, and Macdonald (1992) have reported similar findings using positron emission tomography imaging. Activity in the FFA is greater in the right hemisphere than in the left when an individual is viewing faces (for review see Kanwisher & Yovel, 2006). Kanwisher et al. claimed that the FFA was “a module

for face processing”. Researchers have questioned the selectivity of the FFA for faces, however. Researchers (Gauthier et al., 1997; Gauthier et al., 2000) have posited that the FFA is not a module for face processing per se, but rather mediates the processing of objects for which the participant has acquired expertise. Gauthier et al. (2000) conducted a study in which bird experts and car experts performed object recognition both within and outside their area of expertise. Gauthier et al. reported that the FFA was activated more when participants performed object recognition within their area of expertise. Grill-Spector et al. (2004) reported that although the FFA was activated in experts while they performed object recognition, its activity level did not correlate with their performance on the task. Nonetheless, Grill-Spector et al. (2004) reported that, in the same set of subjects, the FFA did correlate with the ability to perform face recognition. In contrast to the results of Grill-Spector et al., Harley et al. (2009) examined the performance differences between expert and novice radiologists in identifying abnormalities in x-ray images. Harley et al. found that although there was not a reliable difference in the FFA activation between expert and novice radiologists, the activation of the FFA was highly correlated with behavioral performance for experts but not for novices.

Researchers have begun to examine how the manipulation of a face’s parts (e.g., face, mouth, and nose) and how the manipulation of a face’s configuration (e.g., the spacing between the parts of a face) affects activity in the FFA and other areas involved in visual processing (Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001; Rossion et al., 2000; Rotshtein, Geng, Driver, & Dolan,

2007; Yovel & Kanwisher, 2004). There currently exists no clear consensus on the precise anatomical locations that respond to changes in features and those that respond to changes in the configuration of features, as indicated by fMRI. For example, some studies have found that part changes for faces (and objects) increase activity in the *lateral occipital cortices* (LOC, Lerner et al., 2001; Yovel & Kanwisher, 2004), and others have found increased activity for part changes in the left FFA (Rossion et al., 2000). For configuration changes, some researchers have reported increased activity bilaterally in the fusiform gyrus (Lerner et al., 2001), while others found activity unilaterally in the right FFA (Rossion et al., 2000), and still others failed to find any effect of configuration changes on activity in the FFA compared to part changes (Yovel & Kanwisher, 2004). More recently, Rotshtein et al. (2007) found that the nature of the task can differentially affect fMRI activity. Rotshtein et al. found that part changes to faces correlated with greater activity in the LOC during face discrimination tasks, while configuration changes correlated with greater activity in the right FFA during face recognition tasks.

Occipital Face Area

The *occipital face area* (OFA) is one of the least understood face-selective regions in humans (see Figure 1 for location; Gauthier et al., 2000; Puce, Allison, Asgari, Gore, & McCarthy, 1996). The OFA is a region in the LOC that displays greater activation for faces or parts of faces than for non-face objects or parts of non-face objects (for reviews see Atkinson & Aldophs, 2011; Pitcher, Walsh, & Duchaine, 2011). The OFA tends to be larger in the right hemisphere than in the

left (Atkinson & Aldophs, 2011), and at present, researchers do not agree on the functional role of the OFA (Atkinson & Aldophs, 2011).

Some research, using *transcranial magnetic stimulation* (TMS), has provided data that suggest the OFA represents the features of a face (e.g., nose, eyes, and mouth; Pitcher et al., 2011). TMS is a research technique in which brief magnetic pulses are applied to a region of interest on the scalp in order to briefly disrupt neural signaling in a localized area of interest (Bolognini & Ro, 2010). Pitcher, Walsh, Yovel, and Duchaine (2007) applied repeated TMS to the right OFA while participants performed a feature discrimination task for faces and houses and found that TMS to the right OFA impaired participants' ability to discriminate features of faces but not their ability to discriminate features of houses. Further, Pitcher et al. (2007) reported that participants did not show deficits in discriminating the distances between features of the face when TMS was applied to their right OFA. As a result of these studies, Pitcher et al. (2011) posited that the OFA is involved in the initial coding of the features of a face (rather than coding the distances between features) and precedes the activity observed in the FFA.

A growing body of literature, using fMRI, suggests that the OFA and the FFA appear to be more active when participants view faces rather than non-face objects. Rhodes, Michie, Hughes, and Byatt (2009) posited that the OFA also plays a role in the coding of the spatial relations of a face, while others posited that the OFA and FFA are not face selective processing regions, but are involved

in individuating specific stimuli from within a given category (Haist, Lee, & Stiles, 2010).

Laterality Studies

The fMRI literature shows that regions of the right cerebral hemisphere appear to be more involved in the recognition of faces than most non-face objects. In addition to neuroimaging studies, researchers have performed laterality studies to investigate whether face recognition tasks are performed faster in the right hemisphere. Consistent with the fMRI literature, many researchers have found that face recognition is performed faster when presented to the left visual field (LVF)/right hemisphere (RH) than to the right visual field (RVF)/left hemisphere (LH; for review, see Ellis & Young, 1989; Hillger & Koenig, 1991; Leehey, Carey, Diamond, & Cahn, 1978; Levine Banich, & Koch-Weser, 1988). In contrast, most forms of basic-level object recognition (i.e., discriminating objects with different structural descriptions) fail to display laterality effects (Biederman & Cooper, 1991a; Bryden & Rainey, 1963; Kimura & Durnford, 1974; Levine & Banich, & Koch-Weser, 1982; Young, Bion, & Ellis, 1980).

Although most forms of basic-level object recognition do not show hemispheric differences in visual processing speed, a number of studies suggest certain forms of object recognition may be partially reliant on the processing the RH subserves. Specifically, many lines of research suggest that there are hemispheric differences in the processing of categorical relations (i.e., judging the relative positions of visual primitives to one another) and coordinate relations

(i.e., judging the precise metric distances of the visual primitive from one another). In particular, studies that have required participants to compute the relations between objects have shown different hemispheric effects that depended on whether or not the task required categorical or coordinate processing (Hellige & Michimata, 1989; Kosslyn, 1987; Kosslyn, Chabris, Marsolek, & Koenig, 1992; Kosslyn et al., 1989; Rybash & Hoyer, 1992; Sergent, 1991). Tasks in which participants were required to code the coordinate information (i.e., exact metric distances) between two objects, such as deciding whether a dot was within 3 mm of a line, show a strong RH advantage. In contrast, tasks in which participants are required to code categorical information between two objects, such as deciding whether a dot was above or below a line, have either shown a small RH advantage (Hellige & Michimata, 1989; Kosslyn et al., 1989) or no hemispheric advantage (Rybash & Hoyer, 1992; Sergent, 1991).

In recent years, researchers have examined whether the RH advantage observed for coordinate tasks that required participants to judge the coordinate relations between two objects could also be observed in object recognition tasks in which coding of the precise coordinate locations of an object's primitives would be required for object recognition. A number of studies have found a RH advantage for tasks that require a participant to code the coordinate relations of an object (Burgund & Marsolek, 2000; Brooks & Cooper, 2006; Cooper & Brooks, 2004; Laeng, Zarrinpar, & Kosslyn, 2003; Marsolek, 1999; Saneyoshi & Michimati, 2009) and a LH advantage for tasks that only require participants to code the categorical relations of an object (Burgund & Marsolek, 2000; Laeng,

Zarrinpar, & Kosslyn, 2003; Marsolek, 1999; Saneyoshi & Michimati, 2009).

Basic-Level Object Recognition

Hitherto, the paper has only discussed dissociations between face recognition and basic-level object recognition without discussing theories about how the representations of basic-level objects and faces differ. This section will discuss theories about how basic-level objects are represented for the purpose of recognition.

First-order Relations

Diamond and Carey (1986) proposed that most forms of basic-level recognition are performed using *first-order relations*. Diamond and Carey posited that objects that do not share what they call, “the same configuration” can be distinguished from one another using first-order relations, which are “the spatial relations among similar parts” (p110). Diamond and Carey used Rosch’s (1978) *superimposition test* when determining whether or not an object shares the same configuration. Rosch classified two objects as having different configurations if the outlines of two objects superimposed have very little overlap (e.g., superimposing a dog and house). Diamond and Carey’s example of first-order relations is “the distance between a foreground rock and a background tree” in a landscape. A limitation of Diamond and Carey’s first-order relations is that they merely give an example to explain first-order relations without giving a formal definition. Recently, Maurer, Le Grand, and Mondloch (2002) defined the first order relations of a face as “seeing a stimulus as a face because its features are arranged with two eyes above a nose, which is above a mouth”, which appears

to be contrary to Diamond and Carey's definition, which involved distances between primitives rather than relative positions. Like Diamond and Carey, Maurer et al. do not mention exactly how first-order relations are coded.

Recognition by Components

Biederman (1987) proposed that the human visual system performs basic-level object recognition using a representation that codes an object's parts and the categorical relations between the parts. Such a representation is called a *structural description* (Biederman, 1987). In theories positing a structural description, the relations among the parts of an object are coded using broad categories rather than specific metric distances. Hummel and Biederman (1992) proposed that the relations among an object's parts are defined by their relative position ("above", "below", and "side of"), size ("larger than", "smaller than", and "equal to") and orientation to one another ("parallel to", "perpendicular to", and "oblique to"). For example, in Biederman's (1987) theory, the coffee mug in Figure 2 would be coded as a "cylinder with a curved cylinder to the side", whereas the bucket in Figure 2 would be coded as a "cylinder with a curved cylinder above".



Figure 2. Examples of how structural descriptions can be used to differentiate basic-level objects. In a structural description theory, the mug would be coded as a “cylinder with a curved cylinder to the side”, and the bucket would be coded as a “cylinder with a curved cylinder above”.

There are a number of computational advantages to using a structural description for object recognition. The same structural description for an object can be activated regardless of an object’s size, position, and orientation, and recognition using structural descriptions is robust to noise and partial occlusion (Biederman, 1987). Biederman and Cooper (1991b) tested whether a structural description coding an object’s parts is activated during object recognition using visual priming experiments. They found that the visual priming effect in their study was entirely mediated by the representation for an object’s parts.

Theories About How the Representation for Recognizing Objects & Faces Differ

A number of theorists have attempted to describe the differences in the representations used to identify objects at the basic-level and faces. *Configural*,

holistic, and *coordinate* are three forms of representation that theorists have used to characterize how the representation of faces for purposes of recognition differs from that of objects.

Configural and Holistic Processing

There is great variability in how researchers use the terms “configural” and “holistic”. For example, some researchers define configural processing as a *style of mental processing* (Mauerer, Le Grand, & Mondloch, 2002; McKone, 2008), while others have defined configural processing as a *type of information* that codes the metric distances between the parts of an object (Leder & Carbon, 2006). Although many researchers use holistic and configural processing synonymously (for reviews see McKone & Yovel, 2009; Rossion, 2008), some researchers posit that holistic processing is qualitatively different from configural processing (Maurer et al., 2002; Tanaka & Farah, 1993). For example, Maurer et al. defines holistic processing as “glueing together the features into a gestalt”(p. 255).

Tanaka and Farah (1993) define holistic representations as “representations without an internal part structure” (p. 225). Tanaka and Farah posit that holistic representations code the entire face without any decomposition of the parts of the face. Tanaka and Farah found that participants were better at identifying a part of a face when presented in the context of a whole face than when a part of the face was presented in isolation. Further they argued that holistic representations are unique to face processing because they failed to find a part identification advantage for houses (e.g., performance for the recognition

of a “door” did not improve when it was presented in its normal location in a house as compared to in isolation).

Coordinate Relations

A problem arises for structural description theories when an individual has to differentiate two objects that share the same structural description. For example, structural description theories cannot explain how the visual recognition system can differentiate the two mugs in Figure 3. Both mugs’ structural descriptions would be identical (i.e., “a cylinder with a curved cylinder to the side”). Cooper and Wojan (2000) posited that object recognition tasks that require a participant to differentiate two objects sharing similar structural descriptions would rely on coordinate relations. Coordinate relations representations code the precise distances of each object primitive (i.e., part) from a fixed reference point or set of fixed reference points. For example, Figure 4 illustrates how a categorical representation (i.e., a structural description) and coordinate relations representation would code the position of my right eye (from the viewer’s perspective). A categorical relations representation would code my right eye as being, “to the side of the left eye, above and to the side of the nose, and above and to the side of the mouth.” In contrast, a coordinate relations representation would code my right eye as being 4 units below and 2.66 units to the right of the specified reference point.



Figure 3. These mugs would not be differentiated by a structural description representation.

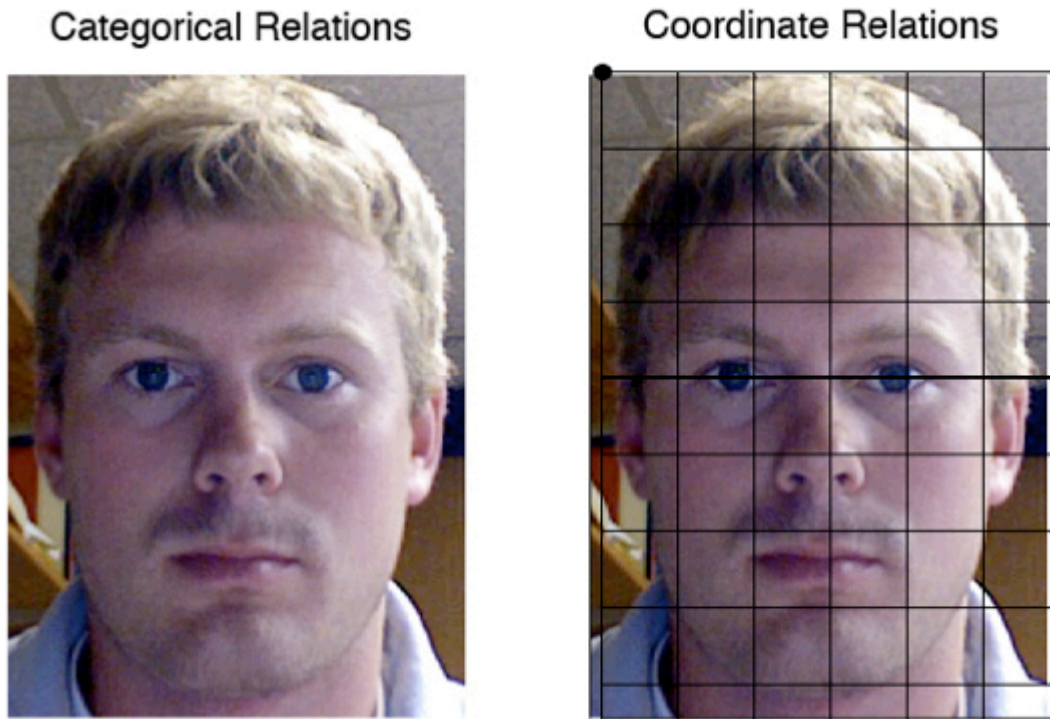


Figure 4. Illustration of how categorical (left picture) and coordinate relations (right picture) would code the position of the left eye of a face. Categorical relations would code the left eye as “side of” the right eye, “above” and “side of” the nose, and “above” and “side of” the mouth. In contrast, coordinate relations would code the left eye as 4 units below and 2.66 units to the right of the given reference point.

The *coordinate relations hypothesis* (Cooper & Wojan, 2000) proposes that most basic-level object recognition tasks use a representation of shape that codes the spatial relations among the parts categorically, but that face recognition and other tasks that require discrimination between objects sharing the same structural description are accomplished using a representation that codes coordinate relations (Cooper & Wojan, 2000). A number of studies show that distinguishing non-face objects that share structural descriptions produce behavioral effects that are similar to those that are found in the face recognition literature (Brooks & Cooper, 2006; Cooper & Brooks 2004; Cooper & Wojan, 2000). For example, Cooper and Brooks (2004) found that the effects of planar

rotation on the recognition of animals produce a rotation function similar to that for recognizing faces. Additionally, the data from ERP, prosopagnosia, single unit recordings, and fMRI also suggest that common neural structures are used when discriminating faces and when discriminating non-face objects that share the same structural description. Cooper and Wojan's coordinate relations theory, unlike the configural representation theory, makes specific predictions as to the circumstances when the representation used for basic-level object recognition will be used to perform a recognition task and the circumstances when the representation used for face recognition will be used. The coordinate representation should be used any time the test requires subjects to distinguish stimuli sharing the same structural descriptions.

Expertise

A number of vision scientists stress that expertise is needed in order for the visual system to code the representation of non-face objects in the same fashion that it codes faces (for a review, see Bukach, Gauthier, & Tarr, 2006). There is no doubt that experience with objects is necessary for the proper development of the visual system (Hubel & Wiesel, 1959; Wiesel, 1982), however, it is not necessarily the case that expertise with a given class of visual stimuli is required in order for non-face objects to display face-like properties. For example, when participants are asked to discriminate among different animals that share the same structural description, their performance is hindered by rotation, just as it is for faces. The coordinate relations hypothesis can account for the effects of expertise if one presumes that the coordinate

representations used to distinguish objects that share the same structural description become more finely calibrated as a result of experience with making the discrimination. For example, the resolution of the coordinate representations of dog show judges for distinguishing Labrador Retrievers may become more precise for those regions of the dogs where the metric variations important for judging the dogs occur.

Additionally, the coordinate relations hypothesis predicts that judgments in a person's area of expertise would display face-like effects only when the objects to be discriminated share similar structural descriptions. For example, literate people have considerably more experience recognizing letters and words than recognizing faces, however, because different letters and words have different structural descriptions, the coordinate relations hypothesis would predict that distinguishing different letters and words would not display the behavioral effects associated with face recognition.

CURRENT STUDIES

The current set of studies seeks to answer a number of questions pertaining to the differences in the representations used for basic-level object recognition and for face recognition. The current studies tested whether the coordinate relations theory can explain the instances in which recognition of non-face objects exhibits face-like recognition effects.

As noted when the neurophysiological and brain-lesion literature was reviewed, there is a significant amount of data demonstrating neurological differences in the recognition of faces and most forms of basic-level object recognition. Cooper and Wojan (2000) posited that both categorical and coordinate representations are activated for every viewed object and that the nature of the object recognition task determines which representation is used. Specifically, Cooper and Wojan stated that a categorical representation is used for object recognition tasks that require participants to differentiate objects with different structural descriptions, and a coordinate representation is used for object recognition tasks that require participants to differentiate objects with the same structural description.

The purpose of the current dissertation is to determine whether a holistic representation, as defined by Tanaka and Farah (1993), is needed to explain the effects of planar rotation on the recognition of faces or whether a coordinate representation can explain the effects of planar rotation on the recognition of faces (Cooper & Wojan, 2000). The current series of experiments used planar rotation in order to determine whether faces are processed qualitatively

differently than non-face stimuli (Experiments 1 and 2), whether a coordinate representation can explain the face inversion effect (Experiment 3), and if non-face stimuli can show inversion effects similar to faces (Experiment 4).

Planar Rotation of Faces and Objects

Jolicoeur (1985) reported that times to recognize objects at the basic-level increase as planar rotation increases, but that there is a dip in response times at 180°. The dip in response times at 180° has since been reproduced by a number of studies (e.g., Cooper & Brooks, 2004; Jolicoeur, 1988; Jolicoeur & Milliken, 1989; McMullen & Farah, 1991; McMullen & Jolicoeur, 1990). In contrast, researchers examining the effects of planar rotation on face recognition never find a dip in response times at 180° (Ashworth, Vuong, Rossion, & Tarr, 2008; Valentine & Bruce, 1988). While some studies have found a linear relationship between response times to recognize faces and their degree of planar rotation (Ashworth et al., 2008; Valentine & Bruce, 1988), other studies have found a non-linear relationship between planar rotation and response times that resembles an inverted-U shape (Jemel, Coutya, Langer, & Roy, 2009; Rossion & Boremanse, 2008). However, *all* studies on the effects of planar rotation on face recognition fail to find the dip in response times at 180° that is observed for basic-level object recognition.

The different planar rotation functions observed for basic-level object recognition and face recognition can be explained by the coordinate relations hypothesis (Cooper & Wojan, 2000). Specifically, for tasks that require a participant to discriminate objects that share different structural descriptions,

Hummel and Biederman's (1992) object recognition model predicts an M-shaped recognition time function in which reaction times to recognize an object increase linearly from 0° to 135° of planar rotation but then decrease after 135° until they reach a local minimum at 180° of planar rotation from an object's upright viewpoint. That performance is poorest at 135° of planar rotation can be explained by the fact that it is the point at which all of the categorical relations among the parts of an object are spurious (i.e., "above", "below", and "side of"). Figure 5 provides an illustration of why planar rotation of an object that is recognized using categorical relations would produce an M-shaped recognition time function. In Figure 5, as the watering can is rotated in the picture plane, the cylinder and spouts' categorical relations change from "spout side of cylinder" at 0° to "spout above cylinder" at 90°, but return to "spout side of cylinder" at 180°. Although an object's "side of" relations are restored at 180°, Cooper and Brooks (2004) would predict that reaction times at 180° will not dip down as far as the reaction times at 0° if the object contains parts with "above" and "below" relations because "above" and "below" relations will be reversed from upright when the object is upside down. For example, in Figure 5, although the watering can's "side of" relations are restored at 180° of planar rotation, the watering can's cylinder and handle categorical relations are different than at 0°. Consistent with Hummel and Biederman's object recognition model, Cooper and Brooks (2004) found an M-shaped function in response times when participants had to recognize planar rotated objects that all had unique structural descriptions.

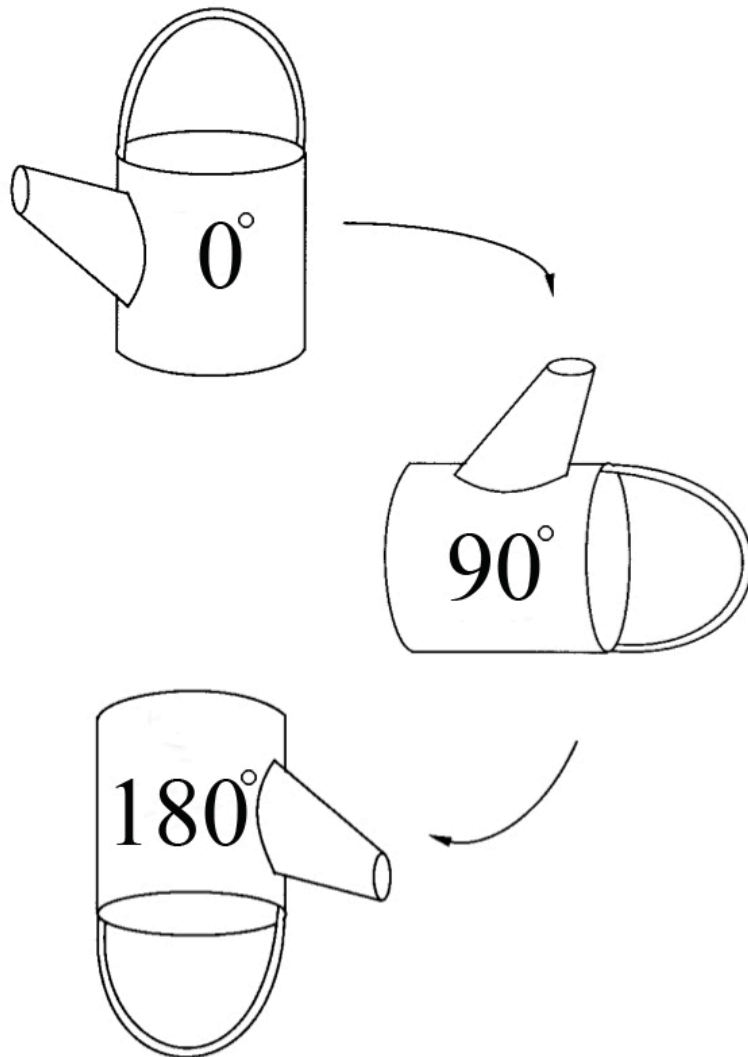


Figure 5. The watering can is rotated in the picture plane in 90° increments. The categorical relations of the watering can's cylinder to the other parts change from "side of" the spout and "below" the handle at 0° , to "below" the spout and "side of" the handle at 90° , to "side of" the spout and "above" the handle at 180° .

In contrast, Cooper and Brooks (2004) predicted that tasks that involve differentiating objects with the same structural description would produce a monotonic increase in recognition time as the amount of planar rotation approaches 180° . The monotonic increase is predicted because the primitives in a coordinate representation of an object become monotonically more distant from their stored upright representations as planar rotation approaches 180° .

Consistent with the coordinate relations hypothesis, Cooper and Brooks found that in an animal recognition task that required participants to name animals with similar structural descriptions, reaction times showed a monotonic increase as the amount of rotation approached 180°.

Some researchers have proposed that mental rotation can be used to explain the response time functions observed for the recognition of objects rotated in the picture plane (Shepard & Metzler, 1971). Shepard and Metzler's *mental rotation model* posits that participants mentally rotate objects to their upright orientation prior to object recognition. If subjects are performing mental rotation of an object prior to object recognition, their reaction time functions should show a linear increase from 0° to 180° of rotation and then a linear decrease from 180° to 360° because the time required to mentally rotate an object is a linear function of the amount of rotation the object has undergone (Shepard & Metzler, 1971). The mental rotation model thus predicts that reaction time, as function of planar rotation, should resemble an inverted-V.

Phenomenologically, most people would concede that one can mentally rotate an object, however, researchers question whether mental rotation is needed prior to the recognition of an object rotated in the picture plane (e.g., Cooper & Brooks, 2004; Perrett, Oram, & Ashbridge, 1998). Perrett et al. wrote a critical review of the mental rotation model and presented evidence from the single unit recording literature to conclude that the increased reaction times required to recognize rotated objects can be explained by the firing properties of the cells in the inferior temporal lobes. Perrett et al. posited that the speed to

recognize an object depends on the rate of accumulation of activity from neurons selective for an object. For any familiar object, observed in its appropriate orientation, more neurons will be tuned to the coordinate representation of the object in its upright orientation than to any planar rotation of the object away from upright. Perrett et al. posit that the planar rotation function in reaction times observed for objects can be explained by the length of time it takes for neurons in the inferior temporal cortex to become tuned to reach threshold for recognition of a given object. Perrett et al. posited that more posterior regions from the inferior cortex in the visual pathway likely are tuned more to the structural description of an object than to the coordinate representation.

Another problem with the mental rotation model for basic-level object recognition is that, rather than an inverted-V function for the recognition of objects rotated in the picture plane, basic-level object recognition often displays an M-shaped rotation function (e.g., Cooper & Brooks, 2004; Jolicoeur, 1985). However, the inverted-V function, posited by the mental rotation model, is consistent with the planar rotation functions observed by some researchers in face recognition tasks (e.g., Valentine & Bruce, 1988). Rather than a stimulus being mentally rotated before it is recognized, another possibility is that the activation level of the representations used for tasks that require discriminating objects with identical structural descriptions simply decreases as the Euclidean distance of an object's features from their stored coordinates increases. Specifically, the further the visual primitives of an object are from their standard upright coordinates, the lower the activation level of the representation used to

recognize the object and, therefore, the longer recognition will take (this is called the *Euclidean distance model*). Whereas the mental rotation model predicts an inverted-V function for planarly rotated objects, the Euclidean distance model predicts an inverted-U function. The Euclidean distance model predicts an inverted-U function because as an object is initially rotated from upright, the Euclidean distance of the features from the original positions change rapidly, but as the planar rotation of an object approaches 180°, the change in its Euclidean distances of the features from the stored coordinates become smaller and smaller. The Euclidean distance model of planar rotation is consistent with studies that have found an inverted-U function in reaction times for the recognition of faces (e.g., Ashworth et al., 2008; Jemel, Coutya, Langer, & Roy, 2009; Rossion & Boremanse, 2008) and objects (e.g., Ashworth et al., 2008; Cooper & Brooks, 2004) that have been rotated in the picture plane. Further, the Euclidean distance model is congruent with the single unit recording account of object recognition provided by Perrett et al. (1998).

An advantage of the coordinate relations hypothesis over the mental rotation model is that the coordinate relations hypothesis can explain instances in the planar rotation literature where researchers have found different rotation functions for the same set of stimuli when they changed the nature of the task (Jolicouer, 1988). For example, Jolicouer (1988) had subjects perform an object naming task and an orientation decision task (is the object facing left or facing right?) on the same set of objects. In the orientation task, subjects had to decide whether a rotated object would face left or right if it were in its upright orientation.

Jolicoeur found that the planar rotation function for reaction times in the object-naming task resembled an M-shaped function, but the rotation function for reaction times in the left-right decision task resembled an inverted-V function (indicating that mental rotation may have been involved). Experiments 1 and 2 will compare the rotation functions of faces, animals, and objects determine whether non-face objects, that require participants to discriminate objects that share structural descriptions, display a rotation function similar to faces. Further, Experiments 1 and 2 will attempt to replicate the M-shaped function for objects recognized at the basic-level.

Face Inversion

A number of researchers have conducted studies examining the face inversion effect (which is a special case of planar rotation in which the researcher compares the recognition of upright (0° planar rotation) faces from the recognition of inverted (180° planar rotation) faces (for reviews see, Rossion, 2008; McKone & Yovel, 2009)). Tanaka and Farah (1993) proposed that “holistic processing” was disrupted when faces were inverted and that holistic processing was unique to the recognition of upright faces (meaning holistic processing is activated by no other types of stimulus). During the study phase of their experiment, Tanaka and Farah first had participants learn the names for a series of scrambled-face and whole-face stimuli. During the test phase, participants then performed a feature discrimination task and a full-face discrimination task. In the feature discrimination task, participants were presented with an isolated feature of a face (e.g., a nose) they learned in the study condition and a feature

that served as a distractor. Participants had to indicate which of the presented features was part of a particular face they had learned during the study phase (e.g., identify “Larry’s nose”). In the full-face condition, participants were presented with two faces and asked to identify which of the two faces was a particular face they had learned during the study phase (e.g., identify “Larry”). In the full-face discrimination task the only difference between the two faces was a single feature (e.g., nose)—all other features and relations were held constant. Tanaka and Farah reported that participants were better at identifying the features of a face when presented in the context of a full-face than they were at identifying the same feature presented in isolation. Tanaka and Farah failed to find the aforementioned advantage for feature identification in full-object recognition for scrambled faces, inverted faces, and houses. Tanaka and Farah used the feature identification advantage observed when participants identified a face feature in its appropriate location in an upright face as evidence for a holistic representation of upright faces. Tanaka and Farah defined holistic representations as “representations without an internal feature structure”.

Some researchers have proposed that disruptions in the holistic representation of a face are a major contributor to the face inversion effect (Tanaka & Farah, 1993; Maurer et al., 2002). Consequently, if holistic processing were primarily responsible for the face inversion effect, then one would not expect significant face inversion effects for the inversion of features of a face removed from the context of a whole face. Therefore, a holistic representation cannot explain instances in which researchers have found

inversion effects for isolated features (e.g., isolation of the eye and brow region) of a face (Leder, Candrian, Huber, & Bruce, 2001; Rakover & Teucher, 1997). For example, Leder et al. found inversion effects across three different face-context conditions: eyes, eyes and nose, and eyes, nose and mouth.

Rather than proposing the existence of a third representation used for the processing of upright faces, an alternative explanation of the results obtained by Tanaka and Farah is that inversion of a face produces disruptions to the stored coordinates of the faces' features as the Euclidean distance of a face's features from their stored coordinates increases. For example, Figure 6 presents two versions of a face: a three-feature face and a whole-face. The whole-face and three-feature faces (e.g., two eyes and a mouth) in Figure 6 exert different demands on the coordinate representation system. Whole-faces have a greater amount of coordinate information to be coded than three-feature faces. When whole-faces are inverted, the coordinate representation of the whole-face is more disrupted than the coordinate representation of the three-feature face. The Euclidean distance model predicts that the further the visual primitives of a face are from their standard upright coordinates, the lower the activation level of the representation used to recognize the face and, therefore, the longer the recognition will take. The coordinate relations model predicts that the overall disruption of an inverted face-image would be less for a two-feature face than a whole face. As a result, the coordinate relations model would predict a greater face inversion effect as the number of features to be coded for a visual stimulus by the coordinate representation system increases.

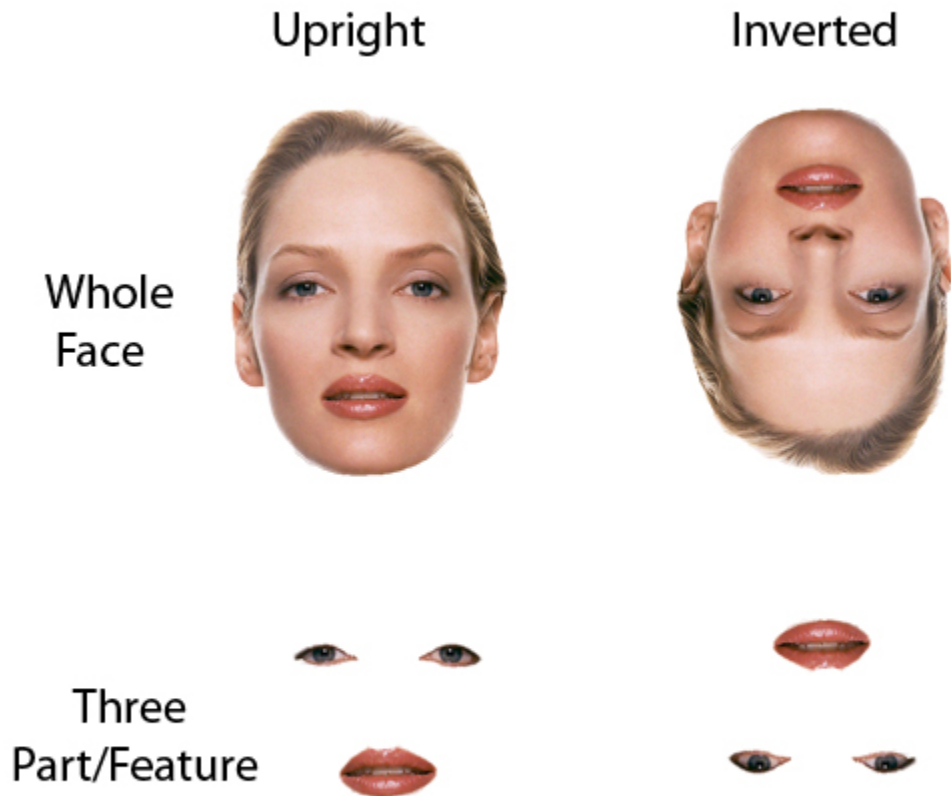


Figure 6. The whole face and three-feature faces (two eyes and a mouth) above exert different demands on the coordinate representation system. Whole faces have a greater amount of coordinate information to be coded than three-feature faces. When whole faces are inverted the coordinate representation of the whole face is more disrupted than the coordinate representation of the two feature faces.

Although most studies have found that inverting faces produces greater impairments in recognition than inverting non-face objects, researchers have found inversion effects for the recognition of certain types of non-face stimuli as well (McKone & Yovel, 2009). For example, the planar rotation literature has found greater recognition deficits for the recognition of non-face objects sharing similar structural descriptions that are rotated 180° in the picture plane, when compared to their standard upright orientations (for review, see Graf, 2006).

Consistent with studies of planar rotation, researchers find face-like inversion effects when participants are required to differentiate objects sharing similar structural descriptions (e.g., differentiating different animals; Cooper & Brooks, 2004). Researchers have reported large inversion effects when participants have extensive familiarity with non-face stimuli that requires differentiating visual stimuli sharing similar structural descriptions. For example, researchers have found inversion effects for expert dog judges (Diamond & Carey, 1986), participants trained to become experts in Greeble recognition (Gauthier & Tarr, 1997), and participants trained to discriminate visually similar houses (Husk, Bennett, & Sekuler, 2007).

Experiments 3 and 4 will test the coordinate relations model's predictions about the effects of inversion on a coordinate representation against Tanaka and Farah's holistic model. Experiment 3 will examine whether the inversion effect becomes larger as the number of features of a face to be coded by the coordinate representation system increases. Experiment 4 will examine whether the inversion effect becomes larger as the number of features of a house to be coded by the coordinate representation system increases.

Experiment 1

Cooper and Brooks (2004) examined the effects of planar rotation functions for two types of recognition tasks: an animal recognition task and an object recognition task. In the animal recognition task participants named animals that had similar structural descriptions, whereas in the object recognition task, participants named objects that all had different structural descriptions.

Consistent with the coordinate relations hypothesis (Cooper & Wojan, 2000), Cooper and Brooks found an inverted-U shaped rotation function in response times when participants named animals and an M-shaped rotation function in response time when participants named objects (see Figure 7). It is possible that the different rotation functions observed by Cooper and Brooks, and predicted by the coordinate relations hypothesis (Cooper & Wojan, 2000), could explain the face inversion effect. Specifically, for the recognition of faces at 180° of planar rotation, reaction times should be the slowest because that is the point where the face's coordinate representation is most disrupted. In contrast, for the recognition of basic-level objects at 180° planar rotation, reaction times would show a local minimum (rather than a maximum) because of the restoration of *side of* relations. As a result, when comparing basic-level object recognition to face recognition at 180° planar rotation, a "face inversion effect" is observed in which inverted faces appear to be more affected by rotation than inverted objects.

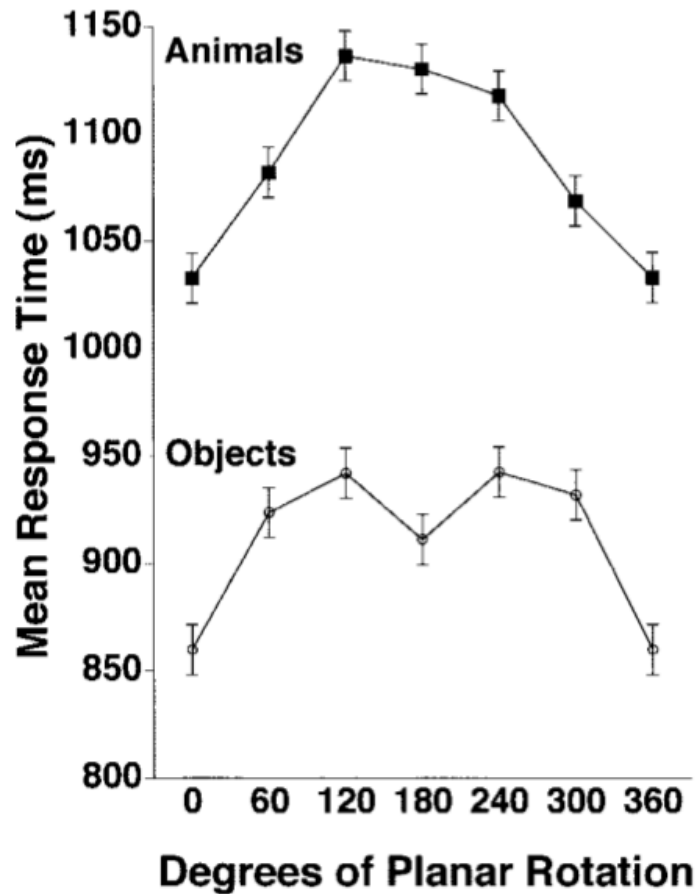


Figure 7. The rotation function obtained by Cooper and Brooks (2004) displayed an inverted-U function for animal recognition and an M-shaped function for object recognition.

Experiment 1 and 2 tested whether the inverted-U shaped rotation function observed for animal recognition by Cooper and Brook's (2004) would be similar for face recognition. Further, Experiment 1 and 2 tested whether the m-shaped rotation function observed for objects by Cooper and Brooks could be replicated using objects that had unique structural descriptions. In addition to using animals and objects, Experiment 1 also had participants perform a face recognition task in order to compare the rotation function of animals to that of faces to determine if the rotation functions for faces and animals differ qualitatively.

Experiment 1 differed from Cooper and Brooks (2004) in two ways. Participants in Experiment 1 were not required to generate names for the stimuli because Experiment 1 adds famous faces to the stimuli used by Cooper and Brooks, and previous research has established that generating names for faces is a difficult task (Cohen, 1990; Cohen & Faulkner, 1986; Young, Hay, & Ellis 1985). In Experiment 1, rather than requiring participants to verbally name the visual stimuli that are presented to them, participants saw a visual stimulus followed by a name and had to decide whether or not the name matched the visual stimulus. Cooper and Wojan (2000) previously used this method successfully to study face recognition. Second, whereas Cooper and Brooks had 36 stimuli for each category of visual stimuli, Experiment 1 used 72 visual stimuli in each category, because, unlike Cooper and Brooks, the current study had both positive (same) and negative (different) trials and only data from “same” trials were of interest.

If Experiment 1 replicates the rotation functions obtained by Cooper and Brooks (2004), then the results for the animal and object conditions should look similar to the hypothetical data presented Panel A in Figure 8. If faces are differentially affected by planar rotation (relative to the other types of stimuli), then the rotation function for faces should be qualitatively different from the rotation functions for animals and objects (e.g., the results should look like Panel B in Figure 8). However, if Experiment 1 fails to find a reliable difference in the rotation functions for faces and animals, then the results would suggest that there is not a qualitative difference in the representations used to recognize faces.

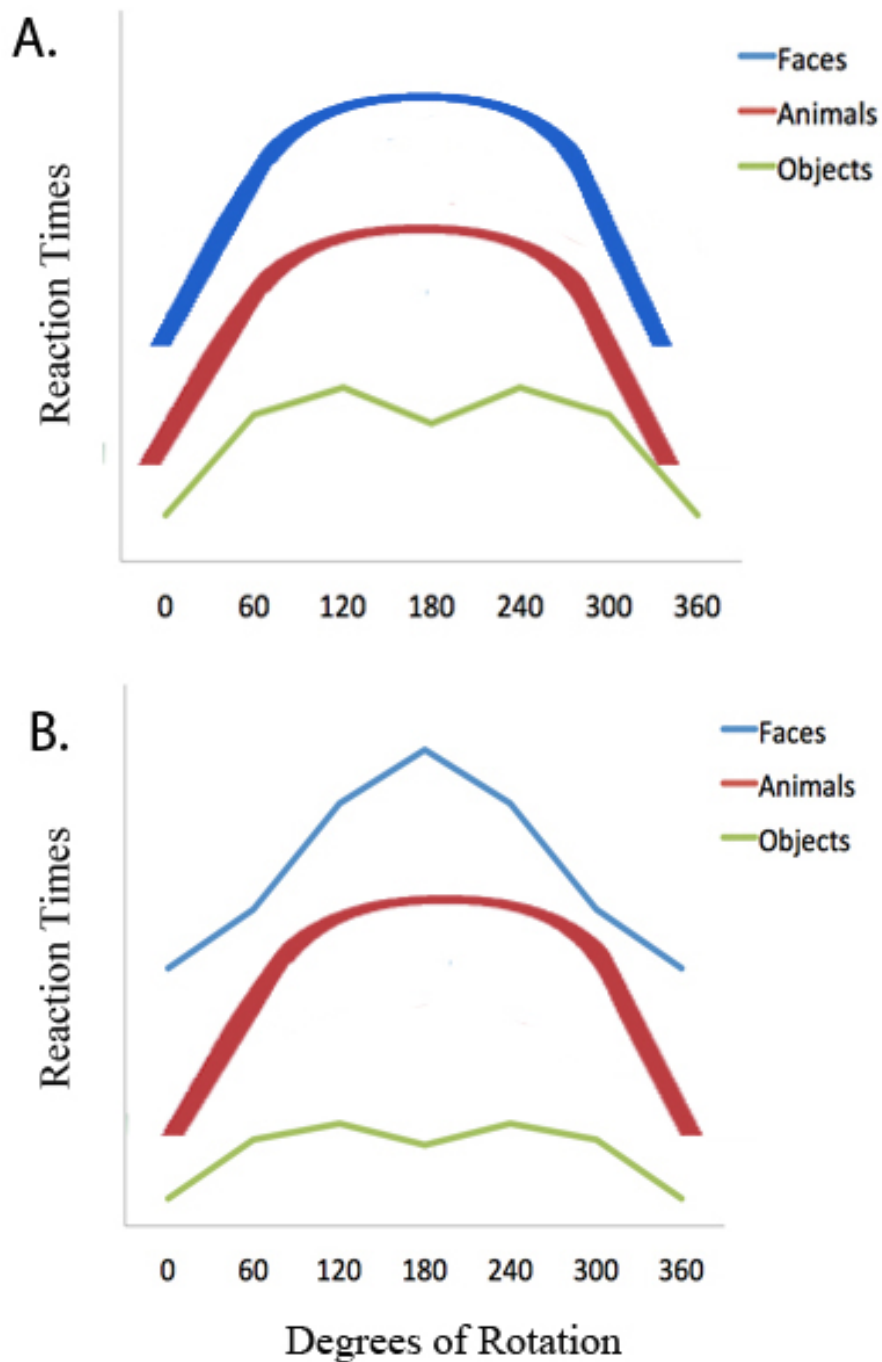


Figure 8. Two graphs displaying different rotation functions predicted by the coordinate relations hypothesis and holistic representation hypothesis. If a coordinate representation can be used to explain the rotation function of faces, then the rotation function for faces should resemble the rotation function for animals and there should not be an interaction (e.g., Graph A). If faces are represented differently (e.g., the holistic representation hypothesis) from non-face objects, then the rotation function for faces should interact with the rotation function for animals (e.g., Graph B).

Method

Participants

The participants were 144 undergraduate students from the subject pool at Iowa State University who participated in the experiment for course credit. All subjects reported normal or corrected-to-normal vision. The participants consisted of 97 females and 47 males. The mean age of the participants was 20.5 ($SD=4.6$).

Apparatus

Stimuli were displayed on a 20-inch LED display with a resolution of 1680 x 1050 pixels. An Intel Core 2 Duo iMac desktop was used to present the stimuli and collect the data. The experiment was presented using Superlab Pro 4.5 software. Responses were collected via two keys using a standard Macintosh keyboard that gave ± 0.5 ms response time accuracy.

Stimuli for the experiment consisted of color photographs of 72 faces, 72 animals, and 72 objects taken from their canonical upright view. All stimuli had background visual information removed using Photoshop CS5.1. For faces, the sizes of the images were standardized so that the distance from the bottom of the chin to the top of the hairline was 512 pixels (72 pixels per inch). For animals and objects, the images were standardized so that the longest dimension of the photograph is 512 pixels (72 pixels per inch). All stimuli were presented on a white background.

Faces. All the faces chosen in Experiment 1 were of famous people. Half of the faces were female and the remaining half were male. The famous faces

used in this experiment were chosen after a pilot study was conducted to determine which famous individuals were most familiar to undergraduate students (see Appendix A for list).

Animals. The animals chosen for Experiment 1 consisted of animals that share similar structural descriptions with another animal from a different basic-level category (e.g., elk and deer each share similar structural descriptions; see Appendix B for list). This criterion for animals eliminated certain types of animals from Experiment 1. For example, a giraffe's structural description is very different from the structural description of all other animals. In order for an animal to be included in this experiment, the animal had to have a clear upright orientation (e.g., a starfish does not have a standard upright orientation).

Objects. The objects chosen for Experiment 1 consisted of basic-level objects that did not share structural descriptions with one another (see Appendix C for list). In order for an object to be included in this experiment, the object needed to have a common upright orientation.

Procedure

Presentation of the stimuli was self-paced. Participants were positioned so that they were approximately 42 cm away from the display. Participants pressed the spacebar to begin each trial. After the spacebar was pressed, a fixation cue was presented for 500 ms, followed by one of the stimuli for 250 ms, followed by the name of a face, animal, or object until the participant's response. Participants were instructed to press the "m" key if the name presented in the trial matched the picture, and to press the "n" key if the name did not match the

picture. For half of the trials the name matched the previously presented stimulus. For the remaining half of the trials the name did not match the previously presented stimulus (see Figure 9 for a sample trial sequence). For different face trials, the name presented for each different trial was chosen so that the famous name presented matched the previously presented image for gender and ethnicity (e.g., Barack Obama's face was presented followed by Denzel Washington's name). For the different animal trials, the name that was presented for each different trial was chosen so that the name of the animal presented matched the presented animal image's structural description (e.g., a dog was presented followed by the name "fox"). For the different object trials, the name presented for each different trial was chosen so that the name of the object presented did not match the presented object's structural description (e.g., a car was presented followed by the name "bicycle").

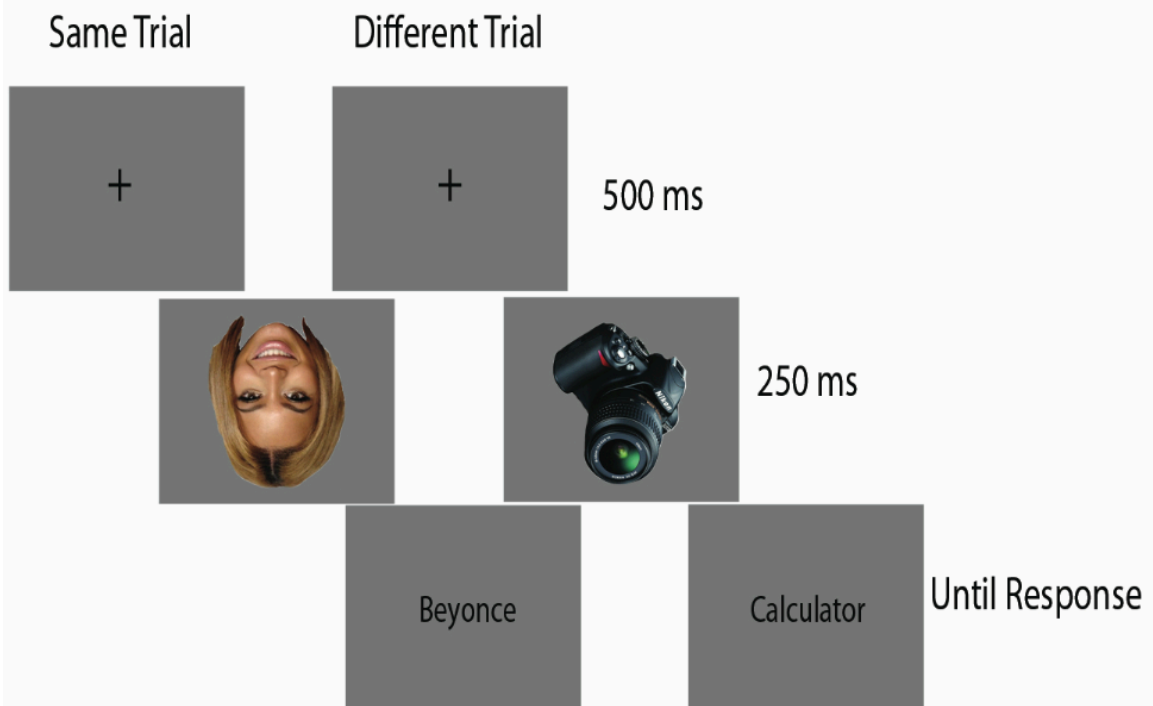


Figure 9. Samples of the event sequence used for the same and different trials in Experiment 1. In the “same” trials of Experiment 1, a face, animal or object was presented at one of six degrees of planar rotation (0, 60, 120, 180, 240, or 300), followed by the name of the presented stimulus. In the example above, Beyonce’s face is presented at 180° planar rotation followed by her name. In the “different” trials of experiment 1, a face, animal, or object was presented at one of six degrees of planar rotation (0, 60, 120, 180, 240, 300), followed by a name that did not match the presented stimulus. In example above, a camera is presented at 60° planar rotation, followed by the name, “calculator”.

Each participant saw 216 experimental trials. For each participant, all 72 faces, all 72 animals, and all 72 objects were presented one time during the experiment. Each participant saw six faces, six animals, and six objects for the same trials at each of the six degrees of planar rotation (0, 60, 120, 180, 240, and 300). The stimuli that were presented for any given trial type (degree of rotation (0, 60, 120, 180, 240, 300) X trial type (same or different)) were counterbalanced across every 12 participants. All of the stimuli were counterbalanced across the same and different trials. Furthermore, the different trials were counterbalanced across degrees of planar rotation. So, for any one

object in the experiment, for half the subjects it was a same trial and for half it was a different trial. Each stimulus occurred equally often across each trial conditions. The order of the trials was randomly chosen for each participant. Face, animal, and object trials were randomly presented in a single block.

Participants were presented with practice trials prior to the experiment using the same presentation sequence that was used during the actual experiment. The practice trials consisted of 18 total trials (six faces, six animals, and six objects). Each participant saw a practice trial at each degree of planar rotation for each stimulus type (faces, animals, and objects). Half of the practice trials were same trials and half were different trials.

Results

Error rates and reaction times for the same trials in Experiment 1 were examined using a factorial within-participants analysis of variance (ANOVA) with stimulus type (face, animal, and object) and degrees of planar rotation (0, 60, 120, 180, 240, and 300) for the same trials as the independent variables. Any subject that did not perform above 70% accuracy for any of the three stimulus types (i.e., animal, face, and objects) was excluded from the analysis in order to eliminate participants who were unfamiliar with the names of the stimuli that were presented. As a result, eighteen subjects were removed and replaced with additional participants. All statistical hypotheses in the current studies were tested with a two-tailed alpha level of .05. The different trials in Experiment 1 were not relevant to the research question, and analysis of the different trials did not display a speed-accuracy trade-off.

Reaction Time Data

There was a reliable interaction between degrees of planar rotation and stimulus type $F(10, 1430) = 6.48, p < .01$. Whereas faces displayed an inverted-U-shaped rotation function for reaction time, animals and objects displayed flat rotation functions (see Figure 10). A post hoc pairwise comparison of reaction time across degrees of rotation for each stimulus type, using the Bonferroni adjustment, was performed. Participants were slower at responding to 120°, 180°, and 240° rotated faces than to 0°, 60°, and 300° rotated faces. There were no reliable differences in reaction time across degrees of rotation for objects or animals. There was a reliable main effect of stimulus type $F(2, 286) = 63.16, p < .01$. Overall, participants responded faster to objects than to animals or faces, and faster to animals than to faces. There was a reliable main effect of degrees of rotation $F(5, 715) = 7.55, p < .01$.

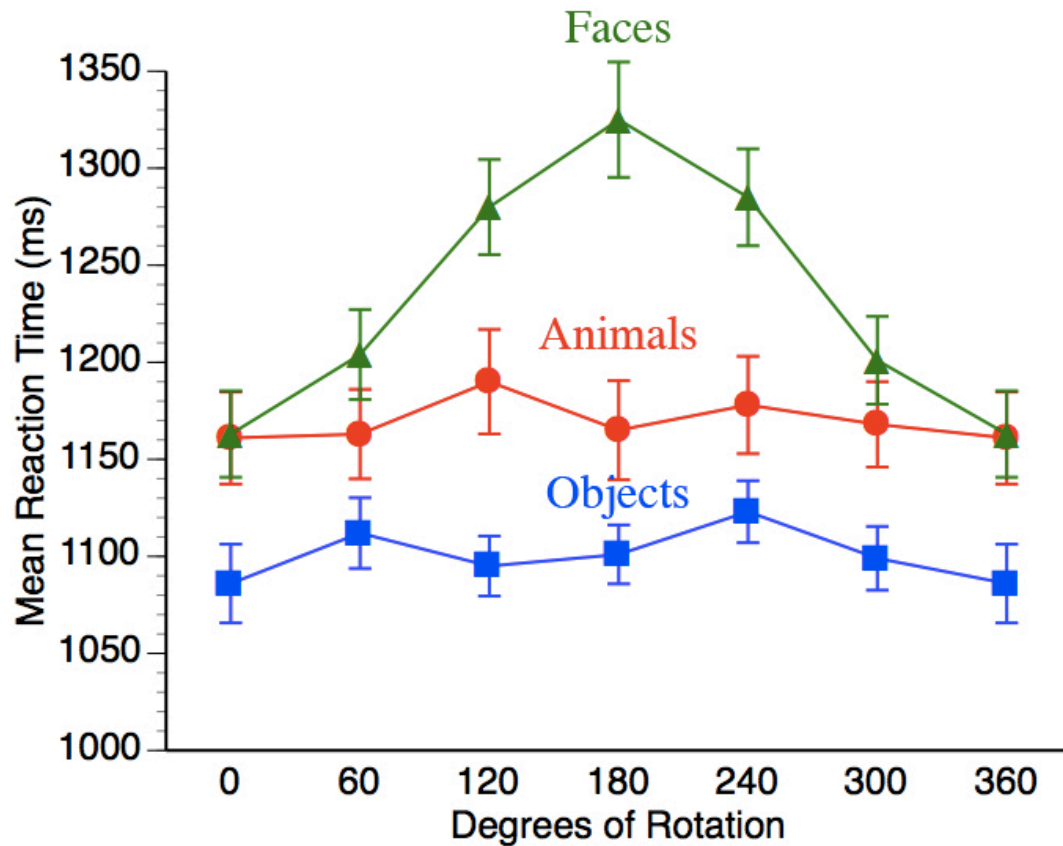


Figure 10. The graph displays the mean reaction times across each degree of rotation for each stimulus type for same trials. Standard error bars are shown for each degree of planar rotation X stimulus type.

Error Rate Data

There was a reliable interaction between degrees of planar rotation and stimulus type $F(10, 1430) = 9.29, p < .01$. Whereas faces displayed an inverted-U-shaped rotation function for error rates, animals and objects showed a flat function (see Figure 11). A post hoc pairwise comparison of percentage error across degrees of rotation for each stimulus type, using the Bonferroni adjustment, was performed. Participants made more errors to 120°, 180°, and 240° rotated faces than to 0°, 60°, and 300° rotated faces. There were no reliable differences in error percentage across degrees of rotation for objects or

animals. There was a reliable main effect of stimulus type $F(2, 286) = 50.35, p < .01$. Overall, participants made fewer errors to objects, followed by animals, and they made the most errors responding to faces. There was a reliable main effect of degrees of rotation $F(5, 715) = 9.27, p < .01$.

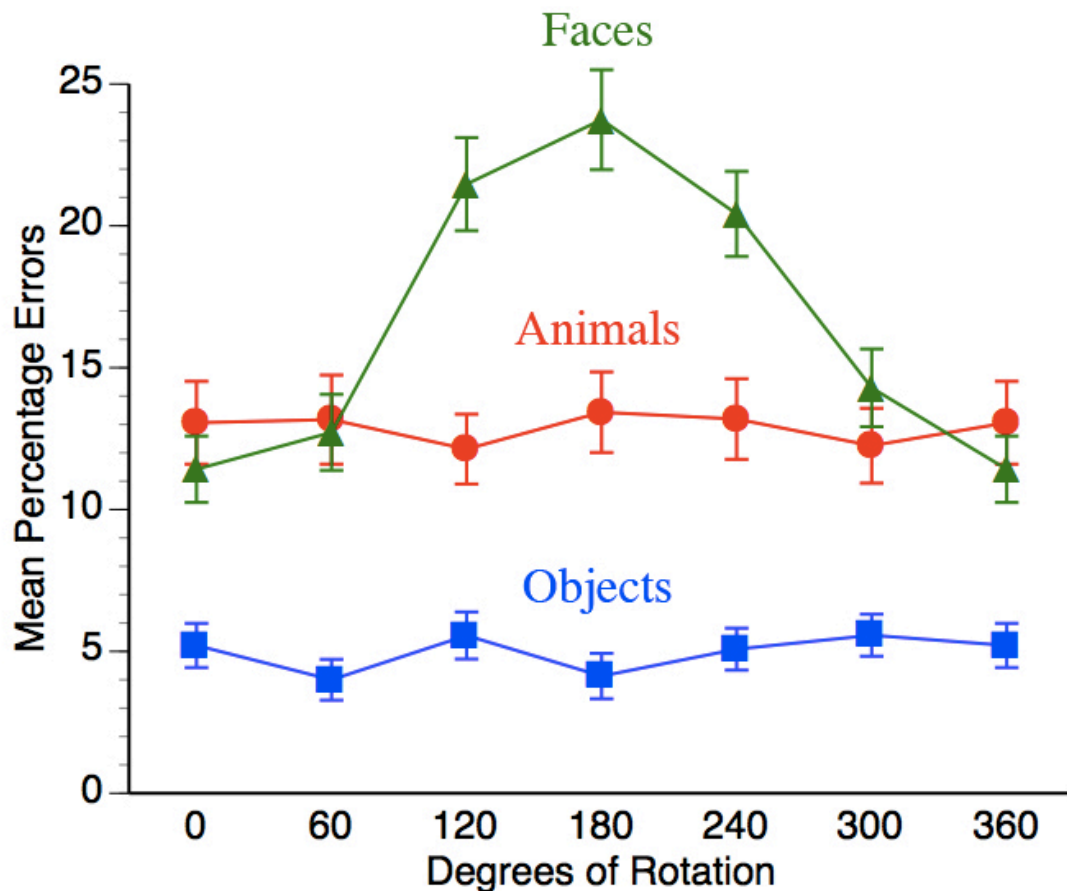


Figure 11. The graph displays percentage errors across each degree of rotation for each stimulus type for same trials. Standard error bars are shown for each degree of planar rotation X stimulus type.

Function Fitting

For each stimuli type (face, animal, and object), the mean RTs for the different rotations used in Experiment 1 were correlated with the best fitting linear model of the data and the best fitting model of the form $c\sqrt{2 - 2\cos(\theta)} + b$ (i.e.,

the Euclidean distance), where c and b are constants and θ is the angle of rotation. For the mean reaction times for the six different rotation conditions for objects used in Experiment 1, the best linear fit produced a smaller correlation, $r = .38$ (accounting for 14.4% of the variance), than the best Euclidean fit, $r = .50$ (accounting for 25.4% of the variance). For animals, the best linear fit produced a smaller correlation, $r = .41$ (accounting for 17.1% of the variance), than the best Euclidean fit, $r = .57$ (accounting for 32.5% of the variance). For faces, the best linear fit produced a slightly larger correlation, $r = .99$ (accounting for 97.2% of the variance), than the best Euclidean fit, $r = .96$ (accounting for 91.3% of the variance). Taking into account the best fitting functions of each stimulus class, it does not appear that a mental rotation model of planar rotation (i.e., the best linear fit) does a better job at predicting the effects of planar rotation than a Euclidean distance model of mental rotation.

Discussion

The results of Experiment 1 failed to support the predictions of the coordinate relations hypothesis (Cooper & Wojan, 2000). Although the faces displayed an inverted-U shaped function for both reaction times and error rates, the rotation function for both dependent variables for the animals was flat. The rotation functions for animals and objects observed in Experiment 1 did not replicate the inverted-U shaped function for animals and the M-shaped function for objects produced by Cooper and Brooks (2004). The interaction in the rotation function for both reaction time and error rates between faces and animals suggests that there is something qualitatively different about the

recognition of faces, compared to animals, when they are rotated in the picture plane.

Experiment 1 had considerable variance in the data for many subjects. Specifically, there were only six data points for any given stimulus type x rotation condition. As a result, the data are likely to be noisy. Also, whereas Cooper and Brooks (2004) had participants verbally name the stimulus that was presented, Experiment 1 required participants to indicate whether the name of a stimulus matched the previously presented image. As a result, Experiment 1 added a word recognition component that may have further increased the noise in the data. However, it is clear from the results of Experiment 1 that the rotation function for identifying faces is considerably steeper than that for recognizing animals (thus falsifying Cooper & Wojan's (2000) explanation of the face inversion effect).

Experiment 1 failed to replicate the M-shaped function for the recognition of objects at the basic-level that has been observed by many studies (e.g., Cooper & Brooks, 2004; Jolicoeur, 1985; Jolicoeur, 1988; Jolicoeur & Milliken, 1989; McMullen & Farah, 1991; McMullen & Jolicoeur, 1990). It is possible that presentation sequence for Experiment 1 produced a floor effect for the objects that prevented the production of the M-shaped rotation function. Specifically, participants were shown the stimuli for 250 ms before the names of the stimuli was displayed and they could respond. It is possible that participants were able to recognize objects before the name of the object was presented, consequently producing a floor effect in reaction time and a flat rotation function. In order to

determine if the absence of a M-shaped rotation function was a result of having participants wait 250 ms until they could respond to the image presented, Experiment 2 allowed participants to respond immediately upon presentation of a stimulus. If the failure to replicate the rotation functions Cooper and Brooks (2004) found for animals and objects was due to a floor effect in Experiment 1, then Experiment 2 should display the M-shaped rotation function that was absent in Experiment 1.

Experiment 2

Experiment 2 attempted to replicate the rotation functions observed for animals and objects by Cooper and Brooks (2004) using a slightly different experimental task. Experiment 2 required participants to categorize visually presented stimuli rather than to determine whether a name matched a visually presented stimulus. The purpose of Experiment 2 is two-fold. First, Experiment 2 tested the generalizability of the results obtained by Cooper and Brooks (and Experiment 1). Second, Experiment 2 attempted to reduce potential within-subjects variance that is prevalent across trials when using proper name recognition as a dependent variable (for review, see Cohen & Burke, 1993). Previous researchers have found that participants are faster at categorizing visual stimuli than naming them (Johnson & Bruce, 1990; Potter & Faulconer, 1975; Young et al., 1986). Third, Experiment 2 tested whether the failure to find the M-shaped rotation function for objects in Experiment 1 was because participants recognized the objects before they could respond. Finally, all stimuli in Experiment 2 were grayscaled to prevent participants to recognize objects

based on its common color (e.g., a yellow school bus).

The rationale of Experiment 2 was to replicate the inverted-U shaped rotation function observed for animals and the m-shaped rotation function observed for objects by Cooper and Brooks (2004) in order to determine whether the rotation function for faces is qualitatively different from the rotation function for animals and objects. The changes adopted for Experiment 2 were performed in order to obtain cleaner rotation functions for the recognition of faces, animals, and objects.

Method

Unless noted, all procedures in Experiment 2 were the same as those in Experiment 1.

Participants

Ninety-eight undergraduate students from the Iowa State University subjects' pool participated in the experiment for course credit. All subjects reported normal or corrected-to-normal vision. The participants consisted of 51 females and 47 males. The mean age of the participants was 19.9 ($SD=2.6$).

Apparatus

Stimuli for the experiment consisted of grayscale photographs of 30 faces, 30 animals and 30 objects originally taken from their upright canonical view. All pictures were prepared in the same way as Experiment 1.

Faces. All the faces chosen in Experiment 2 consisted of famous people. Half of all the famous faces were actors and half of the famous faces were non-actors. Actors consisted of individuals who are primarily known for their roles in

movies and television shows. Non-actors consisted of individuals whose fame was achieved from anything other than movies and television shows (e.g., politicians, athletes, musicians, and television broadcasters). Half of the faces were female and the remaining faces were male. Gender was balanced across stimulus types (actor and non-actors). The famous faces used in this experiment were chosen after a pilot study was conducted to determine which famous individuals were most familiar to undergraduate students (see Appendix D for list).

Animals. The animals chosen for Experiment 2 consisted of animals that share similar structural descriptions with another animal from a different basic-level category (e.g., donkey and horse each share similar structural descriptions; see Appendix E for list). Like Experiment 1, this criterion for animals eliminated certain types of animals from Experiment 2. In order for an animal to be included in Experiment 2, the animal had to have a common upright orientation. Half of the animals used as stimuli in Experiment 2 are typically found in North America and half of the animals are typically found somewhere other than North America.

Objects. The objects chosen for Experiment 2 consisted of basic-level objects that have a unique structural description (see Appendix F for list). In order for an object to be included in the Experiment 2 the object needed to have a common upright orientation. Half of the objects consisted of objects that are typically used inside a residence (e.g., blender) and half of the objects consisted of objects that are typically used outside a residence (e.g., helmet).

Procedure

Presentation of the stimuli was self-paced. Participants were positioned so that they were approximately 42 cm away from the display. Participants pressed the spacebar to begin each trial. After the spacebar was pressed, a fixation cue was presented for 250 ms, followed by one of the stimuli until the participant's response. Accuracy feedback was given to the participants following each trial. The face, animal, and object stimuli were blocked and counterbalanced across participants.

Face block. Participants were instructed to press the "m" key if the face that was presented was of a non-actor and to press the "n" key if the face that was presented was of an actor. Participants were instructed that they should classify a face as an actor if the individual that was presented was primarily known for their roles in movies or television shows and to classify a face as a non-actor if the individual that was presented became famous as a result of something other than movies or television shows (e.g., musicians, athletes, politicians, and television broadcasters).

Animal block. Participants were instructed to press the "m" key if the animal presented is not found in North America and to press the "n" key if the animal is found in North America. Participants were told that animals that can only be found in zoos or exotic farms should not be classified as North American.

Object block. Participants were instructed to press the "m" key if the object presented was used outside the house and to press the "n" key if the object presented was used inside the house. Participants were instructed that

objects commonly used inside a residence (i.e., house, apartment, or townhome) should be classified as inside, and that objects commonly used, or seen, outside a residence should be classified as outside. Participants were instructed to press the “m” key if the object is used outside the house and to press the “n” key if the object is used inside the house.

The categorization tasks were blocked and counterbalanced across every six participants. The key press was not counterbalanced across participants because the responses for each categorization task (actor/non-actor, North American/not North American, and outside/elsewhere) were averaged together (e.g., “actor” and “non-actor” error rates and correct response times were averaged together).

Each participant saw 180 face, 180 animal, and 180 object experimental trials (540 total trials). For each participant, all 30 faces, all 30 animals, and all 30 objects were presented one time during the experiment at all six degrees of planar rotation (0, 60, 120, 180, 240, and 300). The rationale for repeating images across degrees of rotation was to increase each participant’s number of data points for each degree of rotation in order to reduce random variance. Additionally, whereas Experiment 1 only had 6 “same” trials for each degree of rotation, Experiment 2 had 30 trials of interest for each degree of rotation which allowed for enough responses to remove any response times that fall three standard deviations away from each participant’s stimulus type X degree of rotation mean. The order of the trials was randomly chosen for each participant.

Participants were presented with practice trials prior to each block of the

experiment using the same presentation conditions used during the actual experiment (but with different stimuli). The practice trials consisted of twelve total trials for each block with two stimuli presented at each of the six planar rotations.

Results

The error rates and reaction times from Experiment 2 were analyzed using a factorial within-participants analysis of variance (ANOVA) with stimulus type (face, animal, and object), and degrees of planar rotation (0, 60, 120, 180, 240, and 300) as the independent variables. Any subject who did not perform above 70% accuracy for any of the three recognition tasks (i.e., actor/non-actor, North American/elsewhere, and inside/outside) was excluded from the analysis in order to eliminate participants who were unfamiliar with the famous faces, animals, and/or objects that were presented. Thirteen participants were not included in any of the data analysis because they did not perform above 70% accuracy in all three recognition tasks. The greater number of trials in Experiment 2 allowed outliers to be eliminated in the data from of Experiment 2. All reaction times that fell outside of three standard deviations from each participant's stimulus type X degree of rotation mean were removed (fewer than 3% of the data points were removed).

Reaction Time Data

There was a reliable interaction between degrees of planar rotation and stimulus type $F(10, 970) = 2.02, p < .05$. Specifically, faces displayed a steeper inverted-U-shaped rotation function than animals in reaction time and object reaction times showed a flat rotation function (see Figure 12). A post hoc

pairwise comparison of reaction time across degrees of rotation for each stimulus type, using the Bonferroni adjustment, was performed. Participants were slower at responding to 120°, 180°, and 240° rotated faces than to 0°, 60°, and 300° rotated faces. Participants were slower at responding to 180° and 240° rotated faces and were slower at responding to 180° rotated faces than to 60° rotated faces. Further, participants were slower at responding to 180° rotated animals than to 0° rotated animals. There were no reliable differences in reaction time across degrees of rotation for objects. There was a reliable main effect of stimulus type $F(2, 194) = 331.53, p < .01$. Overall, participants responded faster to objects than to animals or faces, and slower to animals than to faces. There was a reliable main effect of degrees of rotation $F(5, 485) = 12.89, p < .01$.

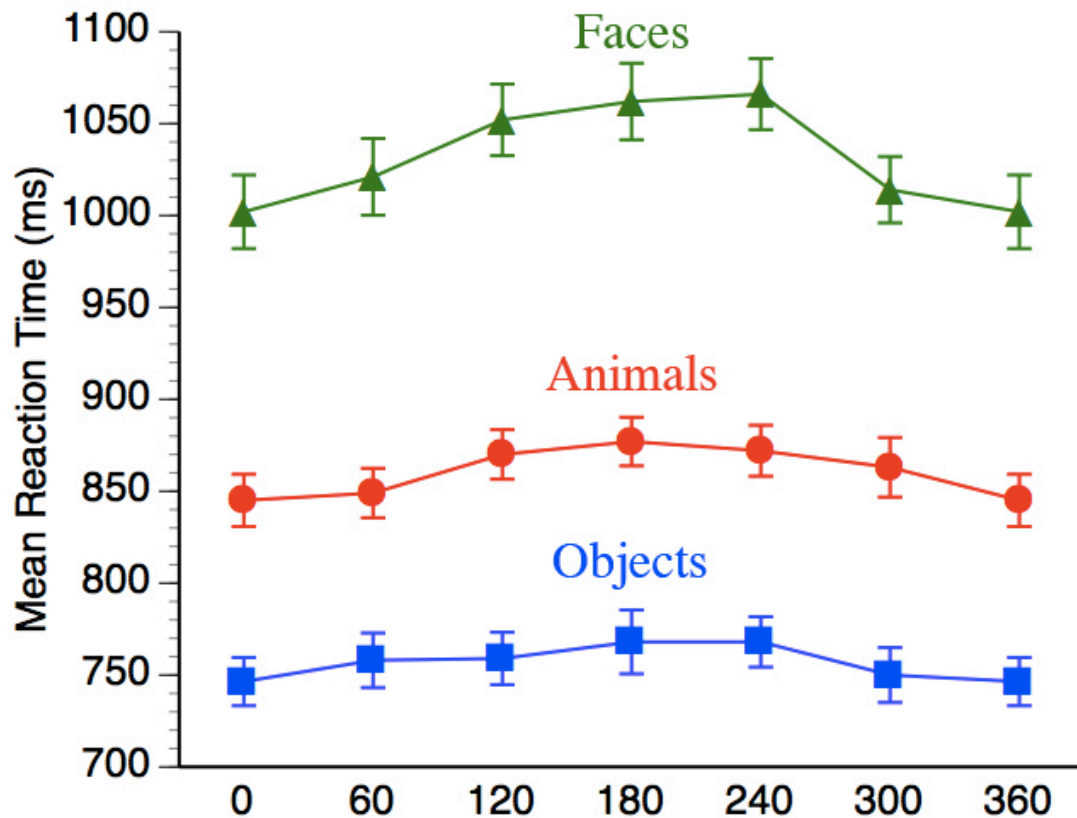


Figure 12. The graph displays the mean reaction times across each degree of rotation for each stimulus type. Standard error bars are shown for each degree of planar rotation X stimulus type.

Error Rate Data

There was a reliable interaction between degrees of planar rotation and stimulus type $F(10, 970) = 6.84, p < .01$. Specifically, faces displayed a steeper inverted-U-shaped rotation function than animals for error rates and objects showed a flat rotation function (see Figure 13). A post hoc pairwise comparison of reaction time across degrees of rotation for each stimulus type, using the Bonferroni adjustment, was performed. Participants made more errors at responding to 120°, 180°, and 240° rotated faces than to 0°, 60°, and 300° rotated faces. Additionally, participants made reliably more errors when responding to 300° animals than to 0°, 60°, and 240° animals; there is no

research that would predict such difference and it is likely that the greater error rates at 300° for animals is noise and reflects a Type I error. There were no reliable differences in error rates across degrees of rotation for objects. There was a reliable main effect of stimulus type $F(2, 194) = 176.06, p < .01$. Overall, participants made more errors to faces, followed by animals, and participants made the fewest errors to objects. There was a reliable main effect of degrees of rotation $F(5, 485) = 8.94, p < .01$.

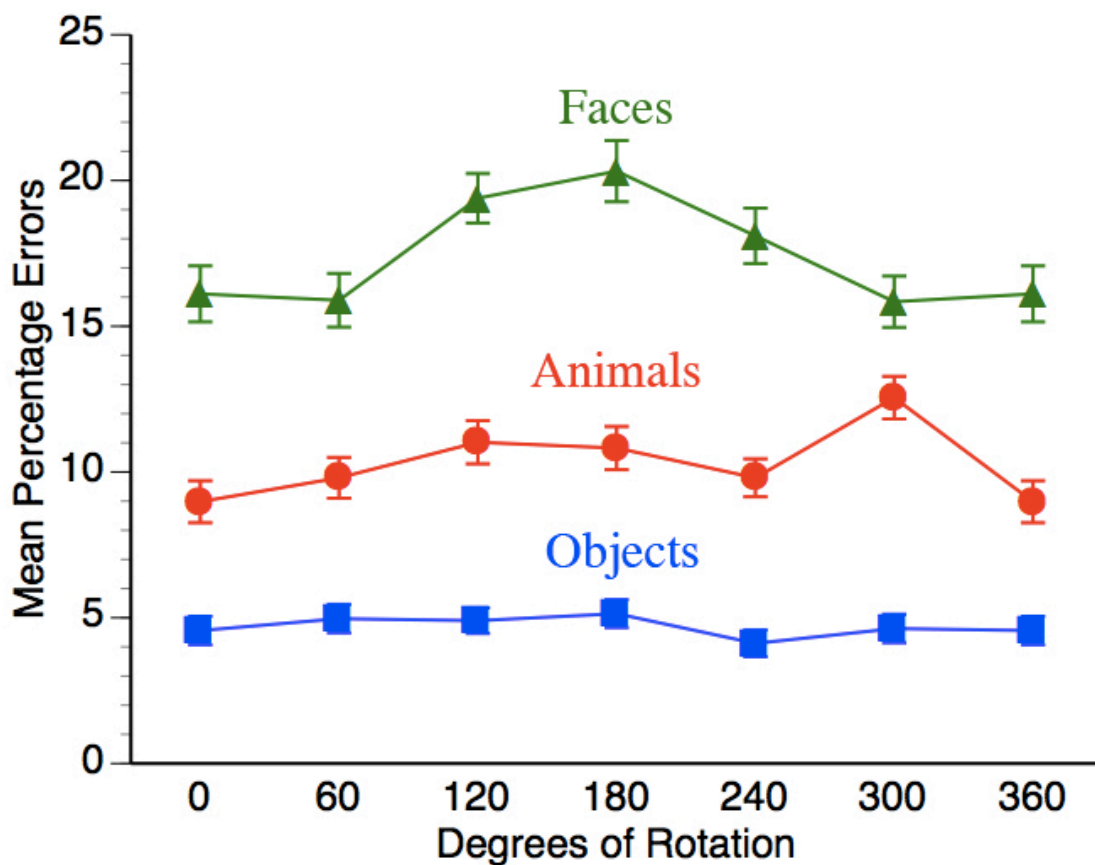


Figure 13. The graph displays the mean error rates across each degree of rotation for each stimulus type. Standard error bars are shown for each degree of planar rotation X stimulus type.

Function fitting

As in Experiment 1, for each stimulus type, the mean RTs for the different rotations used in Experiment 2 were correlated with the best fitting linear model of the data and the best fitting model of the form $c\sqrt{2 - 2 \cos(\theta)} + b$ in order to determine if the linear model or the Euclidean distance model provided a better description of the data. As in Experiment 1, for each stimulus type, the mean RTs for the different rotations used in Experiment 2 were correlated with the best fitting linear model of the data and the best fitting model of the form $c\sqrt{2 - 2 \cos(\theta)} + b$ in order to determine if the linear model or the Euclidean distance model provided a better description of the data. For the objects, the best linear fit produced a similar correlation, $r = .89$ (accounting for 78.2% of the variance), to the best Euclidean fit, $r = .89$ (accounting for 79.7% of the variance). For the animals, the best linear fit produced a similar correlation, $r = .92$ (accounting for 84.2% of the variance), to the best Euclidean fit, $r = .92$ (accounting for 84.6% of the variance). For the faces, the best linear fit produced a smaller correlation, $r = .92$ (accounting for 85.0% of the variance), than the best Euclidean fit, $r = .93$ (accounting for 87.0% of the variance). The fits for the linear and Euclidean distance models appear to be so similar, that the data from Experiment 2 cannot be used to decide which is a better fit.

Discussion

As in Experiment 1, Experiment 2 failed to support Cooper and Wojan's (2000) explanation for the face inversion effect. Cooper and Wojan's (2000) explanation for the effect predicts parallel rotation functions for animals and

faces, and both Experiment 1 and Experiment 2 found much steeper rotation functions for faces than for animals (see Figure 15). Consequently, the recognition of faces appears to be qualitatively different from the recognition of animals and objects.

Whereas Experiment 1 failed to find the inverted U shaped rotation function for animals observed by Cooper and Brooks (2004), Experiment 2 showed such a function. The increased number of data points, for any given stimulus type x degrees of rotation condition likely reduced the noise that was present in Experiment 1 and allowed for the observation of an inverted U shaped function for recognizing rotated animals. Nevertheless, the rotation function was steeper for faces than for animals.

One of the justifications for running Experiment 2 was that it was more likely than Experiment 1 to replicate the M shaped rotation function for objects that has been consistently shown in previous research (e.g., Cooper & Brooks, 2004; Jolicoeur, 1985; Jolicoeur, 1988; Jolicoeur & Milliken, 1989; McMullen & Farah, 1991; McMullen & Jolicoeur, 1990). Like Experiment 1, Experiment 2 did not display an M-shaped rotation function for objects. The failure to replicate the M-shaped rotation function could be due to the nature of the task used in Experiment 2. Whereas Cooper and Brooks found an M-shaped rotation function using an object naming task, Experiment 2 only required participants to classify objects into one of two categories. Although the coordinate relations predicted an M-shaped function in Experiments 1 and 2, it is possible that the difference in the nature of the tasks used in the present study were responsible for the lack of

a rotation function.

As noted in the Introduction, humans tend to have greater experience recognizing faces than other objects that share similar structural descriptions. The steeper inverted-U shaped rotation function for faces than for animals may reflect greater expertise with faces than animals. Suppose that recognizing a face requires finer tuning of the co-ordinate representation than recognizing an animal (i.e. the distances of the primitives from the reference point must be calculated more precisely to distinguish two different faces than to distinguish two different animals). If distinguishing faces requires a more precise coding of distance than distinguishing animals, then disrupting the distances by rotating the stimuli would be more disruptive to face recognition than to animal recognition. Finally, it is possible that the differences in rotation functions between faces and animals reflect the degree to which the face stimuli and the animal stimuli used in the experiment shared structural descriptions. Although participants could not rely on the structural description of an animal to determine whether an animal was North American or not, there was more overall interstimulus perceptual variance (Thierry et al., 2007) among the animals used in the experiment than among the faces. Nevertheless, Experiments 1 and 2 both suggest that there is something qualitatively different about the recognition of faces than animals or objects.

Experiment 3

Experiment 3 tested whether a holistic representation (as defined by Tanaka & Farah, 1993) or a coordinate representation (Cooper & Wojan, 2000)

of a face better predicts the effects of inversion when one manipulates the number of features of a face that a participant has to discriminate. As discussed in the Introduction, Tanaka and Farah (1993) defined holistic representations as “representations without an internal part structure,” and posited that the face inversion effect occurs because the holistic representation can only be activated when the face is right side up. Tanaka and Farah posited that holistic representations code the entire face without any decomposition of the parts of the face. Based on this logic, Tanaka and Farah would predict that a face inversion effect would not occur when participants discriminate features of face outside the context of a whole face. In contrast, the coordinate relations hypothesis posits that there should be an inversion effect for parts of a face outside the context of a whole face because inversion will disrupt the coordinate representation of those face parts (Brooks & Cooper, 2006; Cooper & Brooks, 2004).

Experiment 3 investigated the inversion effects for two-feature (eyes), three-feature (eyes and mouth), four-feature (eyes, mouth, and nose), six-feature (eyes, mouth, nose, and eyebrows), whole-face, and six-features in the context of a non-face object (in the current experiment, a bucket (e.g., eyes, mouth, nose, and eyebrows in the context of a bucket)). The bucket condition was added to the face manipulation conditions to determine whether adding more information that is visually similar (e.g., creating a more similar coordinate representation) would produce a larger inversion effect than the other feature manipulation conditions. If a coordinate representation explains the face

inversion effect, then the face inversion effect should progressively increase as the number of features whose coordinates need to be coded increases (see Figure 14 for hypothetical results).

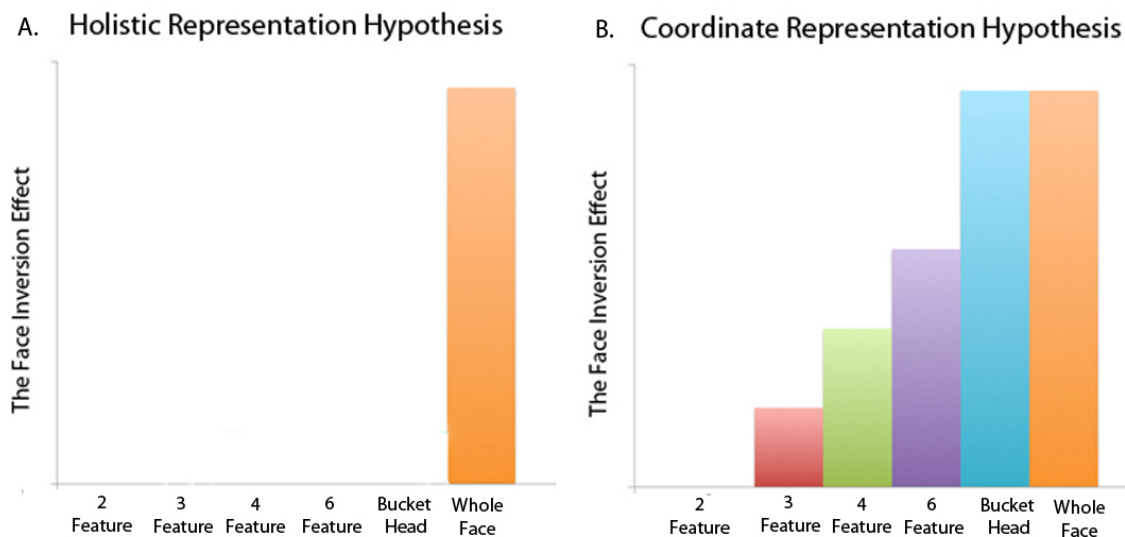


Figure 14. Tanaka and Farah's (1993) holistic representation hypothesis does not predict a significant face inversion effect until a whole face is presented (Panel A). In contrast, the coordinate representation hypothesis predicts that the size of the face inversion effect will increase as the number of features to be coded by a coordinate representation increases (Panel B).

The reason why the coordinate relations hypothesis predicts increasing face inversion effects as the number of features to be coded increases can be explained by the response properties of the neurons in area TE of the cortex that are selective for faces. As mentioned in the Introduction, a small percentage of the cells in TE respond equally vigorously to a particular face regardless of the perspective at which the face is viewed (the viewpoint invariant cells). However, the majority of cells in TE that are selective for faces appear to change their firing pattern based on the perspective at which the face is seen (the viewpoint specific cells; Gross, 1992; Rolls, 2000; Rolls, 2007)). Both Rolls (2000; 2007) and Perrett et al. (1998) posited that the neural representation used to recognize

faces incorporates both types of cells: viewpoint invariant and viewpoint specific.

Perrett et al. (1998) found that as the number of viewpoint specific neurons required to perform a task increases, the more disruptive changing the orientation of the stimulus will be on recognition (i.e, it will take longer for the neural representation of the object to reach the recognition threshold).

Therefore, as the number of features in Experiment 3 is increased, the coordinate relations hypothesis predicts that the amount of noise caused by inversion will increase as well. Thus, the more features that are in the stimulus, the greater the face inversion effect should be.

In contrast, if a holistic representation that is not activated except in the context of a whole face explains the face inversion effect (as proposed by Tanaka & Farah, 1993), then the effect should be dramatically larger if the features are presented in the context of a face than if they are not, and there should be no change in the face inversion effect as the number of features to be coded increases.

Method

Unless noted, all procedures in Experiment 3 are the same as in Experiment 2.

Participants

One-hundred-and-nine undergraduate students at Iowa State University from the subjects' pool participated in the experiment for course credit. All subjects reported normal or corrected-to-normal vision. The participants consisted of 74 females and 35 males. The mean age of the participants was

19.7 ($SD=2.6$).

Apparatus

Stimuli for the experiment consisted of 72 grayscale photographs of famous faces. All the faces were taken from their canonical upright view. Half of the famous faces were male and half of the famous faces were female. Five other face manipulations were constructed for each famous face using Photoshop CS5.1. The additional face manipulations produced stimuli that consisted of two-features (eyes only), three-features (eyes and mouth), four-features (eyes, mouth, and nose), six-features (eyes, mouth, nose, and eyebrows), and six-features in the context of a non-face stimulus (eyes, mouth, nose, eyebrows, presented on a bucket; see Figure 15 for sample stimuli). The distance of the features between one another were held constant across all of the stimulus types. Inverted copies of all the face stimuli were also made.

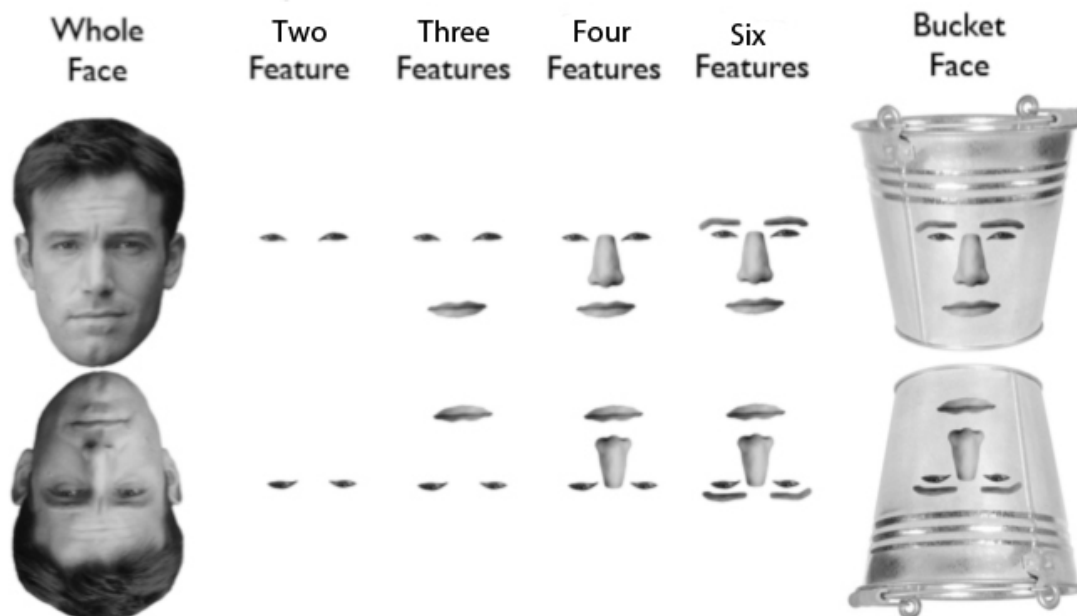


Figure 15. All of the face stimuli created for “Ben Affleck”. The same face stimuli were created for each of the 72 faces.

Procedure

Participants were instructed to press the spacebar to begin each trial. Upon pressing the spacebar, a fixation cue was presented for 500 ms, followed by the presentation of a face stimulus for 250 ms (e.g., a two feature Bill Clinton), followed by a pattern mask for 500 ms, followed by the presentation of a second face stimulus that remained on the screen until the participant’s response (see Figure 16). Participants were instructed to press the “m” key if the two face stimuli that were presented were identical and to press the “n” key if the two face stimuli that were presented were different. The second face was randomly presented at one of four possible locations on any trial (either 1.5° of visual angle above and 1.5° of visual angle to the right, 1.5° of visual angle above and 1.5° of

visual angle to the left, 1.5° of visual angle below and 1.5° of visual angle to the right, or 1.5° of visual angle below and 1.5° of visual angle to the left of the fixation point) and all four locations were presented equally often. Displacing the presentation of the second face from the first face eliminated participants from simply using changes in the retinal image upon presentation of the second face as an indicator of whether or not the two faces were identical. In half of the trials the two faces were identical. For the trials in which the two stimuli were different, the two stimuli were matched for gender and ethnicity (e.g., a three-feature Bill Clinton was compared to a three-feature Michael Douglas).

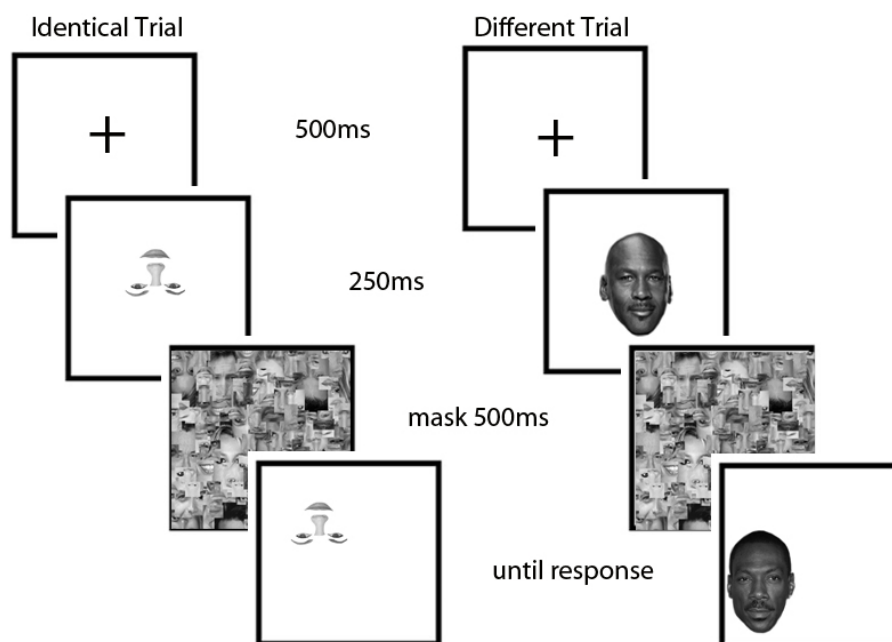


Figure 16. Event sequences for the identical and different trials used in Experiment 3. The face stimuli presented for any given trial can be upright or inverted and consist of two-feature, three-feature, four-feature, six-feature, six-features in the context of a bucket, or whole faces.

Each participant saw a third of the face stimuli in order to avoid fatigue

effects. The experimenters initially ran themselves on all of the stimuli (1728 trials) and reported that the experiment was too long and tiring. Each face stimulus was randomly assigned to one of three blocks and the number of trials for each condition was the same (24 trials for each condition). Each participant saw 576 experimental trials. Participants were presented with each of the face manipulations (whole, two-feature, three-feature, four-feature, six-feature, and six-features in the context of a bucket) for 1/3 (24) of the famous faces at both orientations (upright or inverted) and for both trial types (identical or different). All the famous face stimuli were used across every three participants. The order of the trials was randomly chosen for each participant. For any given trial the first face and second face presented were matched for orientation (e.g., upright then upright) and number of features (e.g., whole faces were always compared to whole faces, and two-feature faces were always followed by two-feature faces).

Participants were presented with 72 practice trials prior to the experiment using the same presentation conditions used during the actual experiment. Each participant saw three practice trials for any given face manipulation x orientation x trial type condition.

Results

Error rates and reaction times and were examined for Experiment 3 using a one-way within-participants analysis of variance (ANOVA) with face manipulation (whole, two, three, four, five, and six feature faces in the context of a bucket) as the independent variable. Nineteen participants were not included in any of the data analysis because they did not perform above 70% accuracy in all

six face manipulation conditions. As in Experiment 2, Experiment 3 had many data points for each condition of interest (24 for Experiment 3). As a result, all reaction times that fell outside of three standard deviations from each participant's orientation X manipulation condition mean were removed (fewer than 3% of the data points were removed).

Face Inversion Effect

A new dependent variable was created for each participant that measured each participant's face inversion effect for each of the face manipulation conditions (i.e., whole face, two-feature, three-feature, four-feature, five-feature, or five-features in the context of a bucket). The face inversion effect was measured by subtracting the upright dependent variables (reaction time and error rate) from the inverted dependent variables for each face manipulation condition. See Appendix G for original upright and inverted mean reaction times and Appendix H for original upright and inverted mean percentage error rates. For example, if a participant in the "identical" three-feature face condition made 30% errors for inverted three-feature faces and 14% errors for upright three-feature faces, that participant's face inversion effect for three-feature identical trials would be 16% errors. The same logic was applied to the reaction time data so that larger scores were associated with a larger face inversion effect.

Reaction time and error rates for the face inversion effect were examined for Experiment 3 using a within-participants one-way analysis of variance (ANOVA) with face manipulation as the independent variable. There was a reliable main effect of face manipulation on reaction time $F(5, 540) = 3.74, p <$

.01. Figure 17 presents the face inversion effect for reaction time for each face manipulation condition. A post hoc pairwise comparison of reaction time across face manipulation conditions was performed using the Bonferroni adjustment. With the exception of the two eyes condition, all face manipulation conditions displayed a reliable face inversion effect for reaction time.

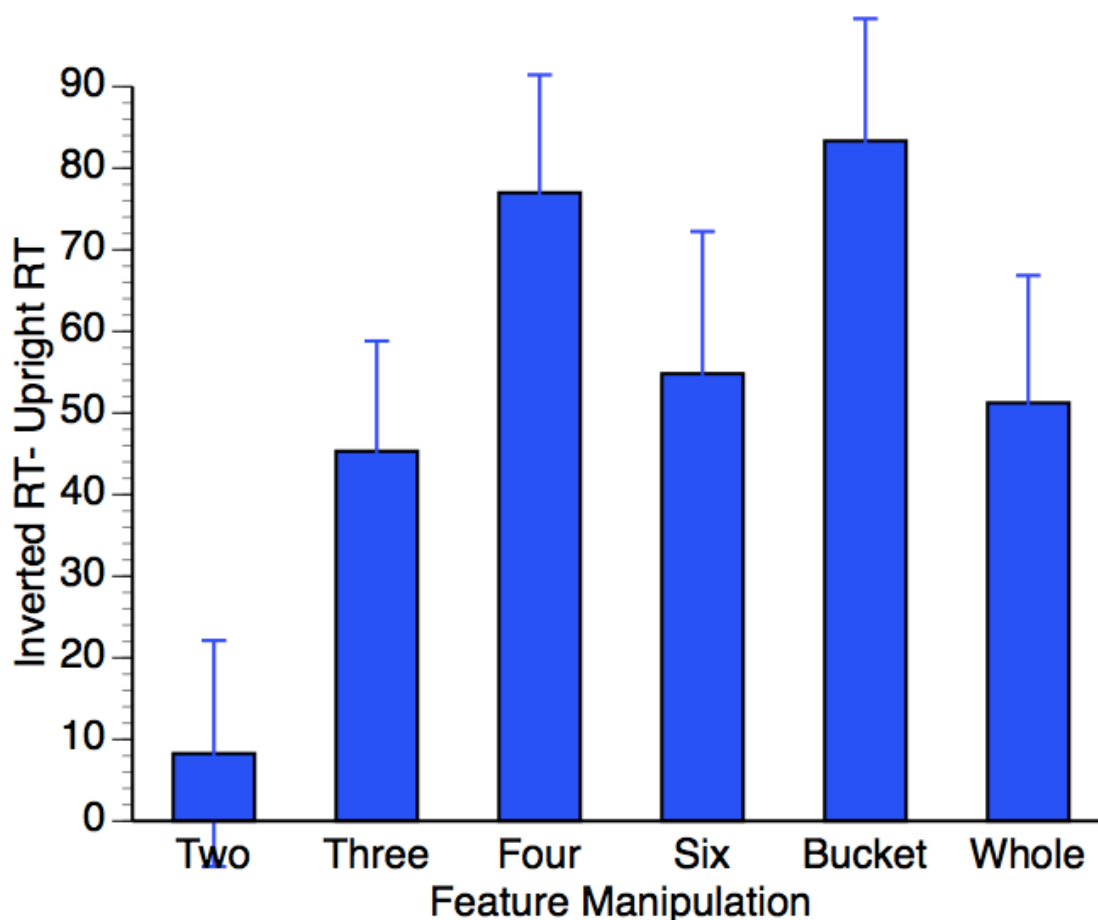


Figure 17. The graph displays the mean reaction time face inversion effect for each of the feature manipulation conditions. Standard error bars are shown for each feature manipulation condition. *Note.* Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket = eyes, mouth, nose, & eyebrows on bucket.

There was a reliable main effect of face manipulation on error rates $F(5, 540) = 26.64, p < .01$. Figure 18 presents the face inversion effect for error rates for each face manipulation condition. With the exception of the two eyes

condition, all face manipulation conditions displayed a reliable face inversion effect for error rates. A post hoc pairwise comparison of error rates across face manipulation conditions was performed using the Bonferroni adjustment. The whole face condition displayed a smaller face inversion effect than all the other face manipulation conditions that displayed a face inversion effect. The three-feature (eyes & mouth), four-feature (eyes, mouth, & nose), and six-feature (eyes, mouth, nose, and eyebrows) conditions displayed a smaller face inversion effect than the six-features in the context of a bucket condition. The six features in the context of a bucket displayed a greater face inversion effect for error rates than the whole face condition.

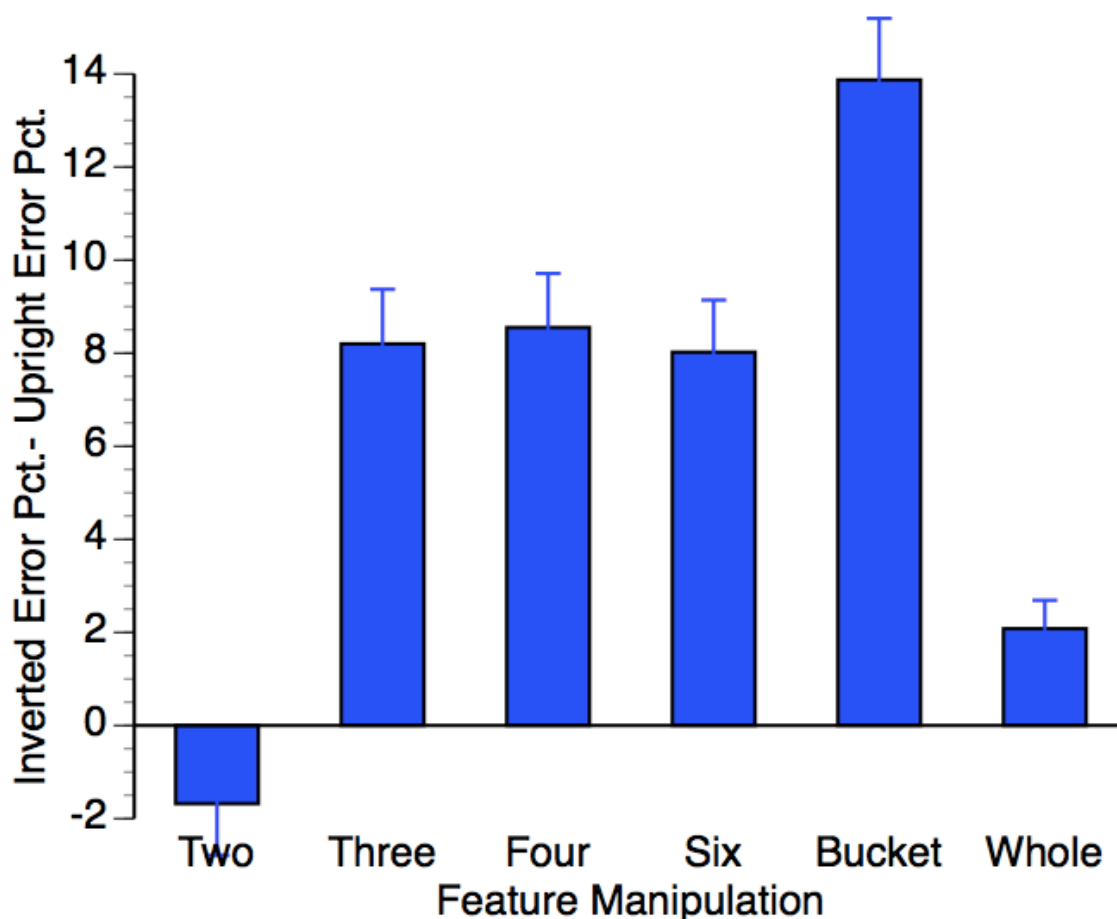


Figure 18. The graph displays the mean error rate face inversion effect for each of the feature manipulation conditions. Standard error bars are shown for each feature manipulation condition. *Note.* Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket = eyes, mouth, nose, & eyebrows on bucket.

Reaction Time and Error Rate Data

A subsequent within subjects' factorial ANOVA was performed on the reaction time and error rate data from Experiment 3 with face manipulation (whole, two, three, four, five, and six feature faces in the context of a bucket) and stimuli orientation (upright vs. inverted) as the independent variables. In other words, the data were also analyzed without creating a new dependent variable for the inversion effects. The reason this subsequent analysis was carried out was to determine whether the differences in the inversion effects for the face

manipulations conditions in Experiment 3 may have been due to floor and ceiling effects.

Reaction time data. There was a reliable interaction between orientation and face manipulation, $F(5, 540) = 3.53, p < .01$ (see Figure 19). There was a reliable main effect of face manipulation $F(5, 540) = 59.1, p < .01$. A post hoc pairwise comparison of reaction time was performed for each face manipulation condition using the Bonferroni adjustment. Overall, participants responded the fastest to whole faces and they responded the slowest to six-features in the context of a non-face stimulus (the bucketheads). Further, participants responded slower to the two eyes condition than to the two eyes and a mouth condition. No other pairwise comparisons were reliably different. As predicted, there was a reliable main effect of orientation $F(1, 97) = 74.26, p < .01$. Participants took longer to respond to inverted faces than to upright faces.

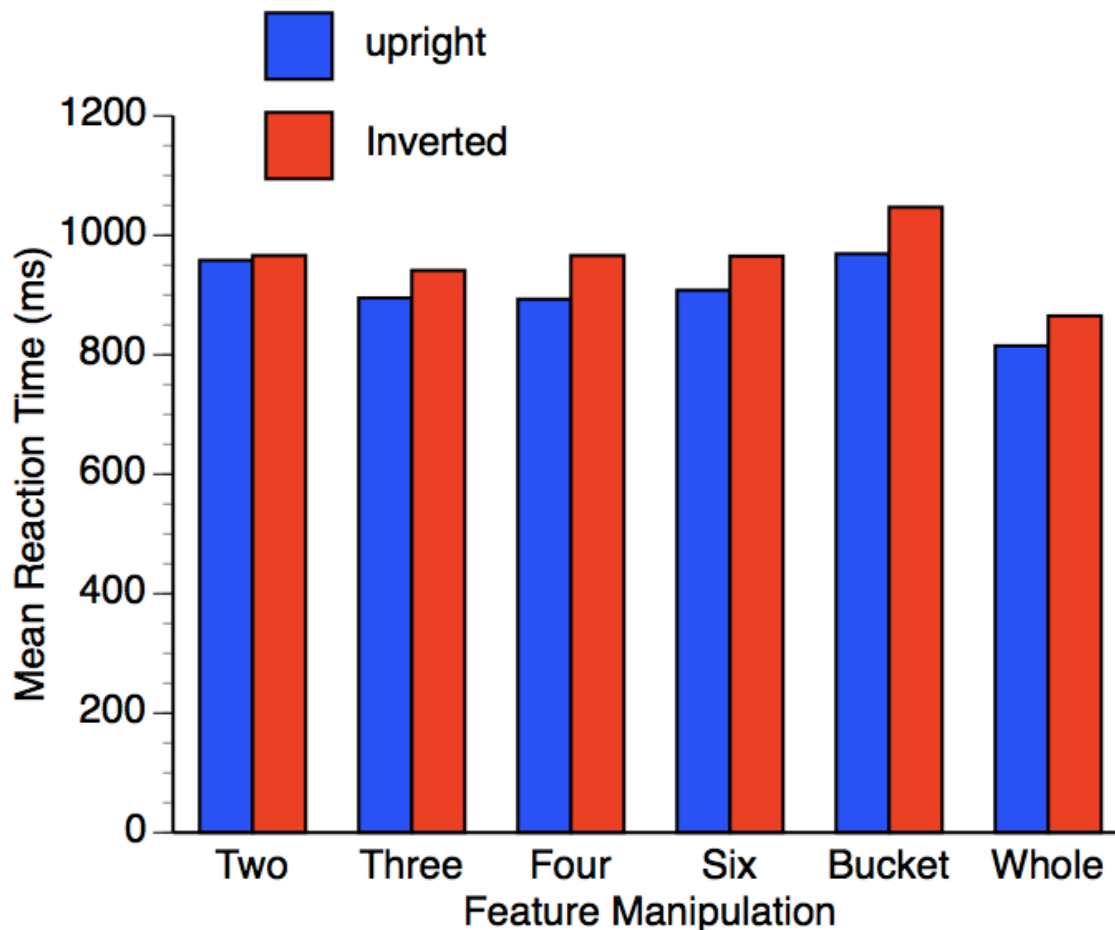


Figure 19. As the number of features of a face increased from two features to three, four, and six features, the difference in reaction time between upright and inverted increased. *Note.* Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket = eyes, mouth, nose, & eyebrows on bucket.

Error rate data. There was a reliable interaction between orientation and face manipulation $F(5, 540) = 26.64, p < .01$ (see Figure 20). There was a reliable main effect of face manipulation $F(5, 540) = 54.14, p < .01$. A post hoc pairwise comparison of error rates was performed for each face manipulation condition using the Bonferroni adjustment. Overall, participants made the fewest errors to whole faces and they made the most errors to six-features in the context of a non-face stimulus (the bucketheads) and the two eyes conditions. No other pairwise comparisons were reliably different. As predicted, there was a reliable

main effect of orientation $F(1, 97) = 152.76, p < .01$. Participants made more errors when responding to inverted faces than to upright faces. Overall, the differences in face inversion effects does not appear to be a result of floor or ceiling effects.

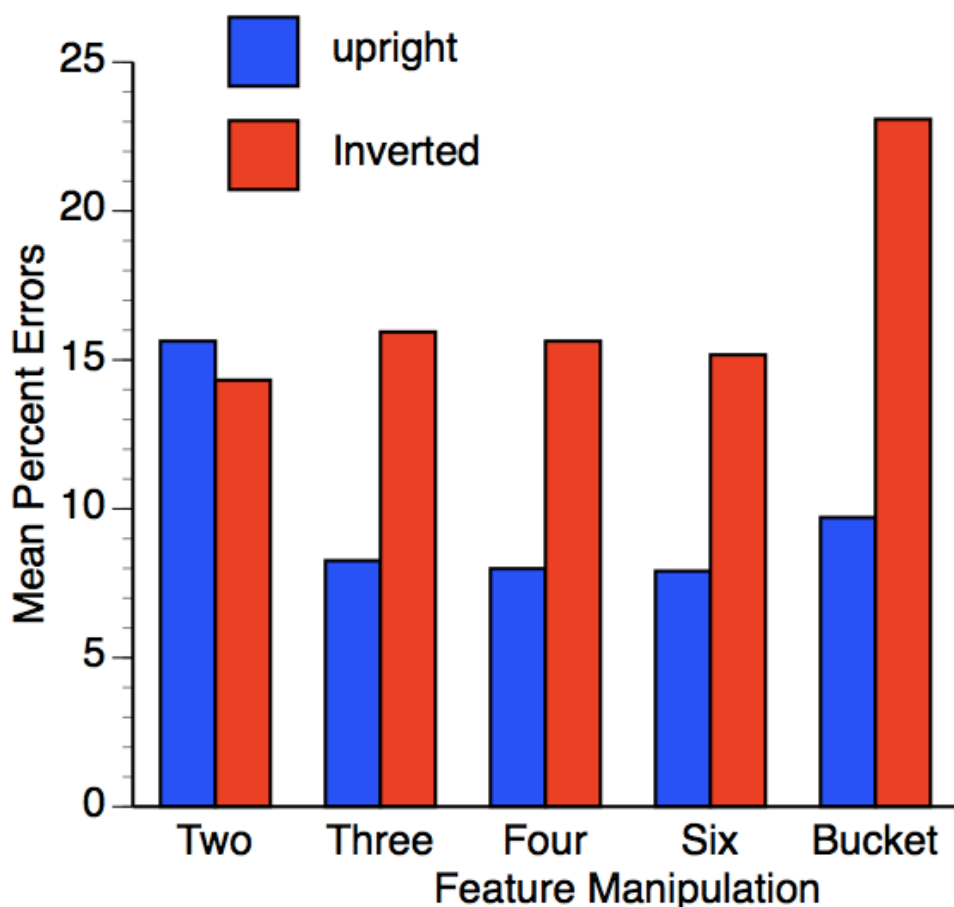


Figure 20. As the number of features of a face increased from two features to three, four, and six features, the difference in error rates between upright and inverted increased. *Note.* Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket = eyes, mouth, nose, & eyebrows on bucket.

Different Trials Reaction Time and Error Rate Data

The different trials in Experiment 3 were not of interest to this study's research question, but reaction time data and error rate data was examined to ensure that there was not a speed-accuracy tradeoff. Table 1 shows that the

different trials in the experiment did not display a speed-accuracy trade off.

Table 1
Mean Face Inversion Effects for Reaction and Pct. Error Rate for the Different Trials

Image Type	Reaction Time		Error Rates	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Two	23.63	165.23	3.2	9.44
Three	54.12	153.38	4.6	10.86
Four	61.11	114.52	7.4	10.99
Six	53.17	110.04	6.0	11.13
Bucket	46.68	141.29	4.0	11.07
Whole	51.23	151.41	2.1	5.95

Note. Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket = eyes, mouth, nose, & eyebrows on bucket.

Discussion

Experiment 3 failed to support Tanaka and Farah's (1993) hypothesis that the face inversion effect is caused by a disruption in a holistic representation. Specifically, apart from the two eyes condition, a face inversion effect was observed for all of the feature manipulation conditions for both reaction time and error rates. In fact, apart from the two eyes condition, the reduced feature face manipulation conditions produced a larger face inversion effect for error rates than the whole face condition. It is possible that Tanaka and Farah's definition of a whole face does not require every part of the face in order to be activated (e.g., holistic processing begins when three features of a face are presented),

nevertheless, their definition of a holistic representation of a face cannot explain the differences in the magnitude of the inversion effects across the feature manipulation conditions. Specifically, a holistic representation of a face cannot explain why the inversion effects for whole faces, six-features in the context of a bucket, and three of the face manipulation conditions (i.e., the three-feature, four-feature, and six-feature conditions) all displayed different sized inversion effects. In contrast, a coordinate representation of a face can explain the different face inversion effects across face-manipulation conditions. Consequently, Tanaka and Farah's holistic representation is incapable of accounting for the face inversion effects shown in Experiment 3.

The results of Experiment 3 partially support the predictions made by the coordinate relations hypothesis, based on the single unit recording literature (e.g., Gross, 1992; Perret et al., 1998; Rolls, 2000; 2007), that the face inversion effect would grow larger as the number of features to be coded by a coordinate representation increased. Specifically, the 3-feature, 4-feature, and six-feature conditions produced a greater face inversion effect than the two-feature condition. Further, the six features in the context of a bucket produced a greater face inversion effect than all the other conditions.

Although Experiment 3 failed to support Tanaka and Farah's (1993) hypothesis that the face inversion effect is caused by a disruption in a holistic representation, the face inversion effect did not produce progressively larger inversion effect every time the number of features of a face increased as was predicted by the coordinate relations hypothesis (i.e., there was no reliable

difference between three-feature, four-feature, and six-feature faces). Research suggests that some features play a larger role in face recognition than others (Brooks & Kemp, 2007; Sadr, Jarudi, & Sinha, 2003; Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J., 2004). Given that some features are more important to face recognition than others, one would not expect the increment in the face inversion effect to increase by a fixed amount as each new feature is added. Thus, failure to find an increasing face inversion effect may be the result of the experiment lacking the power to find small differences when a relatively unimportant feature is added to the stimulus.

It is important to note that the face inversion effect was smaller for whole faces than for any of the other face manipulation conditions that displayed an inversion effect. One explanation for this result was that in the whole face condition, participants were discriminating two sequentially presented famous faces that had slightly different face outlines (e.g., Michael Jordan followed by Samuel Jackson). Previous research has found that the outlines of faces are used in face recognition (Bruce et al., 1999; Young, Hay, McWeeny, Flude, & Ellis, 1985). In contrast, the bucket provided a constant outline for all the features that were placed on them. The variation in face outlines in the whole face condition may therefore have served as an additional feature that made the task easier when the face was inverted. As a result, it was easier to discriminate whole faces than three, four, six, and bucket feature manipulation conditions. If this explanation for the smaller inversion effects for whole faces is correct, one would predict that the whole face inversion effect would be larger when the six-

features were placed on a standardized face outline than when they are presented in the manner of Experiment 3.

Experiment 4

Experiment 4 attempted to replicate the effects in Experiment 3 using non-face stimuli, specifically houses. Additionally, Experiment 4 tested whether the use of structurally dissimilar features across house stimuli (e.g., “House 1” has rectangular windows and “House 2” has round windows) may be the reason why researchers have failed to find either a house inversion effect (Carbon & Leder, 2006) or a part identification advantage for the parts of a house in the context of a whole house as observed for faces (Tanaka & Farah, 1993). Houses were chosen as the non-face stimuli for Experiment 4 because previous research has used houses as a control for faces.

Tanaka and Farah (1993) failed to find an advantage for the recognition of a part of the house in the context of a whole house. One reason why Tanaka and Farah may have failed to find a feature identification advantage for parts of a house presented in the context of a whole house is because the features they used to construct their houses were structurally dissimilar. For example, Figure 21 presents some of the stimuli Tanaka and Farah (1993) used in their house experiment; while one door has three “curved edges”, the other two doors only have “straight edges”. The coordinate relations hypothesis would predict that a coordinate representation would not be required to perform recognition tasks in which the individual features between two objects activate different “geons” (Biederman, 1987; e.g., a round window compared to a rectangular window).

However, the coordinate relations hypothesis would predict that a coordinate representation is necessary for recognition tasks that require participants to differentiate objects whose individual features activate the same geons (i.e., objects that share the same structural description).

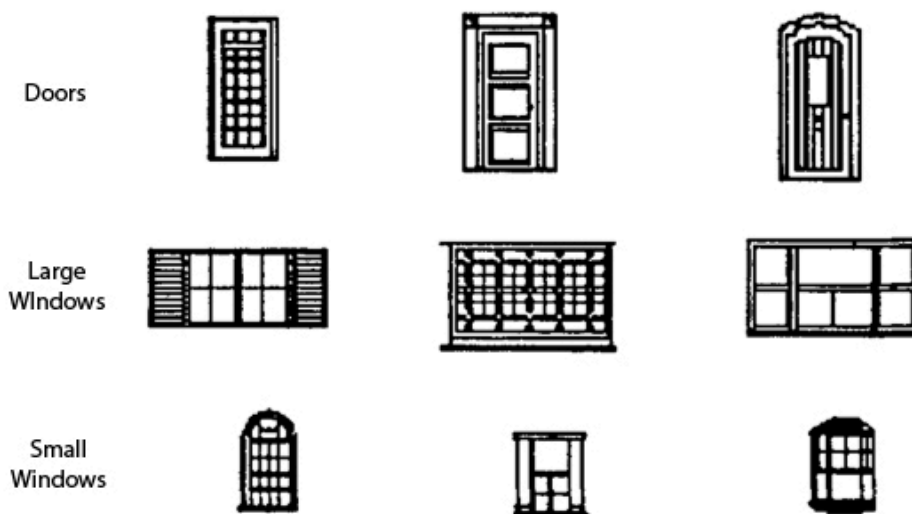


Figure 21. Sample house features used in Tanaka and Farah's experiment (1993). Note that many of the features produce different geons (Biederman, 1987) in the windows. For example, the small window on the left is the only small window that contains one curved edge, while the small middle window has no curved edges and is not symmetrical through any cross-sections, and the small window on the right expands and contracts over the course of its axis.

Experiment 4 investigated the inversion effects for one-feature (front door), three-feature (front door and two windows), five-feature (front door and four windows), six-feature (front door, four windows, and a garage door), and whole house stimuli. Participants determined whether two sequentially presented house stimuli were identical or different. In half of the trials the two house stimuli were identical, and in the remaining half of the trials the two house stimuli were different. In the different trials, half of the trials required participants to discriminate house stimuli with structurally different features (e.g., a house

stimulus with a “curved window” was presented followed by a house stimulus with “rectangular window”), and the remaining different trials required participants to discriminate house stimuli with structurally similar features (i.e., the two house stimuli had identical structural descriptions). For the identical trials, the coordinate relations hypothesis predicts that the inversion effect should progressively increase as the number of features to be coded by the coordinate representation increases. For the different trials, the coordinate relations hypothesis only predicts a significant increase in the inversion effect when participants have to discriminate house stimuli that share structural descriptions. The coordinate relations hypothesis predicts no inversion effect for different trials in which the features between the house stimuli are structurally dissimilar. Note that Tanaka and Farah (1993) would not predict an inversion effect for any of the trial types.

Method

Unless noted, all procedures in Experiment 4 are the same as those in Experiment 3.

Participants

Ninety-eight undergraduate students from the Iowa State University subjects' pool participated in the experiment for course credit. All subjects reported normal or corrected-to-normal vision. The participants consisted of 50 females and 48 males. The mean age of the participants was 19.9 ($SD=2.6$).

Apparatus

Stimuli for the Experiment 4 consisted of 24 houses that were constructed

in Photoshop CS5.1. All the houses that were constructed were initially produced in a canonical upright view. The houses were paired so that each house would have structurally similar features with another house that differed only in the size of the features. Four other feature manipulations were constructed for each of the 24 houses using Photoshop CS5.1. The additional feature manipulations produced stimuli that consisted of one-feature (front door), three-features (front door and two windows), five-features (front door, and four windows), and six-features (front door, four windows, and garage door; see Figure 22 for sample stimuli). The distance of the features from one another were held constant across all of the feature manipulations for each house (e.g., the distance of the front door to the lower-left window were the same in the 3-feature manipulation for “house 1” as well as the 5-feature manipulation for “house 1”). Inverted copies of all the house stimuli were also made.

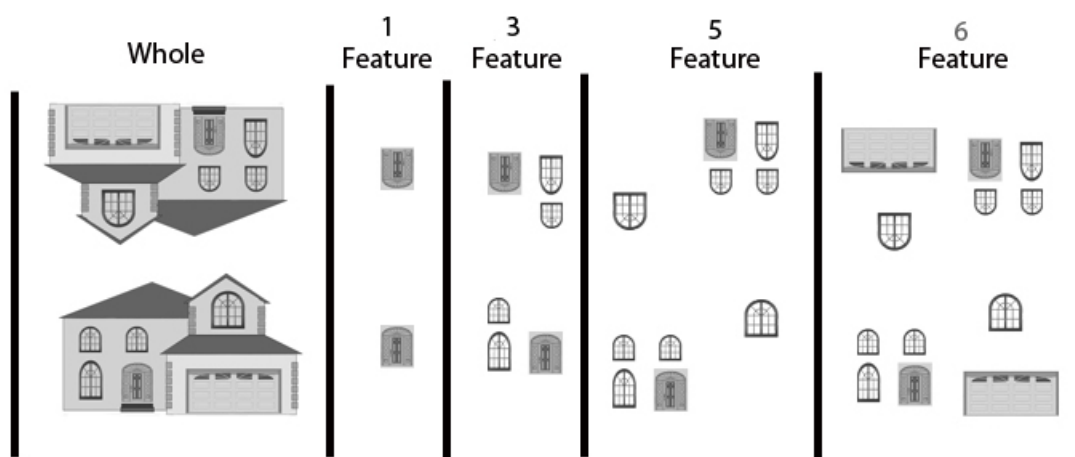


Figure 22. All of the stimuli made for one of the twenty-four houses in the Experiment 4. All of the houses shared the same template (i.e., they all shared the same house outline, roof, bricks, front door step, and siding).

Procedure

Presentation of the stimuli was self-paced. The participants were instructed that they would be presented with a fixation cue, followed by a house stimulus, followed by a mask, and then presented with a second house stimulus. Participants were instructed to press the spacebar to begin each trial. Upon pressing the spacebar, a fixation cue was presented for 500 ms, followed by the presentation of a house stimulus for 250 ms followed by a pattern mask for 500 ms, followed by the presentation of a second house stimulus that remained on the screen until the participant response (see Figure 23). As in Experiment 3, the second stimulus in Experiment 4 was displaced to one of four locations. Half of the trials were identical trials and half of the trials were different trials. In the different trials, half of the time the two different trials shared structural descriptions (i.e., the features had identical non-accidental properties) and half of the time the two different house stimuli did not share the same structural descriptions (e.g., one of the house stimuli may have a “curved edge” on the window, while the other house stimuli has a “rectangular” window).

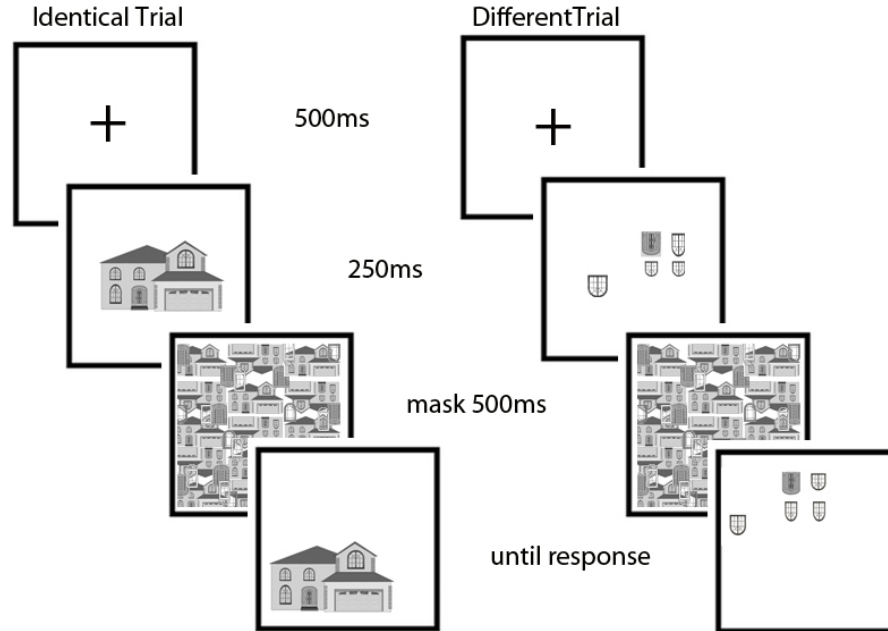


Figure 23. Event sequences for the identical and different trials used in Experiment 4. The house stimuli presented for any given trial can be upright or inverted and consist of one-feature (the front door), three-feature (the front door and two windows), five-feature (the front door and four windows), six-feature (the front door, four windows, and a garage door), or whole houses.

Each participant saw 480 experimental trials. Participants were presented with all twenty-four house stimuli, at each manipulation condition (whole house, one-feature, three-features, five-features, and six-features), at each orientation (upright or inverted), and each trial type (identical or different) condition. Half of the different trials required participants to discriminate two house stimuli that had identical structural descriptions (e.g., they had structurally similar features), and half of the different trials required participants to discriminate two house stimuli with different structural descriptions (e.g., a round window on one house and a rectangular window on another house). The house stimuli used for the two different trial types were randomly assigned for a particular block and counterbalanced across every two blocks (e.g., in Block 1, “House 1” was

compared to “House X” with the same structural description, and in Block 2, “House 1” was compared to “House Y” with a different structural description). The order of the trials was randomly chosen for each participant. For any given trial, the first stimulus and second stimulus on a trial were matched for orientation (e.g., upright then upright) and number of features (e.g., if a five-feature house stimulus is presented, it was followed by another five-feature house stimulus).

Participants were presented with 40 practice trials prior to the experiment using the same presentation conditions used during the actual experiment. Each participant saw two practice trials for any given feature manipulation (five conditions) X orientation (upright or inverted) X trial type condition (identical or different). Half of the different practice trials required participants to discriminate house stimuli with the same structural description, and half of the different trials required participants to discriminate house stimuli with different structural descriptions.

Results

Fifteen participants were not included in any of the data analysis because they did not perform above 65% accuracy in all five feature manipulation conditions. In order to maintain the same presentation sequence conditions as in Experiment 3, Experiment 4 lowered the performance accuracy cutoff to 65% (rather than 70%) due to the increased difficulty of the task. As in Experiments 2 and 3, Experiment 4 had many data points for each condition of interest. As a result, all reaction times that fell outside of three standard deviations from each participant’s orientation x manipulation condition mean were removed (fewer than

3% of the data points were removed).

House Inversion Effect

A new dependent variable was created for each participant that measured each participant's house inversion effect for each of the feature manipulation conditions (whole house, one-feature, three-features, five-features, and six-features). The inversion effect for reaction times and error rates was calculated for each participant in the same manner as Experiment 4. See Appendix I for the mean upright and inverted reaction times for different trial types and Appendix J for the mean upright and inverted percentage error rates for the different trial types. See Appendix K for the mean upright and inverted reaction times and percentage error rates for the same trials.

Different trials.

The inversion effects for reaction time and error rates in Experiment 4 were examined for the two different trial conditions (i.e., the different trials in which the two house stimuli had identical structural descriptions and the different trials in which the two different house stimuli had different structural descriptions) in order to test whether the coordinate relations hypothesis could explain why previous researchers (e.g., Tanaka & Farah, 1993) failed to find an effect of inversion for houses. The coordinate relations hypothesis predicts that previous researchers failed to find a house inversion effect because their houses did not share the same structural description. The coordinate relations hypothesis predicts a house inversion effect only for different trials in which the two house stimuli share structural descriptions. Further, in such trials, the coordinate

relations hypothesis predicts that the house inversion effect should increase as the number of features to be coded by a coordinate representation increases.

Reaction time and error rates of the face inversion effect were examined for Experiment 4 using a factorial within-participants analysis of variance (ANOVA) with feature manipulation (one-feature, three-feature, five-feature, six-feature, and whole houses) and trial type (same structural description vs. different structural description) as the independent variables.

Reaction time. There was not a reliable interaction for reaction times between trial type and feature manipulation $F(4, 320) = 1.93, p > 05$. Figure 24 presents the house inversion effect for reaction time for each feature manipulation condition for the two different trial conditions. There was not a reliable main effect of trial type $F(1, 80) = 0.06, p > 05$. There was not a reliable main effect of feature manipulation $F(4, 320) = 1.28, p > 05$.

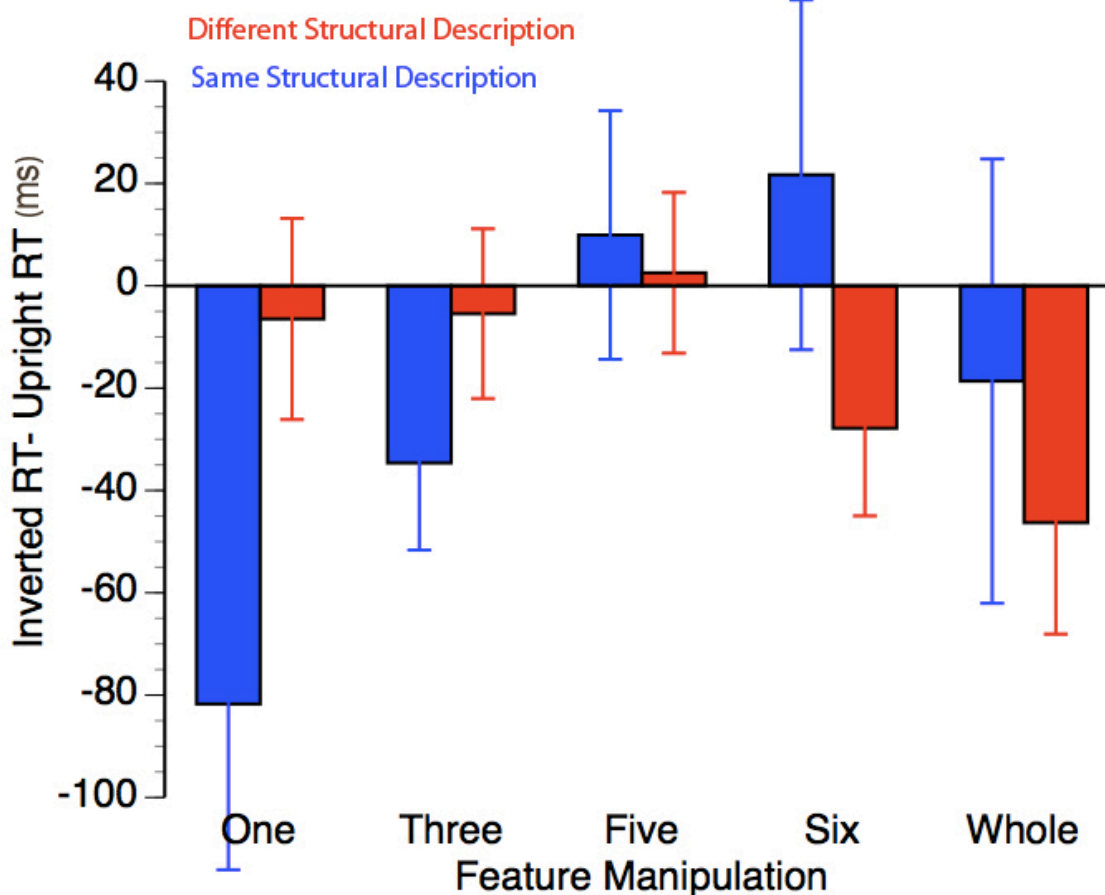


Figure 24. The graph displays the mean reaction time house inversion effects for both different trial conditions (same and different structural conditions) for each of the feature manipulation conditions. Standard error bars are shown for each feature manipulation condition. *Note.* One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

Error rates. Given the large variance in the number of data points for reaction time, and the fact that some participants in Experiment 4 were unable to accurately detect differences between different stimuli in the same structural description conditions (i.e., some participants made over 50% errors in a given condition), error rate was a better measure of the house inversion effect in Experiment 4 than reaction time. Specifically, if orientation differentially affects one's ability to discriminate houses, then there should be a difference in error

rates between upright and inverted house stimuli. For instance, if a participant was at 60% errors for inverted one-feature houses in the same structural description different trials and they were at 40% errors for upright one-feature houses in the same structural description different trials, then the 20% difference in error rate would suggest there is a recovery in the ability for that participant to discriminate one-feature house stimuli when presented upright.

There was an interaction that was approaching significance between trial type and feature manipulation $F(4, 320) = 2.37, p = .052$. Figure 25 presents the house inversion effect for error rates for each feature manipulation condition for the two different trial types. As the number of features of a house increased, the house inversion effect displayed an increase for the same structural description trials but not for the different structural description trials. The trial type main effect approached significance, $F(1, 80) = 3.92, p = 0.051$.

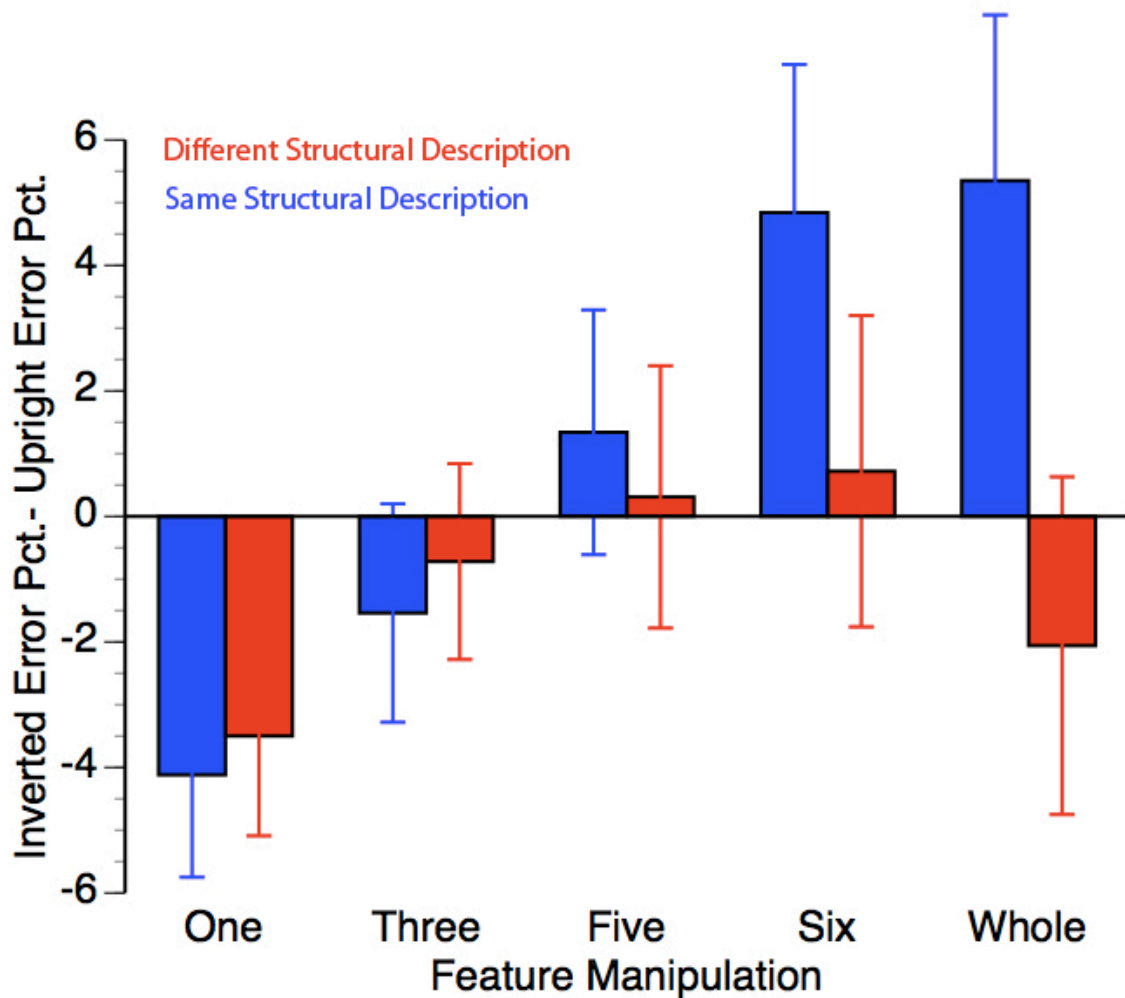


Figure 25. The graph displays the mean error rate house inversion effects for both different trial conditions (same and different structural conditions) at each of the feature manipulation conditions. Standard error bars are shown for each feature manipulation condition. *Note.* One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

There was a reliable main effect of feature manipulation, $F(4, 320) = 4.46$, $p < .01$. A posthoc pairwise comparison using the Bonferroni adjustment was used to compare the error rates for the feature manipulation conditions. One-feature houses showed a reliably lower house inversion effect than all the other feature manipulation conditions. No other pairwise comparisons were reliably different.

Same Trials. The reaction time data for the same trials in Experiment 4 showed a reliable main effect of feature manipulation, $F(4, 320) = 2.91, p < .05$. Figure 26 presents the house inversion effect for reaction time for each feature manipulation condition. A posthoc pairwise comparison using the Bonferroni adjustment was used to compare the house inversion conditions. None of the feature manipulation conditions differed reliably from one another. There was not reliable main effect of feature manipulation on the house inversion error rates $F(4, 320) = 1.74, p > .05$ (see Figure 27).

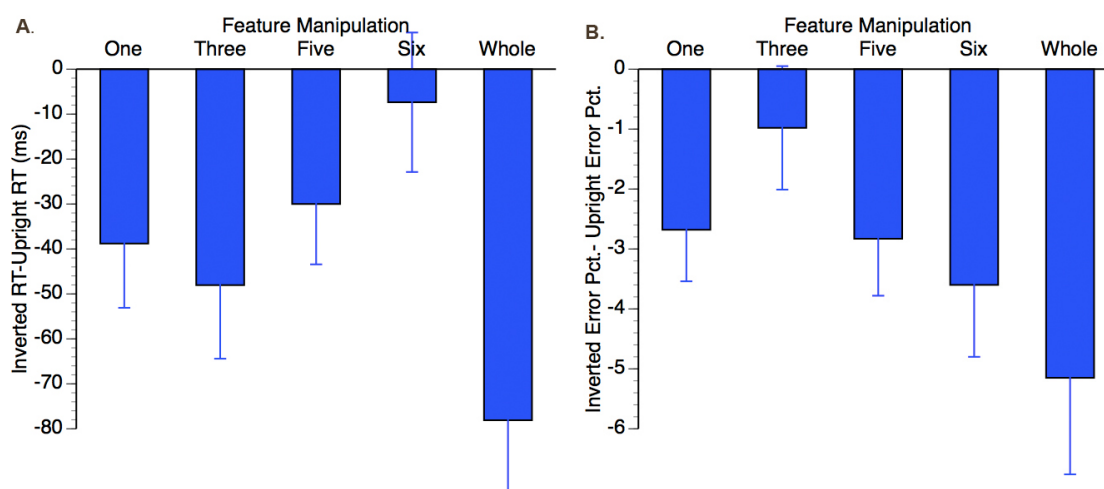


Figure 26. Graph A displays the mean reaction time and Graph B displays the mean error rate house inversion effects for the same trials for each of the feature manipulation conditions. Standard error bars are shown for each feature manipulation condition. *Note.* One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

Raw Error Rate for Different Trials

Just as in Experiment 3, the data from Experiment 4 was examined to determine if the reliable differences observed for the constructed house inversion dependent variable were caused by floor and/or ceiling effects on either the upright or inverted versions of the stimuli. Table 2 presents the mean

percentage error for each feature manipulation x orientation x different trial type condition. Table 2 suggests that the error rates for the one and whole house conditions for the same structural description condition were at chance. However, it is important to note that because the two images being compared shared the same structural description, it is possible that the coordinate representation for one feature and whole conditions were not tuned well enough to detect a difference between the two houses. Nevertheless, if there were a reliable difference in the error rates between inverted and upright houses at a given condition, it would suggest that presentation of the house at a given orientation affects how well one can discriminate the stimuli.

Table 2
Mean Pct. Error for Upright and Inverted at Each House Condition for Each Different Trial Type

Image Type	SSD		DSD	
	U	I	U	I
One	53.29	49.18	25.6	22.1
Three	19.34	17.8	8.9	8.2
Five	27.47	28.81	7.4	7.7
Six	33.54	38.37	9.9	10.6
Whole	49.69	55.04	16.3	14.2

Note. SSD = same structural description; DSD = different structural description; U = upright; I = inverted; One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

Discussion

Experiment 4 failed to support the predictions made by the holistic

representation hypothesis (Tanaka & Farah, 1993). Specifically, there was a main effect of feature manipulation for the different trials' error rates.

Additionally, there was an interaction that was approaching significance across trial type and feature manipulation condition error rates. As discussed in the Introduction to Experiment 4, Tanaka and Farah would not predict an effect of inversion on house recognition, but Experiment 4 clearly demonstrated such an effect.

The coordinate relations hypothesis (Cooper & Wojan, 2000) predicted that the house inversion effect would grow larger for the different trials in which stimuli had the same structural description as the number of features increased, but that inversion would have less of an effect on different trials in which the stimuli had different structural descriptions. Consistent with the predictions of the coordinate relations hypothesis, the house inversion effects on the different trails approached significance for the interaction between trial type (same structural description vs. different structural description) and feature manipulation conditions for error rates.

One unforeseeable limitation of Experiment 4 is that the task was so difficult that a number of participants were excluded from the final analysis (a pilot study was conducted in which all participants were above 85% accuracy for all the trial types, but participants in the actual experiment performed much worse). Although, 113 participants took part in Experiment 4, fifteen participants were removed because they did not achieve above 65% accuracy for all the feature manipulation conditions. Another seventeen participants were excluded

because they did not have a data point at one of the same structural condition trials. It was predicted that the house inversion effects for Experiment 4 would be smaller than face inversion effects observed in Experiment 3. The rationale for this hypothesis is that because participants do not have as much experience discriminating houses as they do faces, their coordinate representation would not be as finely tuned for upright houses as their coordinate representation for faces. As a result, it was anticipated that the house inversion effect would be smaller than the face inversion effect observed in Experiment 3, and in consequence, Experiment 4 would require more participants than Experiment 3 to ensure adequate power. It is possible that the marginally significant interaction for error rates between trial type and feature manipulation that was approaching significance would become reliable with a greater number of participants.

Although not of great theoretical interest, the same trials in Experiment 4 displayed a very odd pattern of results in which subjects were actually faster and more accurate at performing the task on the same trials with houses when they were upside down rather than right side up. One possible explanation for the obtained data could be that there was a response bias for participant's to respond "same" on inverted trials more so than upright trials (see the tables in Figure 27). As the tables in Figure 28 show, subjects showed a stronger bias to say "Same" when the houses were inverted (in which 69.3% of all responses were "Same") than when the houses were upright (in which 55.2% of all responses were "Same").

		Pct. Responses Upright		Pct. Responses Inverted	
		Event		Event	
		Same	Different	Same	Different
Response	Same	85.2	25.24	88.21	50.41
	Different	14.84	74.76	11.79	49.59

Figure 27. The mean percentage of the time participants responded "same" or "different" for the same and different trials collapsed across all feature manipulation conditions. Participants were more biased to respond "same" for inverted house stimuli than they were for upright house stimuli.

An alternative explanation for the increased speed to respond to inverted house stimuli over upright house stimuli for the same trials is that, because the only differences between the stimuli were the features, it is possible that the visual system attempted to establish a coordinate representation of the house stimuli when the stimuli were right side up (because such a code is obligatory for any known stimulus), but the visual system did not attempt to code any type of relations when the house stimuli were presented upside down. When the house stimuli were presented upside down, participants may have relied purely on differences in the features (with no coding of relations) in order to make a response.

GENERAL DISCUSSION

The primary purpose of the four experiments presented in this dissertation was to determine the nature of the representation that causes the face inversion effect. Specifically, the coordinate relations hypothesis (Cooper & Wojan, 2000) predicts that the representation of a face is not qualitatively different from the representation of any non-face object that requires coordinate relations to recognize it. The coordinate relations hypothesis predicts that face-like effects should be observed for identifying non-face objects when the structural descriptions of the objects to be recognized are the same. Four experiments tested: whether the representation of faces is qualitatively different than the representation of non-face stimuli; whether a holistic representation (Tanaka & Farah, 1993; Maurer et al., 2002) is necessary to explain face inversion effects; and whether the coordinate relations hypothesis could predict when inversion effects would be observed for non-face stimuli and consequently explain why some researchers have failed to find face-like effects for non-face stimuli (e.g., houses).

Experiment 1 was conducted to determine whether the rotation function for faces was qualitatively different than the rotation function for animals and objects. Experiment 1 displayed an inverted-U shaped rotation function for the recognition of faces that was significantly steeper than that for animals and objects. Further, Experiment 1 failed to replicate the inverted-U shaped rotation function for animals and the M-shaped rotation functions for objects reported by Cooper and Brooks (2004). The results of Experiment 1 failed to support Cooper

and Wojan's (2000) proposal that the face inversion effect is simply a consequence of the fact that faces show an inverted "U" rotation function that peaks at 180 degrees while objects show an "M" shaped rotation function that has a dip at 180 degrees.

Experiment 2 attempted to replicate the results of Experiment 1 using a categorization task that was less noisy and allowed for the collection of more data. Experiment 2 displayed a significantly steeper rotation function for faces than for animals. Consistent with the results reported by Cooper and Brooks (2004), an inversion effect was observed for animals. However, the M-shaped rotation function for objects reported by Cooper and Brooks was not observed. The results obtained by Experiments 1 and 2 failed to support Cooper and Wojan's (2000) conjecture that the rotation function for animals would be parallel to the rotation function for faces and suggests there is something unique about faces. Additionally, both experiments failed to replicate the M-shaped rotation function for objects that has been produced by many studies (e.g., Cooper & Brooks, 2004; Jolicoeur, 1985; Jolicoeur, 1988; Jolicoeur & Milliken, 1989; McMullen & Farah, 1991; McMullen & Jolicoeur, 1990).

Experiment 3 tested whether a holistic representation, as defined by Tanaka and Farah (1993), or a coordinate representation, as defined by Cooper and Wojan (2000), better predicted how the number of features one has to discriminate would influence the size of the inversion effect. Whereas the holistic representation hypothesis predicted that no inversion effects would occur except when a whole face was presented, the coordinate relations hypothesis predicted

the inversion effect would increase as the number of features to be coded by the coordinate representation increased. Experiment 3 found inversion effects in the same trials for error rates and reaction times for three-feature, four-feature, six-feature, six-features placed on a bucket, and whole faces. Further, for the same trials, six features placed on a bucket displayed a greater inversion effect in error rates and reaction times than three, four, six, and whole faces. Consequently, the results of Experiment 3 failed to support the holistic representation hypothesis of Tanaka and Farah. Although not all of the feature conditions showed reliable face inversion effect differences, the pattern of results obtained were consistent with the predictions made by coordinate relations hypothesis (the failure to find reliable differences in all the feature conditions may have been due to a lack of sufficient power).

Experiment 4 tested whether the coordinate relations hypothesis could explain why some studies (e.g., Carbon & Leder, 2006; Tanaka & Farah, 1993) have failed to find face-like effects for house recognition. House stimuli were created that varied in their number of features and in their structural descriptions. The coordinate relations hypothesis predicted that house inversion effects would only be observed for different trials in which the two house stimuli being discriminated had identical structural descriptions. The coordinate relations hypothesis did not predict a house inversion for different trials in which the two house stimuli being discriminated did not share structural descriptions. The holistic representation hypothesis proposed by Tanaka and Farah, predicted no house inversion for any trial conditions because they posit that holistic

representations are responsible for the face inversion effect and that houses do not activate a holistic representation. Experiment 4 found an interaction that was approaching significance between feature manipulation and different trial type for error rates, which would likely become statistically significant with the inclusion of more participants. The pattern of the interaction was consistent with the predictions made by the coordinate relations hypothesis. An additional result that is incompatible with the predictions of the holistic representation hypothesis was that there was a reliable main effect of feature manipulation for error rates in the different trials in Experiment 4. As in Experiment 3, the results of Experiment 4 failed to support the holistic representation's explanation of the face inversion effect.

What Form of Representation Causes the Face Inversion Effect?

The results obtained from the current set of experiments suggest that there is something unique about the recognition of faces compared to non-face stimuli. Specifically, the inversion effects observed for faces were significantly larger than the inversion effects observed for animals and houses. What accounts for the size of the face inversion effect and how does it differ from the non-face stimuli tested in the current study?

Tanaka and Farah (1993) proposed that faces are processed holistically meaning that they are "represented without an internal part structure". Tanaka and Farah proposed that holistic representations are unique to faces and are what is disrupted when faces are inverted. In accordance with the single unit recording literature discussed in the Introduction (e.g., Gross, 1992; Perrett et al.,

1998; Rolls, 2000; 2007), Experiment 3's results suggest that a holistic representation is not needed to explain face inversion. Further, the holistic representation proposed by Tanaka and Farah cannot explain why the face inversion effect increased as the number of face features to be coded increased when presented outside the context of a whole face. Additionally, the holistic representation theory cannot explain why placing six features of a face on a bucket would produce the largest inversion effects. Finally, if a holistic representation is unique to faces and is responsible for the face inversion effect, then why did Experiments 2 and 4 display inversion effects for non-face stimuli? An inversion effect was observed for animals in Experiment 2 and houses showed substantial inversion effects in Experiment 4. Taking the results of all the experiments reported here together, the holistic representation theory is of no utility in predicting the conditions when a particular recognition task would show an inversion effect.

The results from Experiments 1 and 2 failed to support Cooper and Wojan's (2000) hypothesis that the face inversion effect is due to the rotation function for faces being "Upside Down U" shaped while the rotation function for objects is "M" shaped. However, the results of Experiments 3 and 4 displayed inversion effects that are exactly as would be predicted if a coordinate representation was being used to perform the task. Nevertheless, the results of Experiments 1 and 2 are clear that there is something different about the representation of faces that causes them to be more affected by rotation than other objects. The next logical question to ask is what differences exist between

the coordinate representations used to recognize a face and those that are used to recognize other objects (such as the animals in Experiments 1 and 2) that would account for their different rotation functions?

Based on previous research and the results presented in the current study, it appears that there are three factors responsible for the size of the inversion effects for a particular class of stimuli. First, it appears that inversion effects are more likely to be observed as the precision required to recognize an object using a coordinate representation increases. Second, inversion effects are larger when the amount of visual information to be coded by a coordinate representation increases. Third, inversion effects are larger, and more likely to be observed, as the amount of experience one has coding coordinate representations of visually similar stimuli increases. Each of these factors will be discussed in turn.

Experiment 3 suggested that the size of the inversion effect is not only dependent upon the amount of visual information to be coded by a coordinate representation, but also dependent upon the amount of precision required by the coordinate representation to discriminate faces. Specifically, face inversion effects were smaller for whole faces than three-feature, four-feature, and six-feature faces even though whole faces contained a greater amount of visual information. The major difference between the whole face stimuli, and other face stimuli used in Experiment 3, was that the whole face stimuli contained face outlines that varied across stimuli (i.e., the participants' coordinate representation for whole faces could rely on the differences in head outlines to discriminate

faces more accurately). As demonstrated in Experiment 3, the largest inversion effects were observed when the precision required to discriminate faces was increased by placing the six features of a face on a bucket. I predict that larger inversion effects would be observed than the three-feature, four-feature, and six-feature face conditions if the six features of a face were placed on standardized face outline—increasing both the degree of precision and the amount of visual information to be coded by a coordinate representation. This prediction is supported by previous research that has found larger inversion effects for standardized faces (i.e., the face outlines did not change across face stimuli) than whole faces that were not constructed with the same face outline (for reviews, see McKone & Kanwisher, 2009; Rossion, 2008).

How precisely the locations of the primitives must be coded to discriminate faces and objects can not only contribute to the size of the face inversion effect, but also contributes to the size of other face-associated effects (i.e., the N170). As discussed in the Introduction, Thierry et al. (2007) tested how the degree of interstimulus perceptual variance (ISPV) for face and non-face stimuli affected the N170 (a face-related ERP component). Thierry et al. found that the conditions in their experiment that required fine coding of the locations of the primitives produced a larger N170 than conditions in which only coarse coding was required. The evidence suggests that one cause of the greater inversion effects observed for face recognition than for other tasks is that faces require more precise coding of the locations of the primitives in the representation than the recognition of other classes of objects. The relatively coarse coding (relative

to faces) of the locations of the primitives required to differentiate animals in Experiments 1 and 2 likely contributed to the smaller inversion effects observed for animals than for faces. Based on this logic, it is predicted that the inversion effect observed for animals in Experiment 2 would be larger if participants had to discriminate animals that required greater precision in the coordinate representation (e.g., the categorization task could require participants to discriminate only horses and donkeys).

Experiments 3 and 4 suggest that another important contributor to the size of the inversion effect is the amount of information to be coded by a coordinate representation. Based on the results of Experiments 3 and 4, for face and object stimuli that have been previously coded by a coordinate representation at a standard upright orientation, the inversion effects become larger as the number of features to be coded by the coordinate representation increases. Consistent with studies using single unit recordings (e.g., Perrett et al., 1998; Rolls, 2007), Experiments 3 and 4 both demonstrated that the inversion effect becomes larger as the number of features to be coded by a coordinate representation increases.

Finally, the literature on the face inversion effect suggests that inversion effects will become larger as the participant gains expertise discriminating a particular class of stimuli. Of the stimuli used in the experiments reported here, participants have had far more experience forming coordinate representations of faces than of animals and houses. The literature on the face inversion effect suggests that the lack of experience in coding coordinate representations for the animals and objects also contributed to their decreased inversion effect. Previous

studies that have found that experience with a novel set of stimuli, called “Greebles”, displayed inversion effects for experts, but not novices (e.g., Gauthier & Tarr, 1997; Gauthier et al., 1999).

Future Directions

The interaction between feature manipulation and trial type (same structural description vs. different structural description) that was predicted by the coordinate relations hypothesis in Experiment 4 approached significance, but the experiment appeared to lack sufficient power to reach statistical significance. Future research should try to replicate Experiment 4, but either collect more data, or make the experiment to easier for participants in order to lift performance off the floor. The collection of more data for Experiment 4 is planned.

Based on the research reported here and the previous literature, three variables were proposed in the previous section as collectively determining the size of the inversion effects for a particular recognition task: the amount of precision in the coordinate representation required to discriminate the stimuli (greater precision leads to a greater inversion effect), the number of features that need to be coded to discriminate the stimuli (larger number of features leads to a greater inversion effect), and the amount of experience the observer has at making the discrimination (more experience leads to a larger inversion effect). In order to test whether these three variables can, in fact, be used to predict the size of the inversion effect for a particular recognition task, future investigations should examine the effects of inversion while manipulating each of these variables. For example, one study could be constructed in which participants are

first trained to learn a set of nonsense objects at a particular upright orientation over repeated training sessions. The study would manipulate the participant's experience with the nonsense objects by assigning different groups of participants to different numbers of training trials. The nonsense objects would be constructed such that the number of features varied across different objects. For example, the nonsense stimuli could be constructed so that they were made up of three, five, and six features. Further, the nonsense stimuli for each feature manipulation condition could also vary in the amount of precision that would be necessary in order to discriminate different nonsense objects. For example, some nonsense groups of stimuli would be constructed so that the precision required to discriminate them would be low (i.e., there would be large differences in the coordinate representations of the stimuli), and some nonsense groups of stimuli would be constructed so that precision required to discriminate them would be high (i.e., there would be very small differences in the coordinate representations of the stimuli).

If the previous paragraph's proposed study were carried out, it is predicted that the largest inversion effects would be observed by participants in the high experience condition for stimuli with the greatest number of features in the high precision nonsense stimuli condition. Furthermore, it is predicted that there would be reliable main effect of inversion in error rates and reaction time for the three independent variables (experience, feature number, and degree of precision). If the proposed experiment were conducted, it would be the first time in which precision, feature number, and experience would be tested in the same

experiment. More importantly, if the proposed experiment were able to induce face-like inversion effects for the nonsense stimuli, it would be the first experiment to demonstrate that non-face stimuli (e.g., nonsense stimuli) can produce inversion effects similar to those observed for faces.

REFERENCES

- Allison, T., Puce, A., & McCarthy, G. (2000). Social perception from visual cues: role of the STS region. *Trends in Cognitive Sciences*, 4, 267-278.
- Ashworth, A. R., Vuong, Q. C., Rossion, B., & Tarr, M. J. (2008). Recognizing rotated faces and Greebles: what properties drive the face inversion effect? *Visual Cognition*, 16, 754-784.
- Atkinson, A. P., & Adolphs, R. (2011). The neuropsychology of face perception: beyond simple dissociations and functional selectivity. *Philosophical Transactions of the Royal Society London: Biological Sciences*, 366, 1726-1738.
- Bailey, D. L., Townsend, D. W., Valk, P. E., & Maisey, M. N. (2005). *Positron Emission Tomography*. Singapore: Springer.
- Barton, J. J., Cherkasova, M. V., Press, D. Z., Intriligator, J. M., & O'Connor, M. (2004). Perceptual functions in prosopagnosia. *Perception*, 33, 939-956.
- Baylis, G. C., Rolls, E. T., & Leonard, C. M. (1987). Functional subdivisions of the temporal lobe neocortex. *The Journal of Neuroscience*, 7, 330-342.
- Benson, D. F., & Greenberg, J. P. (1969). Visual form agnosia. *Archives of Neurology*, 20, 82-89.
- Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*, 8, 551-565.
- Biederman, I. (1987). Recognition-by-components: a theory of human image understanding. *Psychological Review*, 94, 115-147.

- Biederman, I., & Cooper, E. (1991a). Object recognition and laterality: null effects. *Neuropsychologia*, *29*, 685-694.
- Biederman, I., & Cooper, E. (1991b). Priming contour-deleted images: evidence for intermediate representations in visual object recognition. *Cognitive Psychology*, *23*, 393-419.
- Bodamer, J. (1947). Die Prosop-Agnosia. *Archiv für Psychiatric und Zeitschrift Neurologie*, *179*, 6-54.
- Bolognini, N., & Ro, T. (2010). Transcranial magnetic stimulation: disrupting neural activity to alter and assess brain function. *The Journal of Neuroscience*, *30*, 9647-9650.
- Booth, M. C., & Rolls, E. (1998). View-invariant representations of familiar objects by neurons in the inferior temporal cortex. *Cerebral Cortex*, *8*, 510-523.
- Bornstein, B., Stroka, H., & Munitz, H. (1969). Prosopagnosia with animal face agnosia. *Cortex*, *5*, 165-169.
- Brand, T., Steinke, W., Thie, A., Pessin, M. S., & Caplan, L. R. (2000). Posterior cerebral artery territory infarcts: Clinical features, infarct topography, causes and outcome. Multicenter results and a review of the literature. *Cerebrovascular Diseases*, *10*, 172-182.
- Brooks, B. E., & Cooper, E. E. (2006). What types of visual recognition tasks are mediated by the neural subsystem that subserves face recognition? *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 684-698.

- Brooks, K. R., & Kemp, R. I. (2007). Sensitivity to feature displacement in familiar and unfamiliar faces: beyond the internal/external feature distinction. *Perception, 36*, 1646-1659.
- Bruce, V., Henderson, Z., Greenwood, K., Hancock, P., Buron, A. M., & Miller, P. (1999). Verification of face identities from images capture on video. *Journal of Experimental Psychology: Applied, 5*, 339-360.
- Bryden, M. P., & Rainey, C. A. (1963). Left-right differences in tachistoscopic recognition. *Journal of Experimental Psychology: Human Perception and Performance, 66*, 568-571.
- Bukach, C. M., Bub, D. N., Gauthier, I., & Tarr, M. (2006). Beyond faces and modularity: the power of an expertise framework. *Trends in Cognitive Sciences, 10*, 159-166.
- Burgund, E. D., & Marsolek, C. J. (2000). Viewpoint-invariant and viewpoint-dependent object recognition in dissociable neural subsystems. *Psychonomic Bulletin and Review, 7*, 480-489.
- Busey, T. A., & Vanderkolk, J. R. (2005). Behavioral and electrophysiological evidence for configural processing in fingerprint experts. *Vision Research, 45*, 431-448.
- Caramazza, A., & Shelton, J. R. (1998). Domain-specific knowledge systems in the brain the animate-inanimate distinction. *Journal of Cognitive Neuroscience, 10*, 1-34.

- Cappa, S. F., Frugoni, M., Pasquali, P., Perani, D., & Zorat, F. (1998). Category-specific naming impairment for artifacts: A new case. *Neurocase*, 4, 391-397.
- Casner, G. E., & Cooper, E. (2006). A Test of the coordinate relations hypothesis: Is prosopagnosia a consequence of damage to the coordinate recognition system? *Unpublished doctoral dissertation, Iowa State University, Ames, IA.*
- Chao, L. L., Martin, A., & Haxby, J. V. (1999). Are face-responsive regions selective only for faces? *Neuroreport: For Rapid Communication of Neuroscience Research*, 10, 2945-2950.
- Cohen, G. (1990). Why is it difficult to put names to faces? *British Journal of Psychology*, 81, 287-297.
- Cohen, G., & Burke, D. M. (1993). *Memory for proper names*. Hove: Lawrence Erlbaum Associates Ltd.
- Cohen, D. J., & Faulkner, D. (1986). Memory for proper names: age differences in retrieval. *British Journal of Developmental Psychology*, 4, 187-197.
- Cooper, E. E., & Brooks, B. E. (2004). Qualitative differences in the representation of spatial relations for different object classes. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 243-256.
- Damasio, A. R., Damasio, H., & Van Hoesen, G. W. (1982). Prosopagnosia: anatomic basis and behavioral mechanisms. *Neurology*, 32, 331-341.

- De Gelder, B., & Rouw, R. (2000). Paradoxical configuration effects for faces and objects in prosopagnosia. *Neuropsychologia*, *38*, 1271-1279.
- De Renzi^a, E. (1986). *Current issues in prosopagnosia*. In M. A. J. H. D. Ellis, F. Newcombe, & A. W. Young (Ed.), *Aspects of face processing*. Dordrecht, The Netherlands: Martinus Nijhoff.
- De Renzi^b, E. (1986). Prosopagnosia in two patients with CT scan evidence of damage to the right hemisphere. *Neuropsychologia*, *24*, 385-389.
- De Renzi, E., Perani, D., Carlesimo, G. A., & Silveri, M. C. (1994). Prosopagnosia can be associated with damage confined to the right hemisphere: An MRI and PET study and a review of the literature. *Neuropsychologia*, *32*, 893-902.
- Desimone, R. (1991). Face-selective cells in the temporal cortex of monkeys. *Journal of Cognitive Neuroscience*, *3*, 1-8.
- Diamond, R., & Carey, S. (1986). Why faces are and are not special: An effect of expertise. *Journal of Experimental Psychology: Human Perception and Performance*, *115*, 107-117.
- Doi, H., Sawada, R., & Masataka, N. (2007). The effects of eye and face inversion on the early stages of gaze directions perception--an ERP study. *Brain Research*, *1183*, 83-90.
- Eimer, M. (2000). Effects of face inversion on the structural encoding and recognition of faces: evidence from event-related potentials. *Cognitive Brain Research*, *10*, 145-158.

- Ellis, H. D., & Young, A. W. (1989). Are faces special? In A. W. Young, & Ellis, H. D. (Ed.), *Handbook of Research on Face Processing* (pp. 1-26). North-Holland: Elsevier Science Publishers.
- Fantz, R. L. (1958). Pattern vision in young infants. *Psychological Record*, 8, 43-47.
- Fantz, R. L. (1965). Visual perception from birth as shown by pattern selectivity. *Annals of the New York Academy of Sciences*, 118, 793-814.
- Farah, M. (2004). *Visual Agnosia* (2nd ed.). Cambridge, MA: The MIT Press.
- Farah, M. J., Levinson, K. L., & Klein, K. L. (1995). Face perception and within-category discrimination in prosopagnosia. *Neuropsychologia*, 33, 661-674.
- Galper, R. E. (1970). Recognition of faces in photographic negatives. *Psychonomic Science*, 19, 207-208.
- Galper, R. E., & Hochberg, J. (1971). Recognition memory for photographs of faces. *American Journal of Psychology*, 84, 351-354.
- Gauthier, I., Curran, T., Curby, K. M., & Collins, D. (2003). Perceptual interference supports a non-modular account of face processing. *Nature Neuroscience*, 6, 428-432.
- Gauthier, I., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). Expertise for cars and birds recruits brain areas involved in face recognition. *Nature Neuroscience*, 3, 191-197.
- Gauthier, I., & Tarr, M. J. (1997). Becoming a "Greeble" expert: exploring mechanisms for face recognition. *Vision Research*, 37, 1673-1682.

- Gauthier, I., Tarr, M. J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (1999). Activation of the middle fusiform 'face area' increases with expertise in recognizing novel objects. *Nature Neuroscience*, *2*, 568-573.
- Gauthier, I., Tarr, M. J., Moylan, J. Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). The fusiform "face area" is part of a network that process faces at the individual level. *Journal of Cognitive Neuroscience*, *12*, 495-504.
- Gelb, A., & Goldstein, K. (1918). Analysis of a case of figural blindness. *Neurology and Psychology*, *41*, 1-143.
- George, N., Evans, J., Fiori, N., Davidoff, J., & Renault, B. (1996). Brain events related to normal and moderately scrambled faces. . *Cognitive Brain Research*, *4*, 65-76.
- Gonzales, C. M. G., Clark, V. P., Fan, S., Luck, S. J., & Hillyard, S. A. (1994). Sources of attention-sensitive visual event-related potentials. *Brain Topography*, *7*, 41-51.
- Graf, M. (2006). Coordinate transformations in object recognition. *Psychological Bulletin*, *132*, 920-945.
- Grill-Spector, K., Knouf, N., & Kanwisher, N. (2004). The fusiform face area subserves face perception, not generic within-category identification. *Nature Neuroscience*, *7*, 555-562.
- Gross, C. G. (1992). Representation of visual stimuli in inferior temporal cortex. *Philosophical Transactions of the Royal Society London: Biological Sciences*, *335*, 3-10.

- Hasselmo, M. E., Rolls, E. T., & Baylis, G. C. (1989). The role of expression and identity in the face-selective responses of neurons in the temporal visual cortex of the monkey. *Behavioural Brain Research*, *32*, 203-218.
- Harley, E. M., Pope, W. B., Villablanca, J. P., Mumford, J., Suh, R., Mazziotta, J. C., Enzmann, D., & Engel, S. A. (2009). Engagement of fusiform cortex and disengagement of lateral occipital cortex in the acquisition of radiological expertise. *Cerebral Cortex*, *19*, 2746-2754.
- Hellige, J. B., & Michimata, C. (1989). Categorization versus distance: Hemispheric differences form processing spatial information. *Memory and Cognition*, *17*, 770-776.
- Hillger, L. A., & Koenig, O. (1991). Separable mechanisms in face processing: Evidence from hemispheric specialization. *Journal of Cognitive Neuroscience*, *3*, 42-58.
- Hoffman, E. A., & Haxby, J. V. (2000). Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature Neuroscience*, *3*, 80-84.
- Hubel, D. H., & Wiesel, T. N. (1959). Receptive fields of single neurons in the cat's striate cortex. *The Journal of Physiology*, *148*, 574-591.
- Hummel, J. E., & Biederman, I. (1992). Dynamic binding in a neural network for shape recognition. *Psychological Review*, *99*, 480-517.
- Humphreys, G. W., & Rumiati, R. I. (1998). Agnosia without prosopagnosia or alexia: Evidence for stored visual memories specific to objects. *Cognitive Neuropsychology*, *15*, 243-277.

- Husk, J. S., Bennett, P. J., Sekuler, A. B. (2007). Inverting houses and textures: investigating the characteristic of learned inversion effects. *Vision Research, 47*, 3350-3359.
- Itier, R. X., & Taylor, M. J. (2002). Inversion and contrast polarity reversal affect both encoding and recognition processes of unfamiliar faces: A repetition study using ERPs. *NeuroImage, 15*, 353-372.
- Itier, R. X., & Taylor, M. J. (2004). N170 or N1? Spatial temporal differences between object and face processing using ERPs. *Cerebral Cortex, 14*, 132-142.
- Jeffreys, D. A. (1989). A face-responsive potential recorded from the human scalp. *Experimental Brain Research, 78*, 193-202.
- Jemel, B., Coutya, J., Langer, C., & Roy, S. (2009). From upright to upside-down presentation: a spatio-temporal ERP study of the parametric effect of rotation on face and house processing. . *BMC Neuroscience, 10*, 1-17.
- Johnson, R., & Bruce, V. (1990). Lost properties? Retrieval differences between name codes and semantic codes for familiar people. *Psychological Science, 52*, 62-67.
- Jolicoeur, P. (1985). The time to name disoriented natural objects. *Memory & Cognition, 13*, 289-304.
- Jolicoeur, P. (1988). Mental rotation and the identification of disoriented objects. *Canadian Journal of Psychology, 42*, 461-478.

- Jolicoeur, P., & Milliken, B. (1989). Identification of disoriented objects: effects of context of prior presentation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*, 200-210.
- Joyce, C., & Rossion, B. (2005). The face-sensitive N170 and VPP components manifest the same brain processes: the effect of reference electrode site. *Clinical Neurophysiology*, *116*, 2613-2631.
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*, *17*, 4302-4311.
- Kanwisher, N., Yovel, G. (2006). The fusiform face area: A cortical region specialized for the perception of faces. *Philosophical Transactions of the Royal Society of London B*, *361*, 2109-2128.
- Kimura, D., & Durnfold, M. (1974). Normal studies on the function of the right hemisphere in vision. In S. J. Diamanond, & Beaumont, J. G. (Ed.), *Hemispheric function in the human brain*. (pp. 25-47). New York: Halstead.
- Kosslyn, S. M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review*, *94*, 148-175.
- Kosslyn, S. M., Chabris, C. F., Koenig, O., & Marsolek, C. J. (1992). Categorical versus coordinate spatial relations: computational analyses and computer simulations. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 562-577.

- Kosslyn, S. M., Koenig, O., Barrett, A., Cave, C. B., Tang, J., & Gabrielli, J. D. E. (1989). Evidence for two types of spatial representations: Hemispheric specialization for categorical and coordinate relations. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 723-735.
- Laeng, B., Zarringpar, A., & Kosslyn, S. M. (2003). Do separate processes identify objects as exemplars versus members of basic-level categories? Evidence from hemispheric specialization. *Brain and Cognition*, *53*, 15-23.
- Landis, T., Graves, R., Benson, F., & Hebbon, N. (1982). Visual recognition through kinaesthetic mediation. *Psychological Medicine*, *12*, 515-531.
- Leder, H., Candrian, G., Huber, O., & Bruce, V. (2001). Configural features in the context of upright and inverted face. . *Perception*, *30*, 73-83.
- Leder, H., & Carbon, C. (2006). Face-specific configural processing of relational information. *British Journal of Psychology*, *97*, 19-29.
- Leehey, S., Carey, S., Diamond, R., & Cahn, A. (1978). Upright and inverted faces: The right hemisphere knows the difference. *Cortex*, *14*, 411-419.
- Lerner, Y., Hendler, T., Ben-Bashat, D., Harel, M., & Malach, R. (2001). A hierarchical axis of object processing stages in the human visual cortex. *Cerebral Cortex*, *11*, 287-297.
- Levine, S. C., Banich, M. T., & Koch-Weser, M. P. (1988). Face recognition: a general or specific right hemisphere capacity? *Brain and Cognition*, *8*, 303-325.

- Levine, S. C., & Calvano, R. (1989). Prosopagnosia: a defect in visual configural processing. *Brain and Cognition, 10*, 149-170.
- Logothetis, N. K., & Sheinberg, D. L. (1996). Visual object recognition. *Annual Review of Neuroscience, 19*, 577-621.
- Luck, S. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.
- Marsolek, C. J. (1999). Dissociable neural subsystems underlie abstract and specific object recognition. *Psychological Science, 10*, 111-118.
- Materna, S., Dicke, P. W., & Thier, P. (2008). Dissociable roles of the superior temporal sulcus and the intraparietal sulcus in joint attention: A functional magnetic resonance imaging study. *Journal of Cognitive Neuroscience, 20*, 108-121.
- Mayer, E., & Rossion, B. (2007). Prosopagnosia. In O. G. a. J. Bogousslavsky (Ed.), *The Behavioral and Cognitive Neurology of Stroke* (pp. 315-334). Cambridge: University Press.
- Maurer, D., & Barrera, M., (1981). Infants' perception of natural and distorted arrangements of a schematic face. *Child Development, 52*, 196-202.
- Maurer, D., Le Grand, R., & Mondloch, C. J. (2002). The many faces of configural processing. *Trends in Cognitive Sciences, 6*, 255-260.
- McKone, E. (2008). Configural processing and face viewpoint. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 310-327.

- McKone, E., & Yovel, G. (2009). Why does picture-plane inversion sometimes dissociate perception of featurea and spacing in faces and sometimes not? Toward a new theory of holistic processing. *Psychonomic Bulletin and Review*, *16*, 778-797.
- McMullen, P. A., & Farah, M. J. (1991). Viewer-centered and object centered representations in the representations in the recognition of naturalistic line drawings. *Psychological Science*, *2*, 275-277.
- McMullen, P. A., & Jolicoeur, P. (1990). The spatial frame of reference in object naming and discrimination of left-right reflections. *Memory & Cognition*, *18*, 99-115.
- McNeil, J. E., & Warrington, E. K. (1993). Prosopagnosia: A face specific disorder. . *The Quarterly Journal of Experimental Psychology*, *46*, 1-10.
- Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., Heeley, D. W., Bettucci, D., Mortara, F., Mutani, R., Terrazzi, E., & Davidson, D. L. W. (1991). Perception and action in "visual form agnosia". *Brain*, *114*, 405-428.
- Moscovitch, M., Winocur, G., & Behrmann, M. (1997). What is special about face recognition? Nineteen experiments on a person with visual object agnosia and dyslexia but normal face recognition *Journal of Cognitive Neuroscience*, *9*, 555-604.
- Orban, G., A., Van Essen, D. V., & Vanduffel, W. (2004). Comparative mapping of higher visual areas in monkeys and humans. . *Trends in Cognitive Sciences*, *8*, 315-324.

- Perrett, D. I., Oram, M. W., Harries, M. H., Bevan, R., Hietanen, J. K., Benson, P. J., Thomas, S. (1991). Viewer-centered and object-centered coding of heads in the macaque temporal cortex. . *Experimental Brain Research*, *86*, 159-173.
- Pitcher, D., Walsh, V., & Duchaine, B. (2011). The role of the occipital face area in the cortical face perception network. *Experimental Brain Research*, *209*, 481-493.
- Pitcher, D., Walsh, V., Yovel, G., & Duchaine, B. (2007). TMS evidence for the involvement of the right occipital face area in early face processing. . *Current Biology*, *17*, 1568-1573.
- Poldrack, R. A., Mumford, J. A., Nichols, T. E. (2011). *Handbook of functional MRI data analysis*. New York: Cambridge University Press.
- Potter, M. C., & Faulconer, B. A. (1975). Time to understand pictures and words. *Nature*, *253*, 437-438.
- Puce, A., Allison, T., Asgari, M., Gore, J. C., & McCarthy, G. (1996). Differential sensitivity of human visual cortex to faces, letterstrings, and textures: a functional Magnetic Resonance Imaging study. *The Journal of Neuroscience*, *16*, 5205-5215.
- Rakover, S. S., & Teucher, B. (1997). Facial inversion effects: parts and whole relationship. *Perception & Psychophysics*, *59*, 752-761.
- Richler, J. J., Bukach, C. M., & Gauthier, I. (2009). Context influences holistic processing of non-face objects in the composite task. *Attention, Perception, & Psychophysics*, *71*, 530-540.

- Rolls, E. (2000). Functions of the primate temporal lobe cortical visual areas in invariant visual object and face recognition. *Neuron*, *27*, 205-218.
- Rolls, E. (2007). The representation of information about faces in the temporal and frontal lobes. . *Neuropsychologia*, *45*, 124-143.
- Rosch, E. (1978). Cognition and categorization. In E. Rosch & B. B. Lloyd (Eds.), *Principles of categorization*. (pp. 27-48). Hillsdale, NJ: Erlbaum.
- Rosch, E., & Mervis, C. B. (1981). Categorization of natural objects. *Annual Review of Psychology*, *32*, 89-115.
- Rosch, E., Mervis, C. B., Gray, W. D., Jounson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, *8*, 382-439.
- Rossion, B. (2008). Picture-plane inversion leads to qualitative changes of face perception. *Acta Psychologica*, *128*, 272-289.
- Rossion, B., & Boremanse, A. (2008). Nonlinear relationship between holistic processing of individual faces and picture-plane rotation: evidence from the face composite illusion. *Journal of Vision*, *8*, 1-13.
- Rossion, B., Campanella, S., Gomez, C. M., Delinte, A., Debatisse, D., Liard, L., Dubois, S., Bruyer, R., Crommelinck, M., & Guerit, J.-M. (1999). Task modulation of brain activity related to familiar and unfamiliar face processing: an ERP study. *Clinical Neurophysiology*, *110*, 449-462.

- Rossion, B., Collins, D., Goffaux, V., & Curran, T. (2007). Long-term expertise with artificial objects increases visual competition with early face categorization processes. *Journal of Cognitive Neuroscience, 19*, 543-555.
- Rossion, B., Dricot, L., Devolder, A., Bodart, J., Crommelinck, M., de Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience, 12*, 793-802.
- Rotshtein, P., Geng, J. J., Driver, J., & Dolan, R. J. (2007). Role of features and second-order spatial relations in face discrimination, face recognition, and individual face skills: behavioral and functional magnetic resonance imaging data. *Journal of Cognitive Neuroscience, 19*, 1435-1452.
- Rumiati, R. I., Humphreys, G. W., Riddoch, M. J., & Bateman, A. (1994). Visual object agnosia without prosopagnosia or alexia: Evidence for hierarchical theories of visual recognition. *Visual Cognition, 4*, 207-218.
- Rybash, J. M., & Hoyer, W. J. (1992). Hemispheric specialization for categorical and coordinate spatial representations: A reappraisal. *Memory and Cognition, 20*, 271-276.
- Sadr, J., Jarudi, I., & Sinha, P. (2003). The role of eyebrows in face recognition. *Perception, 32*, 285-293.
- Sanes, D. H., Reh, T. A., & Harris, W. A. (2011). *Development of the nervous system*. (3rd ed.). Burlington, MA: Academic Press.

- Saneyoshi, A., & Michimata, C. (2009). Lateralization effects of categorical and coordinate spatial processing of component parts on the recognition of 3D non-nameable objects. *Brain & Cognition, 71*, 181-186.
- Schweinberger, S. R., & Burton, A. M. (2003). Covert recognition and the neural system for face processing. *Cortex, 39*, 9-39.
- Scott, L. S., & Nelson, C. A. (2006). Featural and configural face processing in adults in infants: A behavioral and electrophysiological investigation. *Perception, 35*, 1107-1128.
- Sekuler, A. B., Gaspar, C. M., Gold, J. M., & Bennett, P. J. (2004). Inversion leads to quantitative, not qualitative changes in face processing. *Current Biology, 14*, 391-396.
- Sergent, J. (1991). Judgments of relative position and distance on representations of spatial relations. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 762-780.
- Sergent, J., Ohta, S., & MacDonald, B. (1992). Functional neuroanatomy of face and object processing. A positron emission tomography study. *Brain, 115*, 15-36.
- Sergent, J., & Signoret, J. L. (1992). Varieties of functional deficits in prosopagnosia. *Cerebral Cortex, 2*, 375-388.
- Tanaka, K. (1993). Neuronal mechanisms of object recognition. *Science, 262*, 685-688.
- Tanaka, K. (1996). Inferotemporal cortex and object vision. *Annual Review of Neuroscience, 19*, 109-139.

- Tanaka, J. W., & Curran, T. (2001). A neural basis for expert object recognition. *Psychological Review*, *12*, 43-47.
- Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology*, *46*, 225-245.
- Thierry, G., Martin, C. D., Downing, P., & Pegna, A. J. (2007). Controlling for interstimulus perceptual variance abolishes N170 face selectivity. *Nature Neuroscience*, *10*, 505-511.
- Tsao, D. Y., Freiwald, W. A., Tootell, R. B. H., & Livingstone, M. S. (2006). A cortical region consisting entirely of face-selective cells. *Science*, *311*, 670-674.
- Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face recognition. *British Journal of Psychology*, *79*, 471-491.
- Valentine, T., & Bruce, V. (1988). Mental Rotation of faces. *Memory & Cognition*, *16*, 556-566.
- Wada, Y., & Yamamoto, T. (2001). Selective impairment of facial recognition due to a haematoma to the right fusiform and lateral occipital region. *Journal of Neurology, Neurosurgery and Psychiatry*, *40*, 395-403.
- Wiesel, T. N. (1982). Postnatal development of the visual cortex and the influence of environment. *Nature*, *299*, 583-591.
- Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, *81*, 141-145.
- Yin, R. K. (1970). Face recognition by brain-injured patients: a dissociable ability. *Neuropsychologia*, *8*, 395-402.

- Young, A. W., Bion, P. J., & Ellis, A. W. (1980). Studies toward a model of laterality effects for picture and word naming. *Brain and Language, 11*, 54-65.
- Young, A. W., Ellis, A. W., Flude, B. M., McWeeny, K., & Hay, D. C. (1986). Face-name interference. *Journal of Experimental Psychology: Human Perception and Performance, 12*, 466-475.
- Young, A. W., Hay, D. C., & Ellis, A. W. (1985). The face that launched a thousand slips. Everyday difficulties and errors in recognizing people. *British Journal of Psychology, 76*, 495-532.
- Young, A. W., Hay, D. C., McWeeny, K. H., Flude, B. M., & Ellis, A. W. (1985). Matching familiar and unfamiliar faces on internal and external features. *Perception, 14*, 737-746.
- Yovel, G., & Kanwisher, N. (2004). Face perception: domain specific, not process specific. *Neuron, 44*, 889-898.

APPENDIXES

Appendix A: Experiment I Object List

1	Apple	37	Motorcycle
2	Backpack	38	Mug
3	Banana	39	Bus
4	Barn	40	Canteen
5	Bathroom Scale	41	Fishing Pole
6	Bathtub	42	Pistol
7	Bike	43	Pitcher
8	Calculator	44	Pizza
9	Camera	45	Rake
10	Can Opener	46	Rollerblade
11	Car	47	Gazeebo
12	Cardboard Box	48	Sailboat
13	Cell Phone	49	Sattelite Dish
14	Chair	50	Saw
15	Cheeseburger	51	Grill
16	Backhoe	52	Shovel
17	Computer	53	Skateboard
18	Couch	54	Skillet
19	Door	55	Sock
20	Dresser	56	Stapler
21	Bed	57	Sunglasses
22	Fan	58	Table
23	Guitar	59	Tea Kettle
24	Hammer	60	Television
25	Harmonica	61	Tennis Racket
26	Helmet	62	Helicopter
27	Hoop	63	Tricycle
28	House	64	Trophy
29	Iron	65	Typewriter
30	Ironing Board	66	Umbrella
31	Keyboard	67	Vacuum
32	Lamp	68	Wagon
33	Lawnmower	69	Water Cooler
35	Lollipop	70	Jet Ski
35	Blender	71	Paper Punch
36	Microscope	72	Sewing Machine

Appendix B: Experiment I Face List

1	Ashton Kutcher	37	Jessica Alba
2	Ben Stiller	38	Angelina Jolie
3	Bruce Willis	39	Ashley Olsen
4	Kobe Bryant	40	Halle Berry
5	George Bush	41	Beyonce
6	Steve Carrell	42	Britney Spears
7	Will Smith	43	Hillary Clinton
8	George Clooney	44	Condoleeza Rice
9	Robert DeNio	45	Catherine Zeta-Jones
10	Denzel Washington	46	Ellen Degeneres
11	Johnny Depp	47	Drew Barrymore
12	Danny DeVito	48	Whoopi Goldberg
13	Eddie Murphy	49	Gwent Stefani
14	50 Cent	50	Salma Hayek
15	Chris Farley	51	Hillary Duff
16	Jim Carrey	52	Paris Hilton
17	John Travolta	53	Jennifer Aniston
18	Keanu Reeves	54	Jennifer Love-Hewitt
19	Owen Wilson	55	Jessica Biel
20	Leonardo DeCaprio	56	Jessica Simpson
21	Matt Damon	57	Scarlett Johansson
22	Mel Gibson	58	Kate Hudson
23	Micheal Douglas	59	Katherine Heigl
24	Michael Jordan	60	Katie Couric
25	Morgran Freeman	61	Katie Holmes
26	Conan O'Brien	62	Lindsay Lohan
27	Barack Obama	63	Lucy Lui
28	Orlando Bloom	64	Martha Stewart
29	Neil Patrick-Harris	65	Megan Fox
30	Brad Pitt	66	Rosie O'Donnell
31	Ben Affleck	67	Sarah Palin
32	Pee-Wee Herman	68	Natalie Portman
33	Robin Williams	69	Queen Latifah
35	Russel Crowe	70	Rihanna
35	Samuel L. Jackson	71	Oprah Winfrey
36	Paul Shore	72	Sarah Michelle Gellar

Appendix C: Experiment I Animal List

1	Spider	37	Donkey
2	Ant	38	Dove
3	Anteater	39	Duck
4	Antelope	40	Eagle
5	Armadillo	41	Eel
6	Baboon	42	Elk
7	Badger	43	Emu
8	Bat	44	Fly
9	Bear	45	Fox
10	Beaver	46	Frog
11	Bee	47	Gecko
12	Beetle	48	Gopher
13	Squirrel	49	Hippopotamus
14	Boar	50	Horse
15	Buffalo	51	Humpback Whale
16	Butterfly	52	Jaquar
17	Camel	53	Llama
18	Cardinal	54	Lobster
19	Cat	55	Moth
20	Cattepillar	56	Opossum
21	Chameleon	57	Orangutan
22	Cheetah	58	Owl
23	Chicken	59	Parrot
24	Chipmunk	60	Pheasant
25	Cobra	61	Pig
26	Cockroach	62	Pigeon
27	Cow	63	Porcupine
28	Coyote	64	Prairie Dog
29	Crab	65	Rabbit
30	Crane	66	Raccoon
31	Crayfish	67	Rat
32	Cricket	68	Rhinoceros
33	Crow	69	Salamander
35	Deer	70	Seal
35	Dog	71	Shark
36	Dolphin	72	Sheep

Appendix D: Experiment III Face List

	Actors		Non-actors
1	Jessica Alba	1	50 Cent
2	Ashton Kutcher	2	Christina Aguilera
3	Ben Affleck	3	David Beckham
4	Halle Berry	4	Beyonce
5	George Clooney	5	Britney Spears
6	Robert DeNiro	6	George Bush
7	Denzel Washington	7	Bill Clinton
8	Drew Barrymore	8	Gwen Stefani
9	Eddie Murphy	9	Enrique Iglesias
10	Gwyneth Paltrow	10	Steve Jobs
11	Harrison Ford	11	Kim Kardashian
12	Hillary Duff	12	Katie Couric
13	Jennifer Love Hewitt	13	Bill Maher
14	Jessica Biel	14	Martha Stewart
15	Katie Holmes	15	Michael Jordan
16	Keanu Reeves	16	Richard Nixon
17	Leonardo DiCaprio	17	Sarah Palin
18	Sarah Michelle Gellar	18	Rihanna

Appendix E: Experiment III Animal List

	North American		Elsewhere
1	Bear	1	Camel
2	Bison	2	Cheetah
3	Blue Jay	3	Cobra
4	Bobcat	4	Flamingo
5	Deer	5	Hyena
6	Dog	6	Lemur
7	Donkey	7	Lion
8	Fox	8	Llama
9	Goose	9	Meerkat
10	Horse	10	Panda
11	Mountain Lion	11	Parrot
12	Pheasant	12	Peacock
13	Pig	13	Platypus
14	Prairie Dog	14	Tasmanian Devil
15	Rabbit	15	Warthog
16	Raccoon	16	Water Buffalo
17	Sheep	17	Wild Dog
18	Squirrel	18	Zebra

Appendix F: Experiment III Object List

	Inside objects		Outside objects
1	Bathtub	1	Backhoe
2	Bed	2	Barn
3	Blender	3	Bike
4	Chair	4	Bird Bath
5	Computer	5	Car
6	Couch	6	Coat
7	Fan	7	Gazebo
8	Ironing Board	8	Grill
9	Lamp	9	Hoop
10	Microscope	10	Jetski
11	Mug	11	Lawnmower
12	Pitcher	12	Motorcycle
13	Sewing Machine	13	Rake
14	Sink	14	Rollerblade
15	Skillet	15	Sailboat
16	Stapler	16	Tricycle
17	Table	17	Umbrella
18	Tea Kettle	18	Wagon

Appendix G: Mean Reaction Times (ms) for the Same Trials of Experiment 3

Image Type	Upright		Inverted	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Two	957.67	22.46	966.48	20.99
Three	895.13	20.99	940.87	21.18
Four	892.55	20.46	966.09	23.99
Six	907.92	22.33	964.75	25.48
Bucket	968.87	23.63	1046.5	24.13
Whole	815.36	21.38	872.13	24.37

Note. Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket =eyes, mouth, nose, & eyebrows on bucket.

Appendix H: Mean Pct. Error Rates for the Same Trials of Experiment 3

Image Type	Upright		Inverted	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Two	15.6	1.17	14.4	.95
Three	8.3	.64	15.9	1.00
Four	8.0	.68	15.6	1.10
Six	7.9	.75	15.2	1.00
Bucket	9.7	.76	23.1	1.32
Whole	3.4	.40	5.8	.65

Note. Two = eyes; Three = eyes & mouth; Four = eyes, mouth, & nose; Six = eyes, mouth, nose & eyebrows; Whole = whole face; Bucket =eyes, mouth, nose, & eyebrows on bucket.

Appendix I: Mean Reaction Times (ms) for the Different Trials of Experiment 4

Image Type	SSD		DSD	
	U (SE)	I (SE)	U (SE)	I (SE)
One	1097.5 (37.4)	1015.8 (31.8)	914.0 (34.6)	887.7 (21.2)
Three	990.2 (24.5)	955.6 (25.4)	874.7 (18.6)	865.9 (19.5)
Five	1064.6 (28.4)	1074.6 (27.7)	871.4 (19.5)	877.2 (21.0)
Six	1090.1 (30.9)	1111.9 (38.2)	894.2 (21.1)	886.2 (24.4)
Whole	1179.5 (37.2)	1160.9 (39.3)	989.7 (26.2)	943.4 (23.3)

Note. SSD = same structural description; DSD = different structural description; U = upright; I = inverted; One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

Appendix J: Mean Pct. Error Rates for the Different Trials of Experiment 4

Image Type	SSD		DSD	
	U (SE)	I (SE)	U (SE)	I (SE)
One	53.3 (3.1)	49.2 (3.4)	25.6 (1.5)	22.1 (1.4)
Three	19.3 (1.9)	17.8 (1.8)	9.0 (1.0)	8.2 (1.2)
Five	27.5 (2.1)	28.8 (2.4)	7.4 (0.9)	7.7 (1.0)
Six	33.5 (2.6)	38.4 (38.2)	9.9 (1.3)	10.6 (1.1)
Whole	49.7 (2.4)	55.0 (2.8)	16.3 (1.7)	14.2 (1.5)

Note. SSD = same structural description; DSD = different structural description; U = upright; I = inverted; One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

Appendix K: Mean Reaction Time (ms) and Pct. Error Rates for the Same Trials of Experiment 4

Image Type	Reaction Time		Error Rates	
	U (SE)	I (SE)	U (SE)	I (SE)
One	823.9 (23.3)	785.1 (19.3)	9.9 (1.1)	7.3 (0.8)
Three	916.3 (29.1)	868.2 (24.6)	12.3 (1.2)	11.3 (1.0)
Five	974.3 (27.6)	944.3 (25.2)	15.0 (0.9)	12.1 (1.1)
Six	1000.9 (30.2)	993.5 (31.2)	16.1 (1.0)	12.5 (1.3)
Whole	1101.7 (33.3)	1023.6 (29.1)	20.8 (1.6)	15.7 (1.3)

Note. U = upright; I = inverted; One = front door; Three = front door & two windows; Five = front door & four windows; Six = front door, four windows, & garage door; Whole = whole house.

ACKNOWLEDGEMENTS

I would like to first thank my parents, Linda and Dennis Kahl, for always supporting my academic endeavors and epitomizing the meaning of perseverance. Mother you have taught me that I should never be persuaded to give up on aspirations that others claim to be unattainable. Father, you have been the hardest worker and most dependable person I have known (aside from mom of course). Second, I would want like to thank the best dog a boy could have ever asked for, Nora, for always displaying a joie de vivre I desperately needed throughout graduate school. Additionally, I would like to thank my grandparents, Donna and Richard Hartshorne, and grandparents, William and Ellen Taylor, for all their support and guidance throughout the years.

I would like to thank my undergraduate teacher assistants: Jacob Rysted, Larissa Arnold, Aaron Van Gorp, and Maleesa Dunsworth who provided valuable aid in the construction and analysis of the current study.

Finally, I would like to thank Dr. Cooper for being an exemplary advisor and friend. Over the past six years, you have taught me a number of valuable skills that I lacked when I started my graduate studies at Iowa State University. You have taught me how to be a great instructor, how to think and work independently, and valuable leadership skills.