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The central executive and object recognition

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The central executive and object recognition

by

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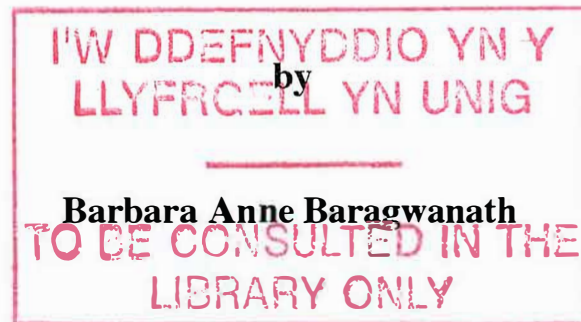
A Thesis submitted to The School of Psychology, University of Wales, Bangor, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

September, 2003

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The present study focused on the involvement of the central executive in non-optimal views recognition. Although research has implied that there may be a role for resources outside of the classic ventral visual stream in such recognition, none have directly investigated a frontal lobe contribution, using dual task methodology. A dual task procedure, based on the working memory model of Baddeley and Hitch (1974), was developed to answer this (and related) questions.

The first series of experiments tested the view dependency of stimuli rotated in the depth plane, taken from the Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993), piloting them in a reaction time paradigm. Four experiments demonstrated decremental performance in terms of response times and error rates for non-optimal, compared to optimal, view recognition.

Having established a role for executive processes in the recognition of stimuli rotated in depth, two further experiments investigated the effect of a central executive secondary task on the recognition of alternative forms of non-optimal views. Results mirrored those in the first set of studies, but expanded on these in suggesting that although the central executive appears to be involved in the recognition of depth rotated stimuli, this does not appear to be the case for stimuli rotated in the picture plane, or for stimuli with a critical feature occluded. Two subsequent experiments addressed the question of category level effects on non-optimal view recognition. Data suggested that subordinate categorisation required additional resources, compared to basic level categorisation, and added further support for an executive contribution in the recognition of depth rotated, but not minimal features stimuli.

The final group of four experiments involved the development of a novel paradigm to investigate two specific subcomponents of executive function: search and inhibition. Results suggested that both search and inhibition appear to contribute to recognition of depth rotated stimuli, but that their involvement was heavily modulated by the frequency of each subcomponent. Findings are discussed in relation to object recognition theories, and the neural substrates mediating object constancy.

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CHAPTER 1: INTRODUCTION

Object Recognition

A fundamental component of human behaviour is the ability to identify and recognise the objects, animals and other humans we encounter within our environment. How the mammalian brain solves the problems of visual recognition has been an issue of research since Hubel and Wiesel (1959) received the Nobel Prize for their work on the receptive field properties of visual cortical neurons in the cat (Tarr, 1995).

For the biological visual system, object recognition appears to be an effortless activity, in contrast, the recognition of common objects remains beyond the capabilities of artificial systems (Ullman, 2000)[1]. An inability in recognising or interpreting objects in the visual field, although rare, can be very disabling and have a huge impact on everyday life. Such a neurological impairment is referred to as "visual agnosia"[2] and is defined as a disorder of recognition and identification of form that cannot be attributed to generalised intellectual deterioration, sensory impairments, disruptions of attention, or language deficits (Ellis & Young, 1996).

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[1] lthough it should be pointed out that the latest neural network models are making substantial progress in this respect (e.g. elman & Intrator, 2003, Stankiewicz & Hummel 2002).

[2] he term "agnosia" is derived from Ancient Greek and translates as "not-knowing".

At the core of what makes visual recognition difficult are two factors. Firstly, any information processing system capable of effective object recognition must derive a representation of a three-dimensional object from a two-dimensional retinal image. Secondly, the internal representation must be linked to a description of that object stored in memory. These two components of object recognition largely conform to the processes originally specified by Lissauer (1890), namely apperception, establishing a stable percept from sensory input, and association, accessing stored semantic information appropriate to the visual stimulus. Lissauer's (1890) "apperceptive agnosia" and "associative agnosia" distinction is still often used as a starting point in identifying various types of visual object agnosia (Humphreys & Riddoch, 1984).

For efficient and accurate visual object recognition, some alliance has to be made between the percept, and the stored knowledge of the object. The nature of this alliance is currently under intense study, and the debate converges on two issues: (a) the character and cortical distribution of the stored information; and (b) the nature of the processes using this information (Gazzaniga, Ivry & Mangan, 1998).

To comprehend this complex series of neural events, one must consider some of the requirements involved. It is essential, primarily, to extract information from the visual array, in order to distinguish objects from their background, and discriminate one object from another. This is achieved by the use of information regarding edges, texture, size, orientation, form,

colour, and motion. Over the last 50 years, psychologists have witnessed a huge increase in knowledge of the mechanisms underpinning such 'early' stages of visual processing (Walsh & Kulikowski, 1998), however, these will not be considered to any great extent, in this review.

The subject of this research, is what has been considered to be a major problem of the 'later' stages of recognition, namely, the ability to recognise that an object has the same structure across changes in viewpoint. As we move through the physical world, we are constantly presented with different views of objects. How are we able to identify an specific object, despite a cornucopia of variations in the retinal image of that object? The ability to achieve recognition under such circumstances is termed "object constancy", and the problem involves deriving a consistent mapping of objects, to a potentially infinite set of images (Tarr & Bülthoff, 1998).

Recognition, of course, also involves the identification of an object as a member of a particular category, even though it may vary only slightly from other objects within the same class. Object recognition must, therefore, be general enough, not only to support object constancy, but also to pick out slight differences between members of a category. Perceptual and semantic categorisation allow us to organise, make sense of and, thereby, reduce the overwhelming variation in the appearance of stimuli (Lawson, 1999).

Establishing the mechanisms responsible for these later stages of recognition is proving to be a formidable challenge for cognitive

psychologists and neuroscientists. Indeed, it is proposed that substantiating the processes underpinning these abilities would signify a major theoretical advancement in the area of vision research. The literature relating to the achievement of this ability is expansive and to date there is little agreement between the representations and processes involved. Traditional models cluster into two general categories, structural descriptions (e.g. Biederman, 1987; Marr, 1982; Hummel & Stankiewicz, 1998), and image-based approaches (e.g. Bülthoff, Edelman & Tarr, 1995; Edelman & Intrator, 2000), considered viewpoint-independent and viewpoint-dependent respectively. This review will address two crucial questions: 1) Is object recognition achieved by viewpoint-dependent or viewpoint-independent mechanisms; and 2) What neuroanatomical areas are involved in object recognition?

Is object recognition achieved by viewpoint-dependent or viewpoint-independent mechanisms?

Early theories of object recognition

The early theories of object recognition include template matching, feature analysis and structural descriptions.

Template Models: With template models the internal representation of an object is a two-dimensional copy of that object. Information on the

retina is matched in parallel with an abundance of internal templates. When a match is found object recognition is complete (Bruce, Green & Georgeson, 1996). However, as objects are seen from multiple viewpoints, a different template for each possible view would have to exist. Furthermore, as there are an enormous range of specific examples for any particular category of object, a different template for each example would also have to exist (Marr, 1982). Such a theory may be capable of accommodating the critical problem of object constancy were it able to utilise a system which encompasses some form of 'normalisation' procedure, whereby the image is transformed into a standard view. Nonetheless, this would be extremely difficult even with simple alphanumerics. For example, an 'R' may match an 'A' template better than its own, and vice versa (see Bruce et al., 1996 for review). A further problem is that objects not previously experienced would have no existing template.

Feature Analysis: Of the feature analysis models of recognition (e.g. Gibson, 1979), perhaps the most influential was Selfridge's (1959) Pandemonium system. This model was originally devised as a computer programme to recognise Morse Code, but was adapted as a model of alphanumeric recognition by Neisser (1967) and Lindsay and Norman (1972). The system consists of a number of classes of 'demons', including feature and cognitive demons. Feature demons respond when specific local configurations are present, and cognitive demons - representing particular letters - are sensitive to combinations of features. Thus, critical features

distinguish one letter from another. However, the Pandemonium model also

relies on patterns in terms of a set of features, analogous to templates, and

object recognition does not merely need to consider features themselves, but

also the relationship amongst them to achieve recognition (Marr & Nishihara,

1978). For example, the representation for F would also respond when E was

viewed, as both have the same features. Such a model would necessitate

some other mechanism, whereby extra features cause inhibition. Also,

objects of the same identity may possess different features, and thus require a

separate set of features for each form. For example, T and L contain exactly

the same features, but not the same form. In this model the internal

representation of an object is a description of the main features, and

candidates for these feature detectors are the simple, complex and

hypercomplex cells in the striate cortex

Structural Descriptions: Structural descriptions theories represent a

more complete account of the visual stimulus than either of the above

mentioned models (Ullman, 2000). A structural description consists of a set

of propositions about a particular configuration, and as such, describes the

nature of the component parts, together with the structural arrangement of

those parts. Early examples of this approach included Clowes (1967) and

Winston's (1970) computational models, together with Sutherland (1968)

and Milner's (1974) models of human visual shape recognition. This is a

much more flexible model, as the description of how the features

interconnect is invariant. The model goes beyond simple features, and

enables emergent properties to be revealed (Ullman, 2000). For example,

when detecting the odd one out, template and feature detection models

predict no difference between A and B (see Figure 1.1). However, subjects

are much faster to detect the odd one out in B compared to A, even though

the differences are identical in both displays (Bruce et al., 1996). This is

accounted for by the structural description model because the description of

how the parts interconnect produces a bigger difference in B than A. For

example, the internal representation of a triangle is more different to that of

arrows, compared to the simple feature differences in Figure A.

A   B
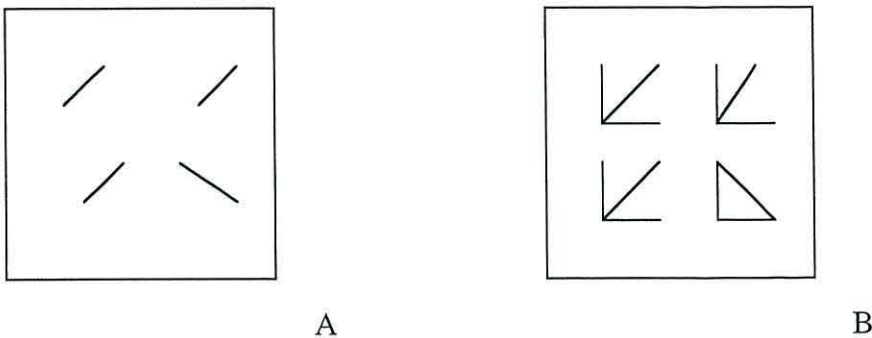
Figure 1.1

It should be noted, however, that before the processes of describing

the features, and how they combine together can take place, features must be

grouped together. In the extremely complex real-world environment, many

features impinge on the retina and, therefore, an important process is the

grouping of features, in order that they can be associated with separate

objects. Much of the knowledge of figure-ground processing comes from the

Gestalt psychologists working in the 1920s and 1930s, in particular Loffka

(1933) and Wertheimer (1923). These researchers described the cues that

allowed individual features to be grouped together within the same object.

The cue of proximity demonstrates that features that are close together

spatially, are grouped into the same object. For example, we see rows, not

columns, in A, and the opposite in B (see Figure 1.2).

A   B
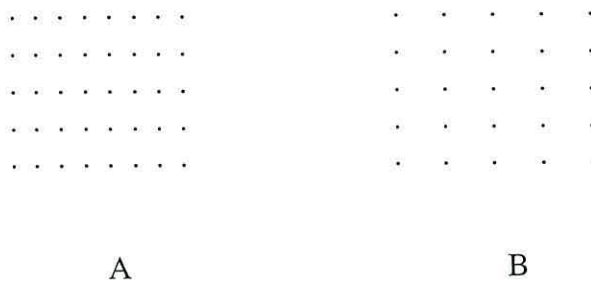
Figure 1.2

The cue of similarity, states that features with the same property, such

as colour, intensity, shape, size and orientation are grouped together into the

same object. Features that, when connected, result in straight or smoothly

curving lines with good continuation, are seen as belonging together. Visual

information is often lost because the visual input is 'noisy', or because of

occlusion by other objects in the environment, it is important, therefore, that

such features are combined together. Separate features seem to be even more

powerfully conjoined when occluding stimuli are present, as the occlusion

helps to explain why the intervening features cannot be seen. Stimuli that are

symmetrical tend to stand out from the background, and this symmetry is associated with the gestalt principle of Pragnanz or simplicity. The principle assumes that every stimulus pattern is seen in such a way that the resulting structure is as simple as possible. The perceptual system's bias to perceive symmetrical shapes as objects against background, and to fill in missing parts to complete the symmetry, is based on biological constraints. Thus, many natural objects that animals have evolved to interact with, are symmetrical. The final grouping cue is common fate. When an object moves, all of its features move together. This cue can efficiently separate figure from ground, even when there are no other cues available. For example, animals can be camouflaged against their backgrounds by disrupting the other grouping cues. Thus, the features of the object and background are the same, good continuation is disrupted, as is symmetry. However, as long as the animal remains stationary, it is very difficult to detect. Any slight movement on the other hand, will allow immediate detection.

Aside from the cues that enable the separation of figure from ground, the Gestalt psychologists also discussed the emergence of object properties which could not be explained by the features present. "The whole is greater than the sum of its parts" principle has re-emerged in psychology within the structural description models of object recognition (Bruce et al., 1996). Any perceptual theory, of course, would have to assume that what is represented is determined by the image (Biederman & Gerhardstein, 1995), however, in certain circumstances recognition uses processes which may be considered

other than perceptual, (e.g. 'reasoning'). For example, a fence on the periphery of a plot of land, may be recognised due to reasoning about its function, as opposed to its visual form (Ullman, 2000).

Viewer-centred and object-centred accounts of object recognition

A core question with regard to how observers recognise objects from different viewpoints, concerns specification of the co-ordinate system, or frame of reference, whereby information is coded. A frame of reference refers to a means of specifying locations in space, which are normally specified to a single fixed point, and often involve the notion of axes, corresponding to specific directions in space (Jolicoeur & Humphrey, 1998). It has been proposed that several frames of reference may exist in parallel and compete for activation. In such a case, recognition is achieved when one frame of reference becomes dominant over another (e.g. Hinton, 1981). With regard to object constancy and frames of reference, the theoretical debate coalesces around two dominant approaches (Perrett, Oram, Hietanen & Benson, 1994) - viewer-centred and object-centred accounts. These differ in the location of the origin of the co-ordinate system, and are considered viewpoint-dependent and viewpoint-independent[2] respectively.

In this review the terms viewpoint-dependent, view-based, orientation-dependent and orientation-specific will be used interchangeably, as will viewpoint-independent, viewpoint-invariant and orientation-invariant.

Seminal cognitive and neuropsychological literature pertaining to viewpoint-dependent and viewpoint-independent accounts of object recognition will be outlined below and will be expanded upon later in the review, under sections based on particular forms of non-optimal views.

Viewpoint-dependent accounts

In viewer-centred accounts, the visual world is directly referenced to the co-ordinates of information falling on the retina. Hence, changes in the observer's position, result in a change in the relative positions amongst the object's parts or features (Gazzaniga et al., 1998).

Viewer-centred accounts of object recognition, defined by a retinotopic frame of reference, rely solely on the orientation of an object relative to the observer and, as such, constitute a viewpoint-dependent theory. A significant body of research supporting this view purports to provide evidence for a strategy whereby the representation of an object, in an unconventional view, is 'normalised' by some form of transformation process, for example, mental rotation. It is proposed that a misoriented object is transformed to a view which is more 'familiar' to the observer, and matched to a stored representation. In a typical experiment, there is an initial effect of viewpoint-dependence, which diminishes with practice (e.g. Jolicoeur, 1985, 1988, 1990; Tarr & Pinker, 1989).

A classic study by Shepard and Metzler (1971) systematically investigated the process of mental rotation and demonstrated a linear function, with mean reaction time increasing proportionately to angle of rotation. In the original experiment, participants were presented with two perspective drawings of three-dimensional, asymmetric objects and asked to judge whether they represented the same, or a mirror-image, object. Data suggested that the time taken to respond increased as a linear function of the angle between the two portrayed orientations. This led to the proposal that participants mentally rotate one object's image into congruence with the other object's image to make their response decision. Assuming a constant velocity of rotation, the larger the angle, the longer the rotation time, and consequently the longer the response time. Indeed, Shepard and Metzler (1971) proposed that the process of mental rotation proceeded at approximately 60° per second. However, it was argued that the block forms, and the task of discriminating between mirror-images, employed by the authors, did not constitute mental rotation per se (e.g. Pylyshyn, 1973).

Jolicoeur's (1985) influential study is also considered to be a classic viewpoint-dependent account of object recognition. The authors demonstrated large systematic effects of orientation on recognition time for familiar stimuli, and provided powerful evidence for a viewer-centred frame of reference. Jolicoeur (1985) proposed that object recognition is achieved through the process of mental rotation, and demonstrated that the time required for object recognition was dependent upon the degree of

misorientation from the upright. However, the increase in reaction time was linear and symmetrical about the 180° misorientation, producing an 'M' form of function. Jolicoeur (1985) explained these results as possibly representing some form of faster 'inversion' process for 180° picture plane rotations. The author also found that reaction times were much slower on the initial presentation of stimuli (which he termed the 'first trial' effect), with smaller orientation effects, when using the same stimuli, on second and subsequent trials. In Experiment 3, however, Jolicoeur (1985) demonstrated that when novel stimuli were presented in later trials, reaction times were equivalent to those of the first trial. Furthermore, when subjects were requested to judge whether an object faced left or right (i.e. handedness), Jolicoeur (1985, Exp. 4) found that there was no significant difference between his data and the results of Shepard and Metzler's (1971) experiment. Hence, the author concluded that mental rotation was used for both naming and handedness tasks, which he proposed were analogous to mirror-image discrimination.

Tarr (1989) and Tarr and Pinker (1989), however, proposed a reduction in the number of necessary views to be stored in memory. In their study participants learned to identify three very similar, but clearly discriminable, stimuli. Initially, participants were presented with, and learned, a small set of fixed orientations. When identification time became equivalent with practice for the fixed orientations, participants were tested with a larger set of orientations, including both learned and novel orientations. Data indicated that participants responded fastest to the learned

orientations, but identification time increased, approximately linearly, with

deviations from any one of the learned orientations. Tarr and colleagues

(1989) proposed that a transformation process was employed to align

misorientations to the nearest learned orientation, and that multiple

orientation-dependent representations, plus transformation, mediated object

constancy.

Following this research, a large number of studies have demonstrated

that recognition latencies increase as a function of the angular distance

between the object's orientation, and the nearest experienced orientation (e.g.

Jolicoeur & Milliken, 1989; Jolicoeur, Snow & Murray, 1997; Jolicoeur &

Humphrey, 1998; McMullen & Jolicoeur, 1990; Leek, 1996, 1998; Tarr,

1995; Tarr & Bülthoff, 1995 - these studies are reviewed in more detail under

the section on picture plane misorientation). This approach has been referred

to as the "multiple-views" hypothesis. It is proposed that such patterns of

performance provide support for a multiple-views theory, in that non-familiar

objects are identified by learning each familiar viewpoint, and then

transforming unfamiliar viewpoints to those views (Tarr & Bülthoff, 1995).

Such theorists contend strongly that objects are recognised on the

basis of stored views. View-based accounts propose that holistic images are

matched to literal views stored in memory, and some form of pre-processing

is employed to normalise for absolute location (as well as size on the retina,

and illumination) (Edelman & Poggio, 1991). View-based models generally

specify these views in two-dimensional co-ordinates of their features, as they

appear in particular views (e.g. Bülthoff & Edelman, 1992; Poggio & Edelman, 1990), but do not involve any decomposition of objects into features or parts (Hummel, 2001). Features are represented in terms of numerical co-ordinates, being metrically precise and, as such, it is argued, that this model confers an advantage for distinguishing between structurally similar objects (Bülthoff et al., 1995). The matching of templates is highly dependent on the metric properties of the template, for example, the degrees of curvature, the angles of intersections, and the aspect ratios.

More recently, it has been proposed that slight rotations may be compensated for by direct generalization from templates, but large rotations involve a transformation process, for example, mental rotation (e.g. Jolicoeur, 1985), image alignment (e.g. Ullman & Basri, 1991), or view interpolation (e.g. Bülthoff & Edelman, 1992), in order to achieve recognition (Edelman & Intrator, 2000). (Alternative hypotheses regarding transformation processes, together with later view-based models, are reviewed in the section on depth plane misorientation).

It has been proposed that an unlimited capacity to transform an object's image would serve to limit the selection of stored representations, and allow direct recognition from any novel viewpoint (Perrett et al., 1994). Within a visual system that optimises information, however, it may be considered that a frame of reference based on the object itself, may prove a more economical solution to the problem of object recognition, than one based on numerous view templates. Object-centred representations are

independent of the viewpoint from which the object is observed, and such accounts are regarded as viewpoint-independent. The prototypical work on this approach to object recognition is reviewed below.

Viewpoint-independent accounts

The idea that the human visual reference frame is tied exclusively to egocentric co-ordinates was challenged by Marr (1982), who provided a powerful theoretical analysis of object recognition. Marr's work had a huge impact on the study of vision, particularly, as it switched the focus of high-level vision research from visual imagery (e.g. Kosslyn, 1980), to visual object recognition.

This theory provides a detailed account of the computations that must be performed by a visual system to solve a problem, regardless of whether this system is composed of neurons or microchips (Marr & Nishihara,1978). Marr (1982) proposed that such a process produces a series of representations which provide increasingly detailed information about the visual environment, from basic retinal information (of which he gives an expansive account), to eventual recognition of an object. According to this account, there is no requirement for a normalisation strategy, as the frame of reference is intrinsic to the object.

Marr (1982) identified the three major kinds of representation in the process, those being the Primal Sketch, the 21/2D Sketch and the 3D model

representation. The Primal Sketch provides a 2D description of the main light intensity changes in the visual input, including information about contours and edges. Marr's (1982) 21/2D Sketch incorporates a description of the depth and orientation of visible surfaces by the use of information provided by, for example, texture, shape, motion, shading and binocular disparity. As with the Primal Sketch, this account is representative of a viewpoint-dependent account, and being viewer-centred, the internal representations of an object will vary considerably depending on the angle from which it is viewed. Although the front and back, the nearer and farther specifications of an object are identified at this level, the volumetric properties of an object, being how far back one surface is from another, are not specified. However, at the final level of object recognition, Marr's (1982) 3D model is constructed, and this is viewpoint-independent. This 3D representation is volumetric, and identifies the relationship among different parts of an object.

Marr and Nishihara (1978) specified three criteria for three-dimensional representation: (1) "accessibility", that the representation can be easily constructed; (2) "scope" and "uniqueness", with scope referring to the extent to which the representation is applicable to all the shapes in a given category, and uniqueness referring to the idea that all the different views of an object produce the same standard representation; and (3) "stability" and "sensitivity", stability indicating the idea that the internal representation

incorporates the similarities between objects, and sensitivity proposing it encompasses salient differences (Bruce et al., 1996).

Marr and Nishihara (1978) proposed a hierarchical organisation of descriptive elements (primitive units) to describe objects. High-level units, providing information about object shape, and low-level units, providing more detailed information. The authors proposed that the 3D model representation is matched to a representation in a catalogue of 3D model representations stored in memory. According to this theory, a critical property for recognition is establishing the major and minor axes inherent to the object. Discussion is restricted to the class of such objects that can be described as a set of one or more generalised cones. For example, a human figure can be described as a set of generalised cones corresponding to the trunk, head, arm and legs. Each of these component cones has its own axis, and together these form the component axes for a representation of a human (see Figure 1.3).
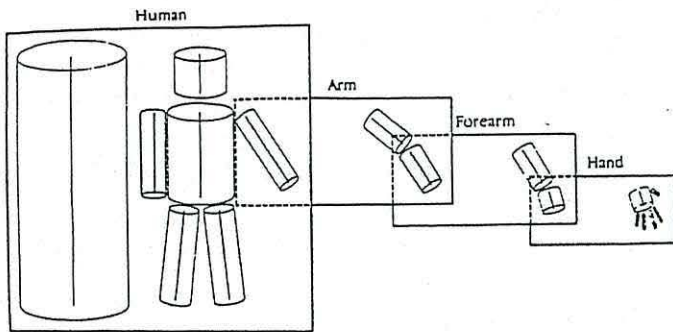
Figure 1.3: A hierarchy of 3-D models. Each box shows the major axis for the figure of interest on the left, and its component axes to the right. From Marr and Nishihara (1978).

The object-centred model of Marr & Nishihara (1978) requires information about the object's principal axis, to be used as a reference to describe the disposition of the object's parts. Accordingly, Marr (1982) concedes that object recognition would be disrupted if the major axis of elongation of the object is difficult to derive, that is, if it is foreshortened. For example, in Figure 1.4, the longest 2D axis of the image does not coincide with the main axis of elongation (Marr & Nishihara, 1978).
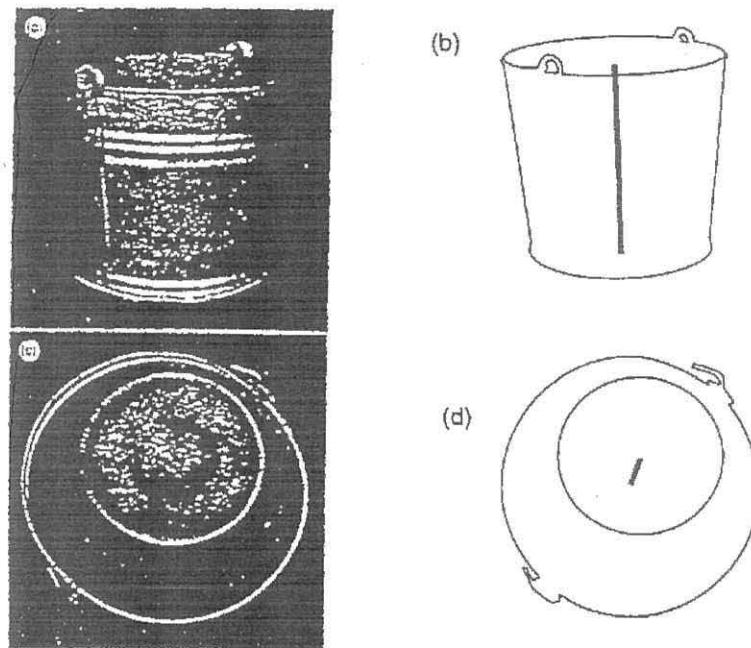
Figure 1.4: Views of a water bucket illustrate an important characteristic of any system based on the derivation of canonical axes from an image. The techniques useful for finding the axis shown in (*b*) from the image (*a*) are quite different from those that are best for situations where the axis is foreshortened as in (*c*) and (*d*).

Lowe (1985, 1987) also postulated an object-centred recognition model, but did not refer to the principal axis of the image. In this model, recognition is accomplished by comparison of the two-dimensional relationship between simple features in the image (e.g. corner, lines) with the relative position of the object parts. This model is dependent on the visibility of multiple (and salient) object parts, and should these parts be occluded, the object would be more difficult to recognise.

A further prominent theory, elaborating on that of Marr (1982) and Lowe (1985, 1987), was Biederman's (1987) 'Recognition-By-Components'

model. Biederman (1987) assumed edge detection, unlike Marr (1982), who detailed this extensively. In concurrence with Marr and Nishihara (1978), however, Biederman (1987) proposed that the initial stage of object recognition involves the parsing of objects into component parts (see Figure 1.5). Biederman (1987) also emphasised the manner and structure in which parts of objects are decomposed - the structural description. The author termed these volumetric components "geons" (geometric ions), numbering approximately 36, and including arcs, spheres, wedges and cylinders etc. It was proposed that it is the combination of these "geons" that differentiates most common objects, his analogy being to the phonemes in spoken language.

Biederman's (1987) theory had its foundations in the work of Binford (1971) and Lowe (1986), with the concept of 'non-accidental' shape properties. These being features from which three-dimensional properties of an object are inferred, barring the unlikely accident of a particular viewpoint. 'Non-accidental' properties (NAPs) include, parallelism, sense of curvature, straightness and co-termination (where two lines terminate close to each other and are construed as touching in 3D space). Biederman's "geons" are based on such properties, and objects are seen as a composition of geons with specified spatial relations, which give rise to the perception of three-dimensional shape that is viewpoint-independent (Edelman & Weinshall, 1998). Biederman (1987) also adds, that non-accidental properties, defining the geons, may be preferentially observed from different viewpoints.

Whereas Jolicoeur (1985) proposed mental rotation to explain reaction time latencies as a function of an objects rotation away from the 'norm', Biederman (1987) proposed that such latencies could be explained by the perturbation of the 'top-of' relations among the components (also proposed by Carpenter and Just, 1978, Rock, 1973).
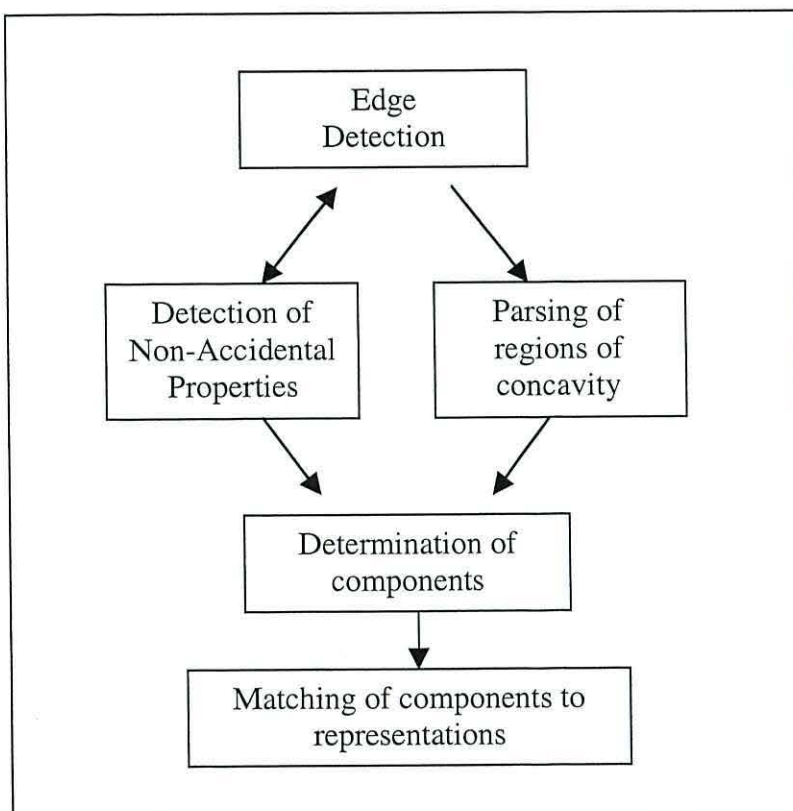
Figure 1.5: An outline of Biederman's recognition-by-components theory. Adapted from Biederman (1987).

According to Biederman's (1987) geon structural descriptions (GSD) theory, objects are recognised in categorical relations[3], and in the model these relations are critical for object recognition. Indeed, viewpoint-independent

theorists have claimed that the only computational approach, which addresses the core problems of object recognition, those being: (a) generalisation across viewpoint; (b) categorization of novel shape categories; and (c) how the arrangement of parts in on object are encoded (i.e. the representation of structure), is structural decomposition (Biederman, 1987).

Biederman and Gerhardstein (1995), as did Biederman (1987), suggested, however, that individuals may employ viewpoint-dependent mechanisms in the search for a distinctive geon or feature, for example, a car logo, but that the subsequent representation would be viewpoint-independent. The authors argued that, in this instance, it was the search (or perhaps mental rotation) process itself that produces rotational costs, as opposed to the viewpoint-independent internal representation.

In this assertion, GSD theory provided an explanation of object recognition encompassing both viewpoint-dependent and viewpoint-independent mechanisms. Biederman and Gerhardstein (1995) proposed that distinctive NAPs, on which GSDs are based, are the spontaneous and preferred representations of the visual object recognition system. In this manner, GSD theory is compatible with the view of Tversky and Hemenway (1984), who proposed that the tendency is for objects to be described as an arrangement of parts.

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[3] Referring to the specification of a cup handle as curved, rather than specifying an exact degree of curvature, and a relation as side attached, as opposed to specifying the metric details of the attachment.

Biederman (1987) also proposed that GSDs are sensitive to picture plane and, to some extent, depth plane rotation (these assertions are discussed on the sections on picture and depth misorientation) It is also proposed that GSDs tolerate generalisation across class members. For example, a mug may be represented as a "curved cylinder (i.e. the handle), side-attached to a straight vertical cylinder (i.e. the body of the mug)". This form of representation, therefore, describes many mugs, and makes the recognition of new instances of mugs straightforward (Biederman, 1987; Marr, 1982).

GSDs, however, necessitate the segmentation of local object parts/features, and the "binding" of these into groups, in order to avoid interference between parts (Hummel, 2001). Hummel and Biederman's (1992) original computational model, JIM, responded to this problem by proposing the "dynamic" binding of such features into their appropriate sets. In "dynamic" binding, using a mug as an example, a representational unit (or collection of units) is capable of representing a curved cylinder, and another unit, the side-attached relation. Synchrony of firing between units, enables the curved cylinder, side-attached to another part (e.g. straight vertical cylinder), to be "dynamically" tagged as bound together.

Hummel and Stankiewicz (1996), however, suggested that "dynamic" binding posed a problem for object recognition, in that, unlike fast and automatic human recognition, the computational demands of "dynamic" binding mean that it is time consuming, capacity limited and demands attentional processes. The authors, therefore, developed a hybrid model,

JIM.2, which employed both " dynamic" and "static" binding processes. Static binding activates a separate unit for each conjunction. For example, one unit responding to "side-attached", and a separate unit responding to the conjunction "above", and so forth. The predictions of this model are that the visual system is able to fragment an object into part attributes and their spatial relation underlined independently of one another, leading to largely viewpoint-invariant recognition. However, it is suggested that if this process were to fail (due, for example, to insufficient processing time or perhaps inattention), part attributes and their interrelations would not be represented independently, and object recognition would become viewpoint-dependent.

Like JIM.2, JIM.3 (Hummel & Stankiewicz, 1998), adapted two complimentary approaches to the problem of feature binding, but departed from the previously mentioned models in that it also explicitly coded object surfaces. This model contains 8 layers, the first 3 representing contours, vertices[4] and axes of symmetry in an object's image, together with shape properties of surfaces. Layer 4 represents a collection of inhibitory gates that project layer 3's outputs to layer 5's independent geon attributes, their independent spatial relations, and a surface map. Layers 6 to 8 are involved in the encoding of these structural descriptions into long-term memory for recognition.

The preceding models, like RBC, code shape dimensions independently, but unlike RBC, these shape dimensions are continuous (i.e.

allow for different degrees of curvature, parallelism etc.), not purely

categorical (i.e. the primary axis is either straight or curved). Of importance

to this research, Hummel and Stankiewicz (1998) proposed that the JIM,

JIM.2 and JIM.3 enlist attentional resources. It is proposed that these

resources permit the visual system to generate part-based structural

descriptions, by the "dynamic" binding of image features (e.g. contours), part

shape attributes, and their spatial interrelations, into parts-based sets. The

suggestion is, that if there were ambiguity concerning an object's

identification, there would be simultaneous activation in multiple

inconsistent units, resulting in the necessity to inhibit competitive units.

Furthermore, in order to keep track of parts for specific objects, Hummel and

Stankiewicz (1998) augmented the model to search for diagnostic features.

This proposal is similar to that of Biederman and Ju (1988), who

suggested that colour and gross features (e.g. overall size and aspect ratio),

may play an inhibitory role in object recognition. The authors postulated that

such features would be employed during the identification process to inhibit

structural representations of objects not possessing the appropriate properties.

The process of inhibition would, therefore, minimise competition from those

object representations.

The literature reviewed above suggests that there is no definitive

answer to the viewpoint-dependent and viewpoint-independent question, but

rather there is a continuum ranging from extreme viewpoint-dependency (e.g.

Where contours join.

Tarr and Bülthoff, 1995) to almost complete viewpoint-invariance (e.g.

Biederman and Gerhardstein, 1995). Both viewpoint-dependent and

viewpoint-independent proponents agree, however, that certain views will be

more efficiently recognised than others. In this respect, the term 'canonical'

was initially introduced by Palmer, Rosch and Chase (1981) to specify that

some views of objects were better for recognition than others. In a series of

experiments, Palmer et al. (1981) demonstrated stable and consistent effects

within subjects (although it was observed that these effects were

idiosyncratic), and proposed that canonical[5] views provided the best access to

internal representations of objects, as they contained the most salient

information about the object.

To summarise, theoretical accounts with neurologically normal

subjects, offer conflicting empirical data, and indicate that object constancy

is a complex ability that is achieved by a variety of means under difference

circumstances (Pinker, 1984). In such an instance, it is paramount to seek

converging evidence from alternative research areas. Neurophysiological

evidence, from single-cell recordings, and neuropsychological studies of

neurological impairment, are indispensable in this respect. Seminal

neurobiological research in the achievement of object constancy is discussed

below. As with the studies reviewed above, additional neurobiological

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n this review, the terms canonical, usual and optimal will be used interchangeably, as will non-canonical, unusual and non-
timal.

literature will be reviewed in later sections, under specific forms of non-optimal views.

What neuroanatomical areas are involved in object recognition?

Clearly, vision evolved in humans for distinct and diverse goals. A visual representation system, linked to memory, planning and communications systems has developed, not merely to identify objects and attach meaning to them, but also to plan and execute skilled movements (Tarr & Bülthoff, 1998).

It may be argued that different visual tasks require different visual representations (e.g. Milner & Goodale, 1993, 1995). Visual guidance for action may require information about objects that is specified with the viewer as the frame of reference. For example, in order to reach and grasp an object, it is imperative that the observer knows the object's position and orientation with respect to himself. Alternatively, a visual pathway, subserving recognition, may well utilise object-centred representations, which generalise across multiple viewpoints (Perrett et al., 1994, Perrett, Oram & Ashbridge, 1998).

Indeed, certain neurological deficits appear to be more "spatial" than "perceptual" in their nature, and these may influence the form of representation employed by the visual system. For example, the loss of spatial aspects in drawing and constructional tasks, the loss of topographic

orientation, visuospatial neglect, and disorders of reaching (optic ataxia). In

some patients, presenting with the above disorders, object recognition

appears to remain relatively intact (Turnbull, Carey & McCarthy, 1997;

Turnbull, Laws & McCarthy, 1995). Significantly, Farah, Hammond, Levine

and Calvanio (1988) demonstrated a double dissociation between visual

representations of stimuli, and spatial locations of stimuli. The authors

concluded that each was subserved by distinct, independent systems. In this

connection, the influential two visual systems approach to understanding

visual function, has been extremely informative in relating object

representation issues to the neural substrate for object recognition (Turnbull

et al., 1997a).

   In 1982, Ungerleider and Mishkin proposed two distinct streams of

processing in the macaque monkey brain. A ventral stream projecting from

the primary visual cortex to the inferotemporal cortex, and a dorsal stream

projecting from the primary visual cortex to the posterior parietal cortex (see

Figure 1.6).
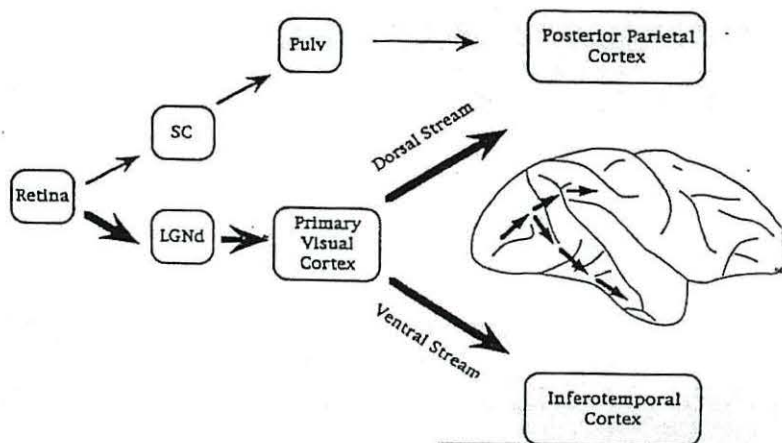
Figure 1.6: Major routes whereby retinal input reaches the dorsal and ventral streams. The diagram of the macaque brain (right hemisphere) on the right of the figure shows the approximate routes to the cortico-cortical projections from the primary visual cortex to the posterior parietal and the inferotemporal cortex respectively. LGNd, lateral geniculate nucleus, pars dorsalis; Pulv, pulvinar; SC, superior colliculus.

Ungerleider and Mishkin (1982) proposed that the ventral ('what') stream plays a crucial part in object vision, enabling identification of an object, whilst the dorsal ('where') stream is involved in spatial vision, enabling localisation of an object in space. This distinction is somewhat similar to an earlier functional dichotomy proposed by Schneider (1969), implicating the essential role of the primary visual cortex in identifying stimuli, and the phylogenetically older structure of the midbrain, the superior colliculus, responsible for the localising of visual stimuli (Tarr & Bülthoff, 1998).

More recently, however, Milner and Goodale (1995) proposed a reinterpretation of Ungerleider and Mishkin's (1982) theory. Rather than emphasising the information handled by the 'what' and 'where' streams, their account focused on the difference in the requirement of the output systems of each stream (Tarr & Bülthoff, 1998). Goodale and Milner (1992) proposed functional and anatomical independence of the two visual streams. The ventral stream being responsible for object recognition, and the dorsal stream, providing critical information on location, size and shape, which would enable one, as suggested earlier, to reach out and grasp objects. Milner and Goodale (1995) acknowledged that dorsal areas may contribute to visuospatial processing, which it was proposed would necessarily require information from both visual streams. It was further suggested that different forms of representation may be employed by the two visual streams. The ventral stream utilising viewpoint-independent representations and the dorsal stream, viewpoint-dependent representations. This proposal sheds light on certain neuropsychological disorders, where access to only one form of representation in one visual stream, results in specific recognition deficits (Turnbull et al., 1997a).

It has been argued that lesions to the right posterior temporal lobe produce deficits in object recognition (e.g. Damasio et al., 1989; Kertesz, 1983). Parietal lesions, on the other hand, appear to result in "spatial" disorders, such as those mentioned previously. In this respect, neurological patients have demonstrated deficits in particular types of tasks. For example,

an inability to identify overlapping objects (De Renzi & Spinnler, 1966), or degraded pictures (Warrington & James, 1967).

Of crucial importance to this research, Warrington and Taylor (1973, 1978) instigated investigation into the neurological substrates underlying the ability to recognise objects over changes in viewpoint. The authors found that patients with damage outside of the ventral visual system (including the parietal and frontal lobes), were selectively impaired in the identification of non-canonical views, compared to canonical views, of the same object. Such patients, with otherwise normal basic visual abilities, were described as having a perceptual classification disorder, known as the 'Unusual Views Deficit' (UVD). Warrington and Taylor (1973) proposed that the critical lesion site for these patients was in fact the inferior parietal lobule.

One explanation offered, regarding such patients, was that their inability to recognise non-optimal views, resulted from an inability to mentally rotate a misoriented object to a familiar or optimal view (Layman & Greene, 1988). As such recognition is based on viewer-centred co-ordinates, the internal representations employed in this process are considered to be viewpoint-dependent in nature.

The models of Marr (1982) and Biederman (1987) have also proved to be extremely important in providing a theoretical framework from which deficits in these particular neurological patients can be understood, and there is plentiful evidence supporting the validity of axis-based accounts of object recognition. For example, Humphrey and Jolicoeur (1993) reported that the

identification of line drawings was noticeably disrupted when objects were depicted with their main axis oriented directly towards the viewer, so that the main axis appeared foreshortened. It was, therefore, considered that the recognition of non-canonical views may be axis-based.

However, Warrington and James (1986) found no systematic relationship between the visibility of the principal axes (see Marr, 1982), but their results were more closely tied to the visibility of salient features. These authors, therefore, proposed a feature-based route for object constancy.

It has also been suggested that structural encoding, using the principal axes, may be dissociated from the processing of local features (Perrett et al., 1994). Humphreys and Riddoch (1984), for example, proposed that the UVD may be explained when there is occlusion of either the distinctive features or the principal axis, of an object. The authors demonstrated a double dissociation between two patients, HJA and JL, who were both capable of naming objects from conventional views, but showed selective impairment in matching foreshortened views. HJA presented with bilateral occipital lobe lesions and appeared to rely on distinctive features, and JL, who suffered right posterior cerebral lesions, relied on axis-based properties of an object to achieve object constancy. (Mental rotation, feature- and axis-based accounts are reviewed in more detail in the following section).

Of major relevance to this research, the research of Kosslyn, Flynn, Amsterdam and Wang (1990) and Kosslyn, Alpert, Thompson, Chabris, Rauch & Anderson (1994), used positron emission tomography (PET) to

investigate non-canonical views of objects, and hypothesised that additional processing would be required for non-canonical views. It was suggested that it was the right dorsolateral prefrontal cortex, and the inferotemporal region, that encodes this additional information.

Similarly to Milner & Goodale (1993, 1995), Kosslyn et al. (1990, 1994) argued that the primary mechanism for object recognition in the ventral stream was viewpoint-independent, and involved the development of viewpoint-independent structural descriptions (Biederman, 1987). The authors further proposed that viewpoint-independent, feature-based recognition, which would suffice for recognition, under certain circumstances, would also take place in the ventral visual stream. Kosslyn and colleagues (1990, 1994) proposed that orientation information (together with scale and position information) may be "adjusted" in the dorsal stream, in order to achieve a match between the image and the existing representation. In doing so, Kosslyn and colleagues' research offered a point of contact between behavioural studies and the neural substrate of object constancy, in proposing that certain adjustments or "transformational" processes may be required for non-optimal view stimuli before a match can be made.

Kosslyn et al.'s (1990, 1994) suggestion led to the proposal that the dorsal stream was involved in the "binding" of viewpoint-dependent and viewpoint-independent information from the dorsal and ventral streams

respectively (Friedman-Hill, Robertson & Treisman, 1995; McCarthy, 1993; Watson, Valenstein, Day & Heilman, 1994). Furthermore, it was proposed that the viewpoint-independent ventral system would require an "optional" resource (McCarthy & Warrington, 1990), based in the dorsal stream, which would contribute to object identification when orientation-specific information was critical (Turnbull et al., 1997a).

It has since been demonstrated that object orientation can be dissociated from object identification. In this respect, Turnbull and co-workers have offered a detailed account of an orientation knowledge deficit within the neurological population. This phenomenon has been referred to as "agnosia for object orientation" (Turnbull, Beschin & Della Sala, 1997b; Turnbull et al., 1995). The authors demonstrated a clear dissociation between the ability to identify objects presented in different orientations, and an inability to recognise whether the orientation was upright. The findings of Turnbull and colleagues, therefore, also suggested that there are two pathways in normal object recognition, one displaying viewpoint-independent properties in the ventral stream, and a second displaying viewpoint-dependent properties, outside of the ventral stream (Turnbull et al., 1995).

Turnbull et al. (1997b) have attempted to account for the UVD, as seen in Warrington and Taylor's (1973, 1978) patients, as a deficit of an "additional" resource(s). As noted, Warrington and Taylor (1973, 1978) proposed that the

critical lesion site for the UVD lies outside the ventral stream, the classical area proposed to be involved in object recognition. From Warrington and Taylor's (1973, 1978) data, optimal view recognition would be processed by the ventral stream, but under non-optimal conditions, this system would plausibly require assistance from a supplementary resource(s) (Turnbull at al., 1997b). This "additional" resource(s) would perhaps undertake instances of "visual problem solving" (Farah, 1990, p.55), and it has been proposed by Turnbull and colleagues that this system may be utilised to: (1) employ a mental rotation strategy (cf. Jolicoeur, 1985); (2) establish the relative depth of foreshortened axes (cf. Marr & Nishihara, 1978); or (3) identify occluded critical features (cf. Biederman, 1987).

The cognitive and neurobiological literature regarding these functions will be detailed in the sections to follow under individual forms of non-optimal views, those being: a) picture plane misorientation; b) depth plane misorientation; and c) the achievement of object constancy via the extraction of distinctive features.

The achievement of object constancy across picture plane misorientation

The vast majority of the early work on recognition of rotated shape focused on picture plane misorientation - stimuli or pictures of objects rotated in the two-dimensional plane. The methodology generally employed was based on memory and transfer of learning, and experiments required both a learning and a testing stage. In the first phase, participants were shown drawings of simple two-dimensional forms. In the testing stage, they were required to discriminate between forms that were either present or absent in the learning phase. If they were present in the learning phase, they were rotated in the picture-plane in the testing phase.

The most well known work, using this paradigm, is that of Rock and colleagues (Rock, 1956, 1973, Rock & Heimer, 1957), who found that recognition accuracy was significantly lower for picture plane rotated forms. This general finding had been reported by a number of earlier researchers (Braine, 1965, Dearborn, 1899, Gibson & Robinson, 1935), in that any two-dimensional rotation, including mirror reversal, resulted in a drop in recognition memory. It was also found that picture plane rotational effects were non-monotonic, in that memory was better for 180° rotations (cf. Jolicoeur, 1985).

The empirical conclusion from such experiments was that some part of the memory or perceptual system is sensitive to two-dimensional orientation of visual shapes. The findings of Rock (1973) and Rock and

Nijhawan (1989), paralleled those of Rock and Heimer (1957), and led to the proposal of two levels of internal representation, one tied to retinal co-ordinates - viewer-centred, and the other to the geometry of the shape, relative to top/bottom spatial relations - object-centred (see earlier in review).

A later method employed to investigate the representations and processes involved in the recognition of picture plane rotated stimuli, involved the recording of response latencies at the time of testing. For example, Corballis, Zbrodoff, Shetzer and Butler (1978) used alphanumeric stimuli in letter/digit verification tasks, the dependent variable being reaction time. The stimulus sets consisted of three letters and three digits, and the methodology involved multiple presentation at different orientations. Although some significant effects were demonstrated, the data suggested that two-dimensional orientation effects on identification time were minimal or, in some cases, non-existent (Corballis, Macadie, Crotty & Beale, 1985). The proposal being that internal representations for recognition were orientation-invariant. In support of Corballis and colleagues (1985, 1978), Eley (1982) and Young, Palef & Logan (1980), used a reaction time paradigm, and also proposed that participants employed orientation-invariant mechanisms in the recognition of picture plane rotations. It was suggested that simple shape recognition was achieved by the extraction of object-specific attributes.

It was argued, however, that the results from such experiments provided inconclusive evidence for a general characterisation of the nature of internal representations, or the processes supporting visual recognition

(Jolicoeur & Humphrey, 1998). The authors contended that such findings resulted purely from the fact that very small stimulus sets were repeatedly presented, allowing participants abundant opportunity to learn orientation-invariant distinguishing features.

This criticism was addressed by Jolicoeur et al. (1987), using a set of stimuli to which participants had not been pre-exposed, and where repeated presentation during experimental trials was limited. Under these circumstances, Jolicoeur and co-workers found that the time to identify picture plane rotated, alphanumeric characters varied systematically, increasing approximately linearly with greater rotation from the upright orientation.

A similar phenomena, using more complex forms, i.e. line drawings of objects, was demonstrated by Jolicoeur (1985, 1988), Jolicoeur and Milliken (1989), McMullen and Jolicoeur, (1990) and Maki (1986). As with earlier research (cf. Jolicoeur, 1985), a non-monotonic effect of misorientation was found, in that the increase in response times was linear from 0^0 to $\pm 120^0$, but decreased from $\pm 120^0$ to 180^0, and naming times were less strongly affected after initial presentation. Lawson, Humphreys and Jolicoeur (2000) have provided additional evidence to support these findings, in that repeated presentation does not eliminate, but does attenuate the effects of two-dimensional rotation.

Jolicoeur (1990) posited two possible explanations for this reduction in picture plane rotational effects. One, participants learned to associate

orientation-invariant attributes with the stimuli, which they came to rely on in order to name the same stimuli on subsequent blocks of trials (cf. Corballis and colleagues, 1978, 1985, Eley, 1982, Young et al., 1980). Alternatively, participants stored multiple views of the object over experimental blocks. According to this theory, participants were able to normalise the input stimulus to any of the previously stored representations rather than to the upright representation (cf. Tarr, 1989, Tarr & Pinker, 1989).

View-based theorists then, proposed that in the absence of specific learning experience, that is, where participants do not have the opportunity to learn which attributes could be used to discriminate shapes from one another, easily measurable orientation effects are observed. It is proposed that the nature of the results are indicative of an incremental, analogue transformation process, for example, mental rotation, employed in picture plane recognition (Jolicoeur & Humphrey, 1998).

Mental rotation

Psychometricians have long considered mental rotation to be a critical ingredient in spatial ability (Corballis, 1988). Seminal research on mental rotation by Roger Shepard and his Colleagues (e.g. Shepard, 1984, Shepard & Cooper, 1982, Shepard & Metzler, 1971) has shown that reaction times are linearly related to the angular disparity between depicted objects.

Studies by Cooper and Shepard (1973) and Hock and Tromley (1978)

strengthened the case for a process of mental rotation, which was reinforced

by participants' subjective reports. Sharp mental rotation functions were

reported in tasks involving mirror-image discriminations, alphanumeric

characters (Cooper & Shepard, 1973), hands (Cooper & Shepard, 1975),

polygons (Eley, 1982), letter-like symbols (Eley, 1982), and common objects

(Tarr, 1995).

Of pertinence to this research, Shepard and Metzler (1971)

demonstrated that the slope of the function was essentially the same for both

picture and depth plane rotations, suggesting that participants relied on both

two- and three-dimensional internal representations. Metzler and Shepard

(1974) reaffirmed this conclusion, demonstrating that mental rotation in

depth was unaffected by parts of the objects disappearing from, or emerging

into, view.

The notion that picture and depth plane rotations are compensated for

in the same manner, however, has been challenged recently by Lawson et al.

(2000). This research demonstrated no interaction between the effects of

picture and depth plane rotation, either on initial naming, or with practice.

Data led Lawson and her colleagues to propose that compensation for picture

and depth plane misorientations reflected at least two sequential and

dissociable processes (cf. Shepard & Metzler, 1971). Picture plane rotations,

it was argued, involved the extraction of specific perceptual attributes at an

early stage of visual processing, prior to recognition. The authors proposed

that such attributes may include the main axis of elongation of the object, the probable top and bottom of the object, and the orientation of axes of symmetry (e.g. Marr, 1982, Biederman, 1987). All of these attributes, it was suggested, provided important information regarding orientation in the plane and hence, were pertinent in any picture plane compensation process (Lawson et al., 2000). Subsequently, the researchers proposed that 180^0 misorientations were faster than would be expected by interpolating from 0^0 to 120^0, due to their main axes of elongation, and axes of symmetry, remaining the same as the upright (Lawson, 1999).

However, Corballis (1988) proposed that there was logical difficulty in supposing that mental rotation was employed for object recognition, in that if one does not know what an object is, how can one rotate it to its upright view. Corballis (1988) did, in fact, propose a normalisation process for two-dimensional rotation, but the author considered that this process was performed after recognition, merely to substantiate identification.

In support of this hypothesis, De Caro (1998), De Caro and Reeves (1995) suggested that picture plane rotated and upright objects were recognised equally efficiently, and that the attenuated rotational effect reflected a double-checking strategy, to ensure correct identification. In their explanation, speedier responses after initial presentation, reflected participants' realisation that double-checking was no longer a necessity, as they were usually correct. In unspeeded tasks, as employed by the above authors, it was argued that this strategy would not result in any penalty, and

no orientation effects would, therefore, be predicted. However, Lawson and Jolicoeur (1998) demonstrated that even briefly presented, masked stimuli produced robust effects of plane rotation, which led to the proposal that orientation effects could not be due purely to a double-checking strategy, as proposed by Corballis (1988), De Caro (1998) and De Caro and Reeves (1995).

Using the same methodology, Lawson and Jolicoeur (1999) found a non-monotonic pattern of performance between views rotated successively by 30^0, from 0^0 to 180^0. The data did not, therefore, support a simple mental rotation account, as observed in typical mental rotation tasks. The authors found that whereas picture plane rotational effects reduced with practice, this was not the case for mirror-image discriminations (cf. Jolicoeur, 1988). The authors concluded that mental rotation was employed for mirror-image judgements only, but not for picture plane rotated stimuli. Much recent research has supported this conjecture (e.g. Jolicoeur, Corballis & Lawson, 1998, Jolicoeur, 1998, Jolicoeur & Lawson, 1999, Lawson, 1999, Lawson & Jolicoeur, 1999).

Latterly, De Caro and Reeves (2000) have also rejected the "rotate-to-recognise" hypothesis, and suggested that upright and near-upright views are matched by a fast direct process, whilst other picture plane misorientations are matched at a featural level, by a slightly slower viewpoint-independent process. In support of this hypothesis, Lawson and Jolicoeur (2003) argued against a single, simple, analogue process of normalisation for the

compensation of plane rotated stimuli. Alternative transformational accounts, however, were proposed by the authors to explain picture plane rotational effects. These included view interpolation (Bülthoff & Edelman, 1992; Ullman & Basri, 1991), and image alignment (Ullman, 1989) (these alternative 'normalisation' approaches are outlined in more detail in the following section on depth plane misorientation).

It is proposed that interpretation of the variances in picture plane rotational effects remains unclear (Lawson et al., 2000). Very recently, Lawson and Jolicoeur (2003), however, have suggested a number of factors, which may be responsible for these anomalous effects, those being that: (1) Rotations of $\pm 30^0$ from the upright may be achieved by the direct matching of orientation-specific representations to broadly-tuned upright views, with no need for any image transformation; (2) Rotations of 90^0, 180^0 and 270^0 may benefit from the fact that the major axes of elongation and symmetry are aligned with, or perpendicular to, the upright view; and (3) 180^0 misorientations may benefit from a rapid depth-rotational strategy of "flipping" (Murray, 1997).

Conversely, viewpoint-independent proponents do not generally agree with any form of transformation process, and originally explained picture plane rotational costs as the perturbation of 'top-of' relations amongst the viewpoint-invariant components (e.g. Marr, 1982; Marr & Nishihara, 1978).

As mentioned previously, Biederman's (1987) RBC and its variant

models (Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996, 1998),

have proposed that objects are recognised as collections of single

volumes/geons in particular categorical relations. It is proposed that these

relations are critical, and do not change whether an object is translated across

the visual field, moved closer/further from the viewer, or left or right

reflected (Biederman and Cooper, 1991). Importantly, however, it is

conceded that a 90^0 picture plane rotation of a mug, so that the body is

horizontal and the handle on top, would result in changes to the GSD, in

which case a mug may become more representative of a bucket (Hummel,

2001).

In acknowledging the visual system's sensitivity to picture plane

misorientations, Stankiewicz and Hummel (2002) developed a unified model

of object recognition, based on a hybrid representation of shape, involving

both viewpoint-independent and viewpoint-dependent mechanisms.

Similarly to JIM (Hummel & Biederman, 1992), JIM.2 (Hummel &

Stankiewicz, 1996) and JIM.3 (Hummel, 2001) (outlined earlier in the

review), MetriCat represents object shape in terms of the qualitative

properties of volumetric parts (i.e. geons, Biederman, 1987) and their

relations, independently of one another. The principles underlying this

model are that: (1) objects are represented as collections of part attributes,

and their relations, which are "dynamically" bound into structural

descriptions; (2) part attributes and their relations are represented in a non-

linear manner, emphasising categorical boundaries, but without discarding metric information (cf. Bülthoff et al., 1995); and of importance to the present research, (3) working memory (and attentional resources) enable the inhibition of competitive geons and the search for diagnostic features (see Hummel, 2001; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996, 1998; Stankiewicz & Hummel, 2002).

It is argued that view-based models are inconsistent in their explanation of the human ability to represent parts, independently of their configuration (Hummel, 2001). Specifically, it is proposed that matching holistic representations of the precise locations (i.e. metric properties) of two-dimensional features directly to memory (e.g. Bülthoff & Edelman, 1992; Poggio & Edelman, 1990; Tarr & Bülthoff, 1995), account for only a fraction of the view invariances of human object recognition.

In summary, both viewpoint-dependent and viewpoint-independent theorists propose that the visual system is sensitive to rotation in the picture plane (e.g. Bülthoff & Edelman, 1992; Cooper & Humphreys, 2000; Corballis, 1988; De Caro & Reeves, 1995; Hummel & Stankiewicz, 1996, 1998; Humphreys, 2001; Jolicoeur, 1985, 1988, 1990; Jolicoeur & Humphrey, 1998; Jolicoeur & Lawson, 1999; Jolicoeur & Milliken, 1989; Jolicoeur et al., 1987; Lawson et al., 2000; Lawson & Jolicoeur, 1999; Lawson & Jolicoeur, 2003; Murray, 1995; Murray et al., 1993; Shepard, 1984; Shepard & Metzler, 1971; Shepard & Cooper, 1982; Tarr, 1989, 1995; Tarr & Pinker, 1989;1990; Ullman, 1989; Ullman & Basri, 1991). However, view-based

proponents argue, that in the vast majority of cases, some form of

normalisation process aligns visual inputs to orientation-specific internal

representations. Nonetheless, it is suggested that the anomalous findings

regarding the non-linear function demonstrated in picture plane recognition,

presents problems for view-based, mental rotation theories (Lawson et al.,

2000).

Similarly, viewpoint-independent accounts of object recognition,

concur that the GSD model faces problems in explaining the recognition of

stimuli rotated in the picture plane (Hummel & Stankiewicz, 1998). However,

it is argued that a model of object recognition, such as MetriCat, which maps

onto the strengths and limitations of human object recognition, and whereby

objects' parts and their relations are represented independently, provides a

natural account of the known properties of human shape perception, and is also

predictive of unknown properties of the same (Stankiewicz & Hummel, 2002).

The neurobiology of object constancy across picture-plane rotation

It has been proposed that the latencies demonstrated in picture plane

recognition, were reflective, at least in certain circumstances, of a process of

mental rotation (e.g. Bülthoff & Edelman, 1992; Eley, 1982; Hock &

Tromley, 1978; Jolicoeur, 1985, 1988, 1990; Shepard & Metzler, 1971; Tarr,

1995; Tarr & Pinker, 1989), and in this connection, there is plentiful

supporting evidence from patients with brain lesions, and from functional imaging

studies, indicating that areas outside of the ventral visual stream, namely the

parietal lobes, play an important role in mental rotation (e.g. Alivisatos & Petrides,

1997; Carlesimno, Perri, Turtiziani, Tomaiuolo & Caltagirone, 2001; Cohen,

Kosslyn, Breiter, Digirolamo, Thompson, Anderson, Bookheimer, Belliveau &

Rosen, 1996; Harris, Egan, Sonkkila, Tochon-Danguy, Paxinos & Watson, 2000;

Harris, Harris & Caine, 2001, 2002; Just, Carpenter, Maguire, Diowadkar &

McMains, 2001; Kosslyn, Digirolamo, Thompson & Alpert, 1998; Passini,

Rainville & Habib, 2000; Richter, Somorjai, Summers, Jarmasz, Menon & Gati,

2000; Richter, Ugurbil, Georopoulos & Kim, 1997; Sugio, Inui, Matsuo,

Matsuzawa, Glover & Nakai, 1999; Yoshimo, Inoue & Suzuki, 2000; Zacks,

Rympa, Gabrieli, Tversky & Glover, 1999).

Additional evidence that the "spatial" attributes of an object, including

orientation, are dissociated from recognition of an object has come from

neuropsychological studies (e.g. Best, 1919; Harris et al., 2001, 2002; Karnath,

Ferber & Bülthoff, 2000; Turnbull et al., 1995, 1997a, b). This research

demonstrated an extensive disturbance in the judgement of orientation, despite

intact ability to identify misoriented objects. Misorientation of letters, shapes and

objects, and the copying of geometric figures, have also been described in other

patients (Davidoff & Warrington, 1999; Robertson, Treisman, Friedman-Hill &

Grabowecky, 1997; Solms, Kaplan-Solms, Saling & Miller, 1988).

Turnbull and colleagues (1995, 1996, 1997) predicted that damage to the dorsal visual pathway would lead to a deficit in generating and using viewpoint-dependent representations, which are arguably necessary for the discrimination of mirror-images, and/or determination of object orientation. The authors described three cases demonstrating a clear dissociation between the preserved ability to identify objects at different orientations, and the inability to recognise whether a depicted orientation was correct (upright). Turnbull and colleagues proposed that as patients were able to name objects, for which they were unable to provide the correct upright orientation, they were employing some form of viewpoint-independent object recognition. Such an argument is consistent with patients having lost the viewer-centred descriptions essential to judge object orientation, although retaining access to viewpoint-independent descriptions necessary for identification. As all three patients showed evidence of parietal lobe (i.e. dorsal stream) damage, the prediction was borne out.

Farah and Hammond (1988), on the other hand, provided evidence to suggest that plane rotated views can dissociate from mirror-image discrimination (typically assumed to involve mental rotation). This patient was poor at neuropsychological tests of mental rotation, but was able to recognise misoriented numbers, letters and drawings. These findings, therefore, represented a classic double dissociation of the processes of mental rotation and orientation-invariant object recognition.

Furthermore, Turnbull and McCarthy's (1996) patient retained the ability to name objects when upright, but showed a substantial increase in naming errors when stimuli were rotated in the picture plane. As the principal axis and critical features were preserved in such rotations, the problem could not be attributed to identifying either of these two attributes, and further, it was demonstrated that the patient retained the ability to mentally rotate. Turnbull and colleagues argued that although mental rotation may be employed in the recognition of misoriented objects (cf. Jolicoeur, 1985; 1990), the necessity of such a strategy was questionable. It was proposed that these findings, with no deficit in accessing axes, features or performing mental rotation, possibly reflected a disorder of a supplementary resource (mentioned earlier in the review). It was further suggested that this resource may be used when recognition was not immediately successful, and this, it was argued, may explain the initial, stronger effects of picture plane rotations on object recognition (Turnbull et al., 1997b).

Turnbull, Della Sala & Beschin (2002) extended the findings of Turnbull and co-workers (1995, 1996, 1997a, b) in collecting reaction time measures for the same patient. In their earlier study, and as with most neuropsychological investigations, the patient had been allowed unlimited viewing and response time for recognition. It was, therefore, impossible to ascertain whether the patients' performance showed the characteristically linear pattern of picture plane misorientation (up to 120^0), as demonstrated by

neurologically intact individuals. It was predicted that the typical linear function would be absent for this patient, who had a parietal lesion and performed poorly on orientation tasks. This hypothesis was substantiated as the patient's performance differed significantly from that of the controls. The patient showed no increase in reaction time as a function of orientation, thus suggesting he was not employing a mental rotation strategy. Interestingly, the authors found that the patient showed good mirror-image discrimination, leading Turnbull and his co-workers to propose that mirror-image discrimination and mental rotation did not share the same cognitive architecture. It was argued that these findings were consistent with the neurophysiological findings of Perrett et al. (1998) and Ashbridge, Perrett, Oram, & Jellema (2000), who proposed a numerical bias of cells in the temporal lobes for canonical views (see below). Further, the data also appeared to add support for behavioural findings (e.g. Lawson and Jolicoeur, 2003), who have dismissed a simple mental rotation strategy for two-dimensional misorientations, but concur with a "rotate-to-recognise" hypothesis in the case of mirror-image discrimination.

Harris et al. (2002) also provided evidence for the independence of picture plane and mirror-image recognition. It was proposed that information regarding the top/bottom and the front/back of objects (e.g. a car has wheels at the bottom, and a dog has a tail at the back), enabled the extraction of salient features from the visual input, based on an object-centred frame of reference, and did not involve mental rotation. Conversely, it was argued

that mirror-image discriminations entailed viewer-centred decisions, in order to map the observers' left/right onto the reference frame of the object, and that this process reliably involved mental rotation.

Further demonstration of preserved knowledge of upright orientation was recently described by Karnath et al. (2000). Here the patients made no errors in orientation judgements for upright stimuli, but accuracy was at chance levels for non-upright orientations. It was argued that multiple viewpoint–dependent representations are encoded in the ventral stream, and that a larger number of cells are tuned to the most frequently encountered view of an object (Ashbridge et al. 2000; Perrett et al., 1998).

In support of this view, single-neuron findings in the macaque money (Rollenhagen & Olsen, 2000; Olsen, 2001) indicated that the visual system may be able to differentiate between objects based on their orientation. It was suggested that this hypothesis may explain why upright orientation is preserved, in that when an upright object is presented, there is a strong match between orientation information contained in the input image and that contained in the stored representation leading to correct recognition. It does not, however, explain why these patients are unable to use this knowledge in the interpretation of other orientations (Rollenhagen & Olsen, 2000).

Karnath et al. (2000) have argued, on the basis of reported errors, that such patients do not have "orientation agnosia", and, consequently, that object structure is coded in an orientation-independent manner (cf. Turnbull

et al., 1995, 1997a). The work of Karnath and colleagues (2000) contended

that errors for upright orientations seldom occur with such patients, and

reported a patient with perfectly preserved knowledge for upright stimuli. To

some degree, this criticism was addressed by Caterini, Della Sala, Spinnler,

Stangaline and Turnbull (2002), who have recently reported three patients

who made as many errors on upright orientations as they did on 120^0 picture

plane misorientations.

Perrett et al. (1998) explicitly challenged the assumption that recognition of

rotated objects requires mental rotation. The authors physiological explanation of

orientation effects, proposed that speed of recognition was dependent on neuronal

accumulation of cells in the temporal lobes, where more cells were tuned to the

most frequently experienced view. A canonical view would, therefore, lead to

faster recognition than picture plane views. Thus, this hypothesis offered an

explanation for the increased time to recognise picture plane rotated views, and it

was argued, may also explain the attenuated effects following training.

Additional neurophysiological evidence that areas in the dorsal

stream code visual information in viewer-centred frames of reference, comes

from Duhamel, Colby and Goldberg (1992). The authors have shown that

neurons in the lateral intraparietal area code information in eye-centred co-

ordinates, and update retinal representations in order to map object location relative

to the observer. It was also proposed that neighbouring brain regions

code information in arm-centred co-ordinates, for reaching and grasping (Sakata, Taira, Kusunoki, Murata & Tanaka, 1997).

In summary, there is strong neuropsychological evidence that object identity and object orientation are processed separately (e.g. Caterini et al., 2002; Turnbull et al., 1995, 1996, Turnbull et al., 1997a, b; Turnbull et al., 2002), and that viewpoint-independent mechanisms (operating on optimal view stimuli) and viewpoint-dependent mechanisms (operating on picture plane stimuli - amongst perhaps other non-optimal views), are dissociable processes. The former showing activation in the temporal (i.e. ventral stream) areas, and the latter processes, in the parietal (i.e. dorsal stream) areas.

Whilst there is an ongoing debate with regard to whether neurons in the ventral stream may code viewpoint-dependent, as well as viewpoint-independent information about object orientation (Ashbridge et al, 2000; Karnath et al., 2000; Rollenhagen & Olsen, 2000; Perrett et al., 1998), there is strong evidence that regions in the dorsal stream (specifically, the parietal cortex) code visual information in a variety of viewpoint-dependent frames of reference (Duhamel et al., 1992; Sakata et al., 1997).

The achievement of object constancy across rotation in depth

It has been suggested that template theories may provide an answer to the resolution of two-dimensional misorientation (Lawson et al., 2000). In

that, the presence of distinctive features/parts, global shape and spatial relations of the intrinsic features/parts remains constant for such rotations (Lawson & Humphreys, 1998), and these attributes are important in influencing the nature of the internal representation mediating recognition (e.g. Biederman, 1987; Hummel, 2001; Humphreys & Riddoch, 1984; Lawson, 1999; Marr, 1982; Marr & Nishihara, 1978).

Predictions concerning the effect of three-dimensional misorientation, on the other hand, are more complex. Depth misorientation produces more visually catastrophic changes in stimuli than picture plane rotation, even though such rotations may be considered more ecologically familiar (Lawson, 1999). When objects are rotated in depth, their surface features/parts undergo geometric distortion due to the change in perspective (Stringer & Rolls, 2002). Change in global shape results in the occlusion of some surfaces and features, and also produces new surfaces and features (e.g. Biederman, 1987; Lawson, 1999).

Rock and his colleagues (Rock & Di Vita, 1987; Rock, Di Vita & Barbeito, 1981), performed some of the first research on the recognition of novel three-dimensional objects, which were rotated in the depth plane. Randomly curved wires were employed during a learning and a testing stage. When the retinal projection was altered by an orientation change in the test stage, participants showed an appreciable drop in recognition accuracy. These results pointed to a viewer-centred mechanism for recognition, being a

function of the match between the retinal projection on first and subsequent
encounters.

A study by Rock, Wheeler and Tudor (1989) confirmed the above finding,
and further proposed that object-centred representations of unfamiliar objects were
not spontaneously achieved. In this study participants were requested to imagine
wire-frame stimuli in different positions and were required to recognise them. It
was reported that participants were unable to perform this task without isolating
specific features of the stimuli for recognition.

Following Rock and colleagues' research, Bülthoff and co-workers (Bülthoff
& Edelman, 1992; Edelman & Bülthoff, 1992) further investigated generalisation
to novel views of depth rotated unfamiliar objects. Using three-dimensional tube-
like stimuli, which afforded limited self-occlusion, the authors trained participants
with two different views of objects. Participants were then tested with new
objects, together with the trained objects presented from novel views. This
research demonstrated that recognition for views within the range of the two
trained orientations, was more accurate than recognition for those views outside of
the trained range. The finding led to the interpolation hypothesis (Bülthoff &
Edelman, 1992), which proposed that internal representations are generated from a
linear combination of stored two-dimensional views. It was also found that views
along a trajectory that extrapolated linearly from the trained views (but were
outside of the range), were more frequently recognised than those views that

deviated orthogonally to the views generated by linear combinations of the stored views.

Ullman and Basri (1991) also proposed that any two-dimensional view of an object can be expressed as a linear combination of the co-ordinates in a finite number of other views. Although storing only two-dimensional views in memory, this model recognises depth rotated objects by deriving which linear combination characterises a given view. The models of Poggio, Edelman and colleagues (e.g. Edelman, 1998; Edelman, Cutzu & Duvdevani-Bar, 1996; Edelman and Poggio, 1991; Edelman & Weinshall, 1991; Poggio & Edelman, 1990), also exploit the properties of the linear co-ordinates between features in different views, but it is argued that these models, unlike that of Ullman and Basri (1991), are capable of recognising three-dimensional objects at novel depth orientations.

A further study by Edelman and Bülthoff (1992) involved computer generated wire-like stimuli (i.e. paperclips), which were presented in both monocular and binocular viewing conditions. It was again found that recognition performance in depth rotations varied with the angular distance from the original training views. Although performance improved when objects were presented binocularly, misorientation error rate, relative to the training view, was the same in the mono and stereo conditions. It was contended that although depth cues increase reliability, they are not guaranteed to yield verdical shape and depth perception (Christou & Bülthoff, 2000).

Farah, Rocklin and Klein (1994) also presented stimuli monocularly and binocularly. Stimuli resembling 'curled potato chips' (produced by bending oval disks of modelling clay), and three-dimensional wire objects (produced by bending modelling string) were employed. The angular difference between identical and novel views was in the range of 30^0 to 60^0. Under binocular viewing conditions, Farah and colleagues found that performance with wire objects was poorer for novel views than for familiar views - shape constancy was not evident. For surface objects (i.e. curled potato chips), however, accuracy performance was the same, and well above chance level, for both familiar and novel views - shape constancy was evident. Under monocular viewing conditions, accuracy was moderately worse for novel views, compared to familiar views. Thus, it was proposed, in agreement with Edelman and Bülthoff (1992), that binocular viewing and surface information facilitated shape constancy.

In attempting to explain performance decrements for foreshortened compared to canonical views, Cutzu and Edelman (1992) proposed that foreshortened views are 'deformed', in that parts/features that are relatively far apart in three-dimensional space would be close in depiction. It was further suggested that invariant shapes, such as geometric figures or characters, were the driving attributes for best recognition, but that these attributes were different for individual participants (cf. Palmer et al., 1981). The research of Cutzu and Edelman (1994) led to the dominant viewpoint-dependent proposal that recognition of unfamiliar, three-dimensional views is

achieved by measurement of the distance between corresponding features in stored

views and the visual image (i.e. the metric properties of the object).

In investigating the emergence of canonical views, Humphrey and Jolicoeur

(1993) produced a series of line drawing of common objects in which the major

axes were foreshortened by 45° and 90°. Despite the visibility of the major

features and parts in both views of the objects being maintained, 45° views were

identified more rapidly and with fewer errors than were 90° views. Performance

on 90° views improved when presented on a background with strong depth cues,

but these views remained inferior compared to 45° views. Results suggested that

performance decrements reflected difficulty in locating the principal axes of

elongation of the objects (cf. Marr, 1982, Marr & Nishihara, 1978).

It has been reported that the recognition of silhouettes is particularly

disrupted by foreshortening (Hayward, 1998; Lawson & Humphreys, 1999; Newell

& Findlay, 1997). It was argued that such stimuli lack internal detail and are,

therefore, dependent upon their global outline for recognition (Lawson et al.,

2000).

Lawson and Humphreys (1999) investigated depth view effects for

both line drawings and silhouettes. The hypothesis being, that if the effects

of depth rotation were mediated by difficulty in assigning the main axis of

elongation (e.g. Humphrey & Jolicoeur, 1993; Marr, 1982; Marr &

Nishihara, 1978), performance should be equal across both stimulus sets.

Outline global shape and aspect ratio were identical for silhouettes and line

drawings. It was found that recognition at 0°, 30° and 60° were almost equivalent for stimulus sets, indicating that global shape was informative. For line drawings at 90° rotations, when global shape was less informative, it was proposed that internal detail aided recognition. At 90°, verification of misoriented silhouettes, lacking both internal detail and global shape, was much slower than for line drawings. It was concluded that internal detail either directly aided recognition or aided in the extraction of the principal or secondary axes.

In addition, Hayward (1998) and Newell and Findlay (1997) compared recognition of shaded pictures of familiar objects and matched silhouettes. The authors demonstrated that silhouettes were disadvantaged only for foreshortened views. It was argued, in accordance with Marr (1982), that under normal conditions, internal detail and shading were unnecessary for rapid and successful recognition, but this was not the case when stimuli are presented with a substantially foreshortened principal axis.

The effects of priming[6] for depth rotation in matching tasks were investigated by Lawson and Humphreys (1996). Initially, in the prime blocks, participants were presented with a canonical and a foreshortened 90° view. As expected, performance was faster for the canonical view. In the target blocks, participants were also faster to match canonical than foreshortened views for trials primed by a canonical view. In contrast, in trials primed by a foreshortened view, foreshortened views were matched

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[6] In priming studies, participants initially see a prime view of and object and are then presented with a target view.

faster than canonical views, suggesting viewpoint-specific priming. As well as matching tasks, Lawson and Humphreys (1998) reported analogous findings for the naming of familiar objects. Where naming was faster when the prime and target were identical. In this study, viewpoint-specific priming effects were reported for depth rotations as small as 10%.

Similarly, Srinivas (1993) used familiar stimuli in the two-phase, transfer-of-learning paradigm, in a naming identification task. Usual (prototypical view, Palmer et al., 1981) and unusual (foreshortened view) stimuli were presented on computer, the main dependent measure being percentage correct. In the study phase of the experiment, stimuli were presented from usual views and unusual views. During the learning phase, participants typed the displayed object's name into the computer. In the test phase, Srinivas found there was significantly more priming when views were equivalent in the test and learning phases, and there was poor transfer from usual to unusual, but good transfer from unusual to unusual. It was proposed that data indicated that the representations mediating priming were viewpoint-specific. Hayward and Tarr (1997) demonstrated similar viewpoint-specific priming effects for novel three-dimensional objects. Srinivas (1995) also reported long-term priming[7] in an object and non-object discrimination task for both familiar and novel objects.

Using speeded naming, Lawson et al. (2000) studied compensation for both picture and depth plane rotations (as mentioned earlier in review in respect of picture plane misorientation). Of importance to this research, Lawson and Humphreys (1998), in proposing dissociable processes for picture and depth plane misoriented stimuli, suggested that compensation for depth rotation (i.e. foreshortened stimuli), may require some form of prolonged memory retrieval, and involve additional perceptual processing. This would be the case, it was argued, where only fragments of the image could be initially identified.

In arguing that a simple mental rotation process compensates for three-dimensional misorientations, Willems and Wagemans (2001) demonstrated that the effects of depth rotation on recognition of novel objects were not systematically related to the axis of rotation. The authors proposed that their results did reflect a normalisation process, but were indicative of the processes of interpolation or linear combination, as supported by the multiple views account of object recognition (e.g. Bülthoff & Edelman, 1992; Tarr & Pinker, 1989).

Moreover, Christou and Bülthoff (2000) have argued that the recognition of a depth rotated object may be achieved either by transformation of an object in memory, or by transformation on the current contents of perceptual experience. It is suggested that a realistic environmental context can provide additional depth cues by which metric aspects of an object's shape could be scaled (Christou, Tjan & Bülthoff,

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[7] The target is seen several minutes after the prime and following intervening items.

1999). The authors proposed that a visual background facilitated object recognition, by providing an implicit specification of the observer's viewing position relative to the environment, and relative to the object.

In Christou et al.'s (1999) computer simulation study, participants were able to rotate themselves around objects, reducing structural ambiguities caused by the accidental occlusion of parts, and hence, reducing depth underestimation. Participants were trained on a familiar view and then tested on all directions around the objects. As with Edelman and Bülthoff (1992), error rates were found to be dependent upon angular displacement from the familiar view. Poorest performance was at 90° depth rotation. Having the background in view during identification reduced errors significantly, although, consistent with Humphrey and Jolicoeur (1993) and Edelman and Bülthoff (1992), errors were attenuated, not eliminated. It was concluded that the scene provided additional depth cues, or was used to specify a spatial frame of reference employed in recognition.

Based on the above-chance performance for some novel views in scene recognition, however, Christou and Bülthoff (2000) proposed that: (a) two-dimensional retinal images do not form the basis of representation; (b) perception is not always analytical; and (c) not only experienced views are stored in memory. On the other hand, the authors argued, as indicated by the viewpoint-dependency of the results, that recognition is considerably dependent upon what is experienced. This view is consistent with Tarr and

Pinker's (1989) proposal, in that long term storage of an oriented object depends on the frequency of encounter with that particular view of the object.

In support of theories proposing that objects are represented in sets of viewpoint-dependent images, Zourtzi and Shiffrar (1999) also proposed that novel views of depth rotating objects can be recognised, even when a new part is revealed. The authors used motion to integrate dissimilar object views across large rotational changes. It was argued that motion, whether it be of the object or the observer, facilitated recognition of depth rotated objects, even when visible structures changed dramatically (Christou & Bülthoff, 2000; Zourtzi & Shiffrar, 1999).

Recently, Riesenhuber and Poggio (1998) developed a view-dependent, neural network model of object recognition, whereby each selective unit is broadly tuned to a particular view of an object. The optimal view is the centre of this 'view-tuned unit', and the researchers suggested that this could be considered a template for input comparison. When a stimulus is identical to its template, the unit is maximally excited, but it also responds proportionally less to similar stimuli. A crucial component of this model is the cortical mechanism, used to provide the sum of afferents to a cell, or enable the activation of the strongest one alone.

Riesenhuber and Poggio's (1999) later model of object recognition is based on units showing the same invariance properties as view-tuned, inferotemporal neurons (Logothetis, Pauls & Poggio, 1995). A signal processing technique selects the peak of the correlation between the signal

and a given matched filter. Learning from multiple examples, represented by view-tuned units, leads to view-invariant units. The notion being, that interpolation and generalisation is learned by simple networks, which combine cell outputs, each broadly tuned to the features[8] in an example image. Invariance to rotation in depth is obtained by the combination of several view-tuned units tuned to different views of the same objects (Poggio & Edelman, 1990).

Recently, a viewpoint-dependent model of object recognition has been proposed by Edelman and Intrator (2000). The Chorus of Fragments (CoF) is a holistic model which combines shape - 'what', and location - 'where' information within the same representational units. CoF is based upon the Chorus of Prototpyes, appearance-, or view-based model of Duvdevani-Bar and Edelman (1999). In this model novel views of an object are recognised by interpolating its 'view space' from a few stored views (e.g. Poggio & Edelman, 1990). The view space of an object is the manifold, formed within the measurement space, as the object undergoes rotational viewpoint transformation. CoF (Edelman & Intrator, 2000) represents an object by a collection of fragments, which are data driven and roughly positioned. It is proposed that spatial location may be coarsely coded by a population of widely tuned, overlapping receptive fields (see Tanaka, 2000). It is argued

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[8] The Riesenhuber and Poggio (1999) model departed from templates in favour of list of scale and translationally invariant features (Hummel, 2001).

that the pattern of activity across such units – a chorus of fragments – would suffice in specifying 'what', as well as 'where' objects are located.

Similar suggestions have been proposed by Burl, Weber and Perona (1998), who have developed a computer-vision model whereby 'local photometry' (i.e. templates for small snippets of images) and 'global geometry' (i.e. the quantification of spatial relations between primitives) are combined. Camps, Huang and Kanungo (1998) also represent objects as appearance-based parts, and their approximate relations. It is argued that coarsely defined local shape, and approximate location information, lead to robust algorithms supporting recognition.

Edelman and Intrator (2000) concur that the CoF model is, to some extent, compositional[9]. Edelman and Intrator (2003), however, proposed that it differs from structural descriptions approaches in three ways, those being that: (1) shape primitives in CoF represent fragments of object images, not generic parts (cf. Biederman, 1987, geons), where fragments are construed as a graded quality, not as all or nothing events. Hence, the acquisition of fragments, and their detection, become computationally manageable; (2) spatial relations are continuous and coarsely coded (i.e. representing each fragment in terms of its similarities to some basis shapes); and (3) primitives are 'naturally' bound to each other by virtue of residing in their proper places

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[9] Objects composed of a small number of generic parts conjoined by universally applicable categorical relations (e.g. Hummel, 2000).

in the visual field, not imposed by an external mechanism (cf. "dynamic" and "static" binding, Stankiewicz & Hummel, 2002).

As proposed, viewpoint-independent research has argued that all views of an object access the same, view-invariant stored structural description (e.g. Marr, 1982). By this theory, however, it was argued that when there were difficulties in assigning the main axis of elongation, decrements in performance would be observed. Similarly, it was proposed that some, but not all, depth rotations would cause problems for GSDs (Hummel & Biederman, 1992). In the case of extreme depth rotations, it is argued that performance costs would, indeed, be incurred (Hummel, 2001). For example, and taking the earlier example of a mug, the authors suggest that if the handle should disappear behind the body, that is, a geon becomes occluded, or if the mug is viewed end-on, making it impossible to perceive the shapes of the parts, recognition would be disrupted (e.g. Biederman, 1987; Hummel and Biederman, 1992). Biederman (1987) suggested that depth rotation does, in fact, alter GSDs, both by occlusion and accretion, and hence, different GSDs would be required for substantially different views.

In this manner, Biederman and Gerhardstein (1993) claimed that view-invariancy in depth rotated stimuli was dependent upon three conditions, that: (1) geons are readily identifiable; (2) each view of an object yields GSDs; and (3) each object is specified by a unique arrangement of geons.

Pizlo and Stevenson (1999), in support of GSD theory, demonstrated that small changes in orientation do not produce large topological changes in

the image. The authors proposed that geons give rise to topologically stable

retinal images, and geon shapes involve the constant of symmetry, which is

present in most objects from our natural environment.

In this respect, Biederman (2000) proposed that much of the stimuli

employed by viewpoint-dependent researchers (e.g. Bülthoff & Edelman,

1992; Cutzu & Edelman, 1992, 1994; Rock & Di Vita, 1987) are

unrepresentative of objects recognised in everyday life. Biederman (2000)

argued that stimuli (e.g. bent paperclips) lack symmetry and other regularities

(see Biederman, 1987), have no extended surfaces (see Marr & Nishihara,

1978), and are very similar in part structure and first order relations (see

Biedrman & Gerhardstein, 1993). In addition, Biederman (2000) argues that

the view-specific effects found in priming studies (e.g. Hayward & Tarr,

1997; Lawson & Humphreys, 1996, 1998; Srinivas, 1993), may not reflect

stored representations used in everyday recognition. It is contended that

information in a short term memory store may produce view-specific

priming, in that the prime precedes the target by only a few seconds, and

there is no intervening stimuli between prime and target (but see Srinivas,

1995).

In response to criticisms aimed at the stimuli employed by viewpoint-

dependent research, Biederman and Gerhardstein (1993) demonstrated that

distinctive non-accidental properties – on which GSDs are reliant - are

enormously beneficial in matching two bent paperclips from two different

depth orientations (45° apart). It was found that the substitution of one

different geon, in a set of ten line drawings of such stimuli, dramatically reduced rotation cost. The authors contended that prior to this geon addition, error rates were so high as to make interpretation of reaction times virtually impossible. It was argued that in the absence of distinguishing GSDs, the critical information for everyday shape recognition was missing and hence, the use of such stimuli were an inappropriate test of viewpoint-variance or invariance.

Biederman (2000) proposed that GSDs were insensitive to exact length or width of an objects (i.e. the metric properties), and to a large extent, therefore, unaffected by depth rotation. On the contrary, it is argued that metric properties (e.g. aspect ratios or angles between parts) do vary with depth misorientation, and produce enormous rotational costs. For example, Biederman and Bar (1999) investigated depth rotation costs, for detecting both non accidental property (i.e. geon) changes, and detecting metric property changes. The authors found that participants matching a sequential pair of novel objects, where there were geon differences, resulted in an increase in error rates of 3.3%. When the same task was performed, where differences in stimuli involved metric properties, a huge increase in error rates was demonstrated (46.2%). Different rotational costs were found for metric properties and geons, even though both changes were selected to be equally discriminable at the optimal/canonical orientation and at depth rotation (as assessed by reaction times and error rates). It was argued that the benefit conferred by non accidental properties, compared to metric properties, was

dramatic (Biederman & Bar, 1999; Biederman & Gerhardstein, 1993). Similarly to Tarr, Bülthoff, Zabinski and Blanz (1997) and Logothetis et al. (1995), the authors concluded that distinctive geon structural descriptions provided an immediate and extraordinary large advantage for recognition.

In concurrence, Hummel (2000) proposed that mental representations are highly structured, and the understanding of how they are structured is imperative to any object recognition model. In support of this notion, to some degree, Marcus (1998) demonstrated that connectionist networks, where all knowledge is represented holistically, as simple feature vectors, were unable to generalise beyond their training space – there always being some inferences that were impossible for the network.

In summary, it is proposed that studies demonstrating a lack of shape constancy in depth rotation, provide strong evidence for the involvement of viewpoint-dependent representations in recognition (Lawson, 1999), and view-based theorists argue that evidence for the advantages of canonical views, poses a problem for viewpoint-independent theorists. Viewpoint-independent theorists (e.g. Biederman, 2000; Biederman & Bar, 1999; Biederman & Cooper, 1992; Biederman & Gerhardstein, 1993; Hummel & Biederman, 1992; Hummel & Stankiewicz, 1996, 1998; Pizlo & Stevenson, 1999) agree that there are, in certain instances, costs in recognising depth rotated stimuli. It is argued, however, that the small costs in the presence of distinctive GSDs, and the large costs in novel view recognition, in the

absence of distinctive GSDs, are representative of their importance in human object recognition.

Clearly, there is diversity in the theoretical accounts of the achievement of visual object constancy across depth rotations, and Biederman (2000) suggested that the theories accounting for depth rotational effect in object recognition are "controversial" (pp. 241). The use of both novel and familiar stimuli have resulted in inconsistent and contradictory data (Pizlo & Stevenson, 1999). Neurophysiological evidence from single-cell recording and neuropsychological evidence from brain-damaged individuals have proven fruitful in this respect.

The neurobiology of object constancy across depth rotation

Logothetis et al. (1995) trained monkeys to perform object recognition with isolated views of novel objects (i.e. paperclips). The authors found that cells in the inferotemporal cortex[10] demonstrated tight tuning to a specific view of one of the training objects. As with earlier results, however, (e.g. Poggio & Edelman, 1990), some of the units showed greater tolerance, and although viewpoint-invariant neurons were also present, Logothetis et al. (1995) found these to be fewer in number. Moreover, functional magnetic resonance imaging (fMRI) data have shown a similar pattern of invariance properties in this area of the human cortex (e.g. Grill-Spectar, Kourtzi &

Kanwisher, 2001; Tanaka, 1996). It was argued that transformation in the image-plane requires training on a single object view (Riesenhuber & Poggio, 2000), but training on multiple views is generally required to recognise objects rotated in depth (Riesenhuber & Poggio, 2002).

Tanaka (2000) proposed that while the image of an object projected onto the retina changes due to depth rotation, the global outputs from TE[11] in the monkey brain, change little. The author proposed that the clustering of cells, which have slightly differing, and somewhat overlapping, selectivities, work as a buffer to absorb changes. It is argued that the responses of single cells in TE tolerate a certain amount of change in orientation aspect and size, but are insufficient to explain the wide range of flexibility of object recognition. Tanaka (2000) argues that there is a continuous mapping of features/parts within columnar cortical units. The mapped features provide a structural basis on which to conduct computations. Such computations, based on local neuronal connections between the cells representing related, but different features, may serve to translate/transform the image of a an object for three-dimensional rotations.

On the other hand, in order to determine the tuning of cells in the inferotemporal cortex of the macaque monkey, Vogels, Biederman, Bar and Lorincz (2001) investigated the salience of non accidental property and metric property differences in object discrimination. Identical stimuli to that

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The homologue of the monkey inferotemporal cortex in the human visual cortex is the lateral occipital cortex.

used by Biederman and Bar (1999), were presented at two different orientations in depth. Results demonstrated that a significant proportion of the neural code of inferotemporal cells represent differences in non accidental properties, as opposed to differences in metric properties, and it was proposed that this neural code enables the spontaneous recognition of novel objects at new views (Vogels et al., 2001).

As discussed, foreshortened views of objects have been found to impair object recognition in brain-damaged patients (Humphreys & Riddoch, 1984; Kosslyn et al., 1994; Layman & Greene, 1988; Warrington & James, 1988; Warrington & Taylor, 1973, 1978).

Warrington and colleagues (Warrington and James, 1988; Warrington and Taylor, 1973, 1978) tested right lesioned patients and found selective impairment in the recognition of depth rotated objects. Warrington and Taylor (1973, 1978) hypothesised that object recognition involved two dissociable processes. Perceptual categorisation (including object constancy) involved right hemisphere processing and semantic categorisation, involving mainly left hemisphere processing. It was proposed that if right hemisphere perceptual categorisation were impaired, patients had no difficulty in recognising canonical views. However, it was suggested that these patients would find difficulty in recognising depth rotated stimuli. This hypothesis

was also supported by Rudge and Warrington (1991) and Warrington and James (1988).

As suggested, evidence for multiple routes across depth rotation also came from Humphreys and Riddoch (1984). Findings led the authors to propose an independent, global shape, axis-based route for the recognition of objects with a foreshortened principal axis. It was also suggested that the problem with such patients reflected a reduced salience of the main axis of elongation, which led them to impose and incorrect two-dimensional, rather than three-dimensional structure on such images. In concurrence with Christou et al. (1999), Edelman and Bülthoff (1992), Farah et al. (1994) and Humphrey and Jolicoeur (1993), it was found that the addition of linear perspective cues improved recognition.

Sugio et al. (1999) used fMRI to investigate non-canonical views, where both the major axis was foreshortened and discriminative parts were occluded, making GSDs difficult to derive. Two regions were found to be more deeply involved in recognition from non-canonical views, being the ventral part of the premotor area and the posterior parietal cortex (including the superior parietal lobule). The authors proposed that shape information was processed in the posterior temporal (ventral) area and transmitted to the superior parietal lobule and premotor (dorsal) areas, for visuospatial, and sensorimotor processing respectively. It was also proposed that functional knowledge from the dorsal stream, was utilised to access canonical object representations from depth-rotated views of objects.

In support of this finding, Grafton, Fadiga, Arbib and Rizzolatti (1997) showed that brain activity in the ventral region of the premotor cortex is related to the observation of 'graspable' objects without any overt motor response (see also Sakata & Taira, 1994; Riddoch &Humphreys, 1987).

In summary, consistent with neuropsychological evidence, image-based and GSD theorists present strong neurophysiological evidence (e.g. Grafton et al., 1997; Sugio et al., 1999; Tanaka, 2000, 2001; Vogels et al., 2001), for the viewpoint-dependence and viewpoint-independence of object recognition across depth rotation. In accordance with this view, the latest view-based models (e.g. Edelman & Intrator, 2000) and structural description models (e.g. Stankiewicz & Hummel, 2002), represent hybrids encompassing both approaches to object recognition.

The achievement of object constancy via the extraction of distinctive features

As stated, the prominent approaches to explain how the human visual system achieves object constancy revolve around whether mechanisms involved are orientation-specific or orientation-invariant. This section addresses object recognition with particular reference to the extraction of distinctive object features by the visual system.

In many cases, as detailed, it has been demonstrated that the time required to recognise picture plane rotated objects increases with

misorientation from their canonical orientation (e.g. Bülthoff & Edelman, 1992;
Edelman & Bülthoff, 1992; Humphrey & Khan, 1992; Jolicoeur, 1985, 1988,
1990; Jolicoeur et al., 1998; Jolicoeur & Milliken, 1989; Jolicoeur et al., 1987;
McMullen & Jolicoeur, 1990; Murray, 1995, 1997; Murray et al., 1993; Rock,
1956, 1973; Rock & DiVita, 1987; Rock et al., 1981; Rock & Heimer, 1957; Rock
& Nijhawan, 1989; Rock et al. 1989; Shepard & Cooper, 1992; Shepard &
Metzler, 1971; Tarr, 1995; Tarr & Pinker, 1989, 1990). Similarly, increasing
depth rotation, producing foreshortening of the principal axis, also increases
naming latencies (Hayward & Tarr, 1997; Humphrey & Jolicoeur, 1993; Lawson
& Humphreys, 1996, 1998, 1999; Newell & Findlay, 1997; Srinivas, 1993, 1995).

As both two-dimensional and three-dimensional rotation produce strong
effects on reaction times and errors, object recognition is considered by the above
researchers to operate on viewpoint-dependent internal representations, and to
involve some form of transformation process (e.g. mental rotation). It has also
been argued that these viewpoint-dependent orientation effects reduce with
practice (Lawson et al., 2000).

It has been proposed, on the other hand, that the reduction in picture plane
rotation effects with practice may represent the retrieval of orientation-invariant
features (e.g. Corballis et al., 1985; Corballis et al., 1978; Eley, 1982; Jolicoeur,
1985, 1988, 1990; Jolicoeur & Milliken 1989; Lawson et al., 2000; Maki, 1986;
McMullen & Jolicoeur, 1990; Young et al., 1980).

Corballis and colleagues generally used a reaction time paradigm, together with a small, letter/digit stimulus set which was presented multiple times to each subject. Although the authors found one significant orientation effect (Corballis et al., 1978), in the majority of cases, the data from these experiments indicated that the effects of orientation on identification time were slight or non existent. As a result, therefore, it was proposed that the human visual systems identifies objects, not in a viewpoint-dependent manner, but by their distinctive features, in a viewpoint-independent manner.

Jolicoeur et al. (1987), however, demonstrated that even for stimuli as simple as those used by Corballis and colleagues (1978, 1985), identification does vary systematically with plane misorientation from the canonical view, and reaction time does reduce with practice. In this experiment recognition time was recorded under unlimited viewing conditions, and in contrast to the former studies, did not involve multiple presentation of a small set of stimuli.

Further evidence for the orientation-specificity of recognition with letter and digit stimuli was demonstrated by Jolicoeur and Landau (1984). The dependent measure in this experiment, however, was error rate, and stimuli were masked immediately after brief exposure. It was found that error rates increased monotonically with rotations from 0^0 to 180^0, but contrary to the findings of Jolicoeur et al. (1987), these effects did not reduce with practice. It was argued that brief, masked presentations made it difficult to encode both the features of the stimuli, and the spatial relations between the same. The proposal being that under these particular circumstances,

subjects were forced to rely on a feature extraction strategy from commencement of trials, which resulted in no change in error rates across trials (Jolicoeur & Humphrey, 1998).

As suggested, the anomalous findings of such studies led Jolicoeur (1990) to propose two functionally distinct routes to object recognition. One of which relies on orientation-specific representation plus normalization, and another which is dependent on orientation-invariant, feature-based mechanisms.

Correspondingly, Lawson and Jolicoeur (1998) suggested that when distinguishable objects are presented many times, subjects may learn feature extraction efficiently. Under extreme conditions, for example, when objects are presented briefly and then masked (cf. Corballis et al., 1985, 1978; Jolicoeur et al., 1987), subjects may be forced to rely on orientation-invariant features. The authors argued, however, that the extraction of such features is unlikely to be effective in achieving object constancy in all situations (Lawson, 1999).

Consistent with Lawson and colleagues (2000), Leder and Bruce's (1998) work on face recognition also proposed that the spatial relations between local distinguishing features may be more difficult to extract for plane rotated views, and this explained increased response latencies. Similarly, Dickerson and Humphreys (1999), proposed that viewpoint-independent features may be employed in such recognition, but that spatial relations between features are not necessarily computed.

As discussed previously, unlike plane rotation, depth rotation results in the spatial relations between features altering, feature deletion and accretion, and distortion of the global outline shape. These changes alter retinal images and this is particularly noticeable when and object's principal axis of elongation is foreshortened (Lawson & Humphreys, 1998). The authors also argued that a search for individual, distinctive features may not support the derivation of three-dimensional object descriptions. Lawson and Humphreys (1998) proposed that only when one cannot utilise configural (e.g. axis-based) information, for example with depth rotated stimuli, are individual features utilised to identify objects.

In this connection, Humphrey and Jolicoeur (1993) produced a series of line drawings in which all the major features and parts were visible in two foreshortened views (45^0 and 80^0) of common objects. Despite the availability of the major features, 45^0 views were identified faster than 80^0 views. Results suggested that foreshortening effects occurred due to difficulty in locating the principal axis of elongation, as opposed to difficulty in determining major features.

The degree to which features drive viewpoint-independent representations during object recognition was also examined by Tarr and Pinker (1990). The authors, in agreement with Lawson et al. (2000), proposed that the visual system typically describes objects using viewpoint-dependent representations, and that viewpoint-independent representations are employed by the system to code featural information purely along a

single axis or dimension. For example, it is contended that symmetrical objects can be distinguished by the relative position of parts along the vertical axis and, therefore, viewpoint-independent mechanisms are employed. On the other hand, when objects are specified by the arrangement of features along two or more dimensions, Tarr and Pinker (1990) proposed that view-dependent representations are employed and individuals normalise misoriented stimuli to align the image with representations in long-term memory. For example, asymmetrical objects can only be distinguished from each other by describing the relative position of parts along both the vertical and horizontal axes simultaneously, and it is argued that this requires viewpoint-dependent representations.

Evidence suggests that strategic processes can also determine the degree to which misoriented object recognition is mediated by distinctive feature extraction. Takano (1989) asked participants to recognise line drawings of novel objects at various orientations. The objects contained orientation-invariant local features that could be used for recognition. The author found response latencies increased with orientation when subjects were unaware of this local feature. When instructed to look for this diagnostic feature, however, response times yielded no effect of stimulus orientation. These results suggested that top-down information had influenced the ability to recognise orientation-invariant local features.

Similarly, Wilson and Farah (2003) demonstrated that plane misorientation effects on reaction time were large, even when the requisite

features were present. It was argued that viewpoint-invariant representations were not, therefore, automatically summoned for object recognition. Further, in support of Tarr and Pinker (1990), the authors also found that subjects effectively employed viewpoint-independent representations to recognise symmetrical objects and conversely, response times for asymmetrical objects were strongly dependent on object orientation. Extending the work of Tarr and Pinker (1990), Wilson and Farah (2003) found that bottom-up stimulus features and top-down control processes (cf. Takano, 1989), jointly determined when the visual system employs orientation-invariant feature-based representations.

The neurobiology of object constancy via the extraction of distinctive features

As previously suggested, neuropsychological evidence has proposed that the errors made by UVD patients (Warrington & Taylor, 1973, 1978) may be related to an inability to mentally rotate stimuli, a difficulty in extracting the principal axis of elongation, or due to there being critical features of the stimuli occluded. In this connection, Warrington and James (1986) extended the unusual views task of Warrington and Taylor (1973, 1978) in examining the recognition of three-dimensional silhouettes of familiar objects. In this task it was demonstrated that patients, compared to controls, required a greater degree of rotation away from the foreshortened

view to recognise an object. However, the authors argued against an axis-based theory of object recognition (e.g. Marr, 1982), as recognition was not found to be uniformly related the availability of the main axis of an object (cf. Willems & Wagemans, 2001). Conversely, Warrington and James (1986) argued that objects are recognised by identifying distinctive features, and that subjects used the same features, given a particular stimuli rotating about a given axis.

In a similar study, Warrington and James (1991) presented two-dimensional silhouettes of real and nonsense objects to right lesioned patients. It was found that patients were impaired at selecting real from nonsense object silhouettes. Results from the earlier and later experiments, in accordance with the findings of Lawson and Humphreys (1999), suggested that these patients had specific difficulties in achieving object constancy for silhouettes due to their lack of internal features (Lawson, 1999).

This suggestion was further investigated by Humphreys and Riddoch (1984) and Riddoch and Humphreys (1987), who described a patient who showed deficits in recognising overlapping line drawings and briefly presented stimuli. However, the patient was better able to identify silhouettes than line drawings of objects. The authors suggested that the patient was impaired at integrating local information into global descriptions, and that his reliance on serial processing resulted in difficulties with briefly presented or overlapping stimuli. It was proposed that the presentation of silhouettes improved his performance due to the lack of internal detail

requiring segmentation. More recently, Butter and Trobe (1994) attained similar results with another agnosic patient.

Humphreys and Riddoch's (1984) patient also showed deficits in recognizing objects from unusual views and matching objects in different viewing positions. Even when the main axis of the objects was preserved, the patient was most impaired when the saliency of diagnostic features was reduced. Conversely, he was adept at matching usual with foreshortened views of objects, if the latter preserved the diagnostic features. It was contended that object constancy was achieved by encoding the presence of distinctive local features in an non-retinotopic manner, in order that feature representations would be matched, even when seen from different views.

An independent feature-based route for object constancy was also proposed by Kosslyn et al. (1994), who suggested that dorsolateral prefrontal areas were strongly activated when searching for distinctive properties or features of objects. However, Sugio et al. (1999) argued that having been given the names of the objects in advance, subjects were aware of the distinctive properties for which they were to search. Nevertheless, controlling for this, and in support of Kosslyn et al. (1994), the authors also demonstrated frontal activation in a search for distinguishing features. In Sugio et al.'s (1999) estimation, frontal activation was mediated by functional properties of objects, and that specific features, for example the handle on a cup, may be considered critical for object recognition.

In a recent PET study, Harris et al. (2001) also reported a dissociation in an Alzheimer's patient, whose temporal lobe function was intact. This individual was unable to determine the orientation of rotated objects, but had preserved recognition for the same upright (and inverted) objects[12]. The authors proposed that the patient relied on orientation-invariant, salient features for recognition, which may be mediated in the ventral stream, and that his deficits reflected a failure of an axis finding mechanism, which, it was proposed, may be mediated in the dorsal stream.

Physiological data also elucidate on the question of critical features in object recognition and show that the cells in the inferotemporal cortex, considered the final purely visual stage of the ventral pathway, project to various brain area, including the prefrontal cortex. It is reported that such cells selectively respond to complex visual object features, with those responding to similar features organised in a columnar fashion, which is elongated vertical to the cortical surface. It is suggested that such columns may be regarded as units for descriptions of object features, but each column also represents variety within a group of features (Tanaka, 2003). The author proposed that this variety in selectivity allows the visual system to achieve precise representation in the discrimination of objects, and also allows object recognition invariance to certain viewing conditions.

The authors concur, however, that due to the widespread degenerative changes in Alzheimer's disease, it is difficult to draw any firm conclusions out exact lesion location in such patients.

Tanaka (2003) further suggested that activation of cells is transmitted to other cells within a column, and to nearby columns that represent related features, through excitatory connections. It was also hypothesised that subtle differences in stimuli can be emphasised by either cell mutual inhibition, or inhibition under top-down control processes in the prefrontal cortex.

Tsunoda, Yamane, Nishizaki and Tanifuji (2001) also studied activation of the inferotemporal cortex by object images, and by features included in the object images. The authors found that the image of an object activated several areas and a feature contained in the object image, activated a subset of these areas. Findings were consistent with the proposal that different areas are activated by different features contained in the object image. Activation by a feature, however, often included new areas that had not been activated by the whole object image. It was revealed that cells within these areas were activated by a single feature, and inhibited by another feature in the whole object image. Findings indicated that stimulus selectivity of inferotemporal columns needed to be described by both the features that suppress activation, and the simplest feature for maximum activation. Tanaka (2003) proposed that this complexity in cell selectivity may aid in reducing erroneous detection. Similarly, Yamane, Tsunoda, Matumoto, Phillips and Tanifuji (2001) found that some of the columns were activated by a global feature of the image, and were more sensitive to the global arrangement of object parts than to the local features.

There is evidence which demonstrates that the ventral visual system is capable of developing neurons that respond with position, view and size invariance to objects or faces (Desimone, 1991; Logothetis et al., 1995; Rolls, 1992, 2000; Tanaka, 1996; Tanaka, Saito, Fukada & Moriya, 1991). In this respect, Stringer and Rolls (2002) proposed the neural network model, VisNet, is closely tied to the hierarchical nature of the cortical visual system and is able to use the knowledge of how features of objects transform, as the object is rotated in depth.

VisNet is a four-layered feedforward network of the primate ventral visual system. These layers correspond to V2, V4, the posterior and the anterior of the inferior temporal cortices. Within the layers there is graded, as opposed to winner-takes-all, competition between neurons (Rolls, 1992, 2000). Stringer and Rolls (2002) have proposed that VisNet is able to solve the problem of recognising depth rotated stimuli by forming viewpoint-invariant representations. As the features of such objects undergo geometric distortion due to perspective change, the neurons learn to respond invariantly to the transforms that the features undergo. In such feature hierarchical systems, the representations of an object are produced by the firing of feature-sensitive neurons at lower levels, which have some invariant properties (Rolls & Deco, 2002).

To summarise, it is proposed that the visibility of salient features is crucially important in object recognition (e.g. Lawson & Humphreys, 1998; Jolicoeur, 1985, 1990; Jolicoeur & Humphrey, 1998; Corballis et al., 1978,

1985). It is additionally contended, however, that orientation-invariant feature extraction may not be the first or foremost route in the achievement of object constancy (e.g. Haywood, 1998; Lawson & Jolicoeur, 1998; Lawson et al., 2000; Newell & Findlay, 1997; Tarr, 1995; Tarr & Pinker, 1989, 1990; Wilson & Farah, 2003).

In line with the cognitive literature, the neurobiological literature clearly demonstrates that the human visual system is able to employ orientation-invariant features in order to achieve object constancy (e.g. Rolls & Deco, 2002; Stringer & Rolls, 2002; Tanaka, 2003; Tsunoda et al., 2001; Yamane et al., 2001). Evidence suggests that the intact visual system uses functionally distinct local/internal features, global/axis information, a normalisation strategy and, in certain circumstances, an additional resource, outside of the ventral system, in order to recognise a misoriented object (e.g. Turnbull & colleagues, 1995, 1996, 1997, 2002).

The nature of this additional resource is yet to be established. It is apparent that when such information is unavailable, or where the system itself is damaged, as in certain neurological patients, the achievement of object constancy in the system begins to break down (e.g. Caterini et al., 2002; Farah, 1990; Harris et al., 2001; Humphreys & Riddoch, 1984; Kosslyn et al., 1990, 1994; McCarthy & Warrington, 1996; Riddoch & Humphreys. 1987; Warrington & Taylor, 1973, 1978; Warrington & James, 1986, 1991; Wilson & Farah, 2003).

Conclusion

A complete computational account of object recognition has yet to be developed (Stankiewicz & Hummel, 2002). Later models (e.g. Edelman & Intrator, 2000, Stankiewicz & Hummel, 2002) propose hybrid theories, however, which encompass both viewpoint-independent and viewpoint-dependent mechanisms within their explanation of object recognition at all levels of abstraction, and are, therefore, consistent with the neurobiological literature in proposing that both viewpoint-dependent and viewpoint-independent mechanisms appear to be involved in visual object recognition.

In this chapter, two important questions have been addressed: 1) Is object recognition achieved by viewpoint-dependent or viewpoint-independent mechanisms; and 2) Which neuroanatomical areas are involved in object recognition? The literature demonstrates that a great deal of effort has been expended in answering these questions, although there remains ambiguity as to the mechanisms and the neural substrates involved in different forms of non-optimal view recognition. Thus, the present study will focus on the question of the mechanisms underlying non-optimal view recognition.

Clearly, object constancy is an extremely complex psychological ability, which involves contributions from several cognitive systems and different areas of extrastriate visual cortex (e.g. Kosslyn et al., 1990, 1994). There is strong neurobiological evidence that areas outside of the classical

object recognition (ventral) system are employed in non-optimal view recognition (e.g. Caterini et al., 2002; Duhamel et al., 1992; Faillenot et al., 1999; Grafton et al., 1997; Sakata & Taira, 1994; Sakata et al., 1997; Sugio et al., 1999; Turnbull et al., 1995, 1996, 1997a, b). It has been suggested that non-optimal view recognition involves a substantial problem-solving component (Farah, 1990), which may involve the intentional and effortful engaging of an additional/executive resource (e.g. Turnbull & colleagues, 1995, 1996, 1997). Additionally, certain patients with frontal lesions have shown a non-optimal views deficit (e.g. Turnbull & McCarthy, 1996).

In this respect, it is proposed that an account of working memory by Baddeley (1986) appears to provide a theoretical framework for an 'executive' processor, thought to have its substrate primarily in the frontal cortex, involved in non-optimal view recognition. Indeed, several neuroimaging findings (e.g. Grafton et al., 1997; Kosslyn et al., 1990, 1994; Sugio et al., 1999) add support for such an hypothesis, in that recognition from non-optimal, as opposed to optimal views, elicits activation in the frontal cortex (together with other areas of extrastriate cortex). Relevant literature on the central executive and working memory is outlined in the following chapter, as part of the general methodology employed in the present study.

The present study

The main aim of this research is to examine the contribution of the central executive of working memory in object recognition. The primary question is whether executive resources are involved in non-optimal view recognition, but not in optimal view recognition? The present study will use of the "dual task" paradigm, employing a central executive secondary task, in an attempt to selectively disrupt executive resources, during an object recognition task. An executive contribution to non-optimal view recognition, using a dual task methodology, has not, to the author's knowledge, previously been attempted. The following chapters will describe a series of twelve experiments.

Chapter 2 outlines some of the studies in the working memory literature, with particular reference to the use of the dual task paradigm, to be employed in 11 experiments in the study. Additionally, this chapter outlines the general methodology used in all of the experiments.

Chapter 3 describes four experiments. One aim of the chapter was to determine that the dual task method was a appropriate instrument in the investigation of object recognition. Additionally, this chapter was concerned with the designing of a suitable primary, and central executive secondary task.

Two experiments in Chapter 4 investigate the effects of a central executive secondary task on two important problems in object recognition: the recognition of picture plane rotated, and minimal features, stimuli.

Chapter 5 examines the effects of a central executive task on subordinate, as well as basic, levels of object categorisation, using depth plane rotated, and minimal features, stimuli.

Chapter 6 reports a new paradigm developed to investigate the component parts of central executive functioning, which may contribute more directly to non-optimal view recognition.

The final chapter discusses the main findings of the study. Results are discussed in the context of the cognitive and neurobiological literature. This chapter also identifies issues that require further clarification, and makes suggestions for future research.

CHAPTER 2: METHOD: WORKING

MEMORY AND THE DUAL TASK PROCEDURE

Rationale for use of the dual task technique

Almost all of the investigations in the present study (Experiments 2 – 12) are based on the dual task paradigm, as employed in the "working memory" literature. Thus, it is appropriate to review its origin and use in the working memory field, as a part of the study's method.

Models of working memory: The "componential" nature of working memory processes are currently understood in the context of Baddeley's (1986) model. The concept of Baddeley's (1986) executive processor is best examined in the context of the earlier "modal model" of short-term memory proposed by Atkinson and Shiffrin (1968). In 1968 Atkinson and Shiffrin attempted to develop the idea of control processes in primary memory by introducing the concept of a complex, short-term memory system as an active working buffer, incorporating both a processing and a storage capacity. An important prediction of the modal model was that combining the two processes, storage and processing, would prove difficult. Baddeley and Hitch (1974) endeavoured to systematically investigate this problem by requesting participants to retain a sequence of digits, whilst concurrently performing a syntactic reasoning task. Data suggested that this was indeed

possible, and led to the authors' conception of working memory as a coherent set of specialised functions.

The original limited-capacity, multi-component model (Baddeley & Hitch, 1974) consisted of a central controlling mechanism, the central executive, and two slave subsystems, the phonological loop and the visuospatial sketchpad (see Figure 1.7). The latter two components being involved in the processing and temporary maintenance of information within a particular domain, namely verbally encoded material and visual and/or spatial material respectively.[13]

Empirical support for the tripartite model is abundant, and is evidenced, for example, in the differential rates of developmental change observed in children (Hitch, 1990), the selective impairments and sparing in brain-damaged patients (e.g. Della Sala & Logie, 1993) and, of importance in this study, the selective interference effects found in normal adults demonstrated by use of the influential dual task paradigm (e.g. Logie, 1995). (Dual task methodology is discussed in detail under the section on the central executive as controller and co-ordinator of the slave subsystems).

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[13] After 25 years, a fourth component to the working memory model, was proposed by Baddeley (2000). The need for this component, the "episodic buffer", stemmed from the need to integrate information from the phonological loop and the visuospatial sketchpad. Baddeley (in press) contends that the episodic buffer represents a storage system, which combines information from long-term memory with that from the slave systems. It is proposed that the buffer fulfils certain functions originally assigned to the central executive by Baddeley and Hitch (1974). The episodic buffer is assumed to be purely mnemonic in character (based on episodic memory, Tulving, 1989) and it is proposed that the capacity of the episodic buffer is reflected in working memory span (Baddeley and Wilson, 2002).

Figure 1.7: **A schematic diagram of the multi-component model of working memory (derived from Baddeley & Hitch, 1974).**

The dominant approach to formulating theory in experimental psychology is to craft models of restricted scope and capability. Models strive to predict properties of behaviour in tasks that are assumed to tap specific mental faculties. Over the quarter century since the seminal paper of Baddeley and Hitch (1974), working memory research has made important theoretical advances in producing a number of well-developed models (e.g. Barnard, 1999; Cowan, 199; Ericcson & Kintsch, 1995; Kieras & Meyer, 1997; Lovett, Reder & Lebiere, 1999; Turner & Engle, 1989).

Although the models appear superficially diverse, there is broad agreement that working memory may be described as a theoretical construct, used in cognitive psychology and cognitive neuroscience, referring to the system underlying the maintenance of task-relevant information, during the performance of a cognitive task (Daneman & Carpenter, 1980). As such, working memory plays an essential role in complex cognition, including such everyday tasks as reading, calculating bills, mentally organising a journey and comparing numerous goods for purchase. In order that these tasks are successfully achieved, it is imperative that the results of several steps are

temporarily retained in mind (Miyaki & Shah, 1999). Baddeley and Logie (1999) proposed that the working memory system:

"comprises those functional components of cognition that allow humans to comprehend and mentally represent their immediate environment, to retain information about their immediate past experience, to support the acquisition of new knowledge, to solve problems, and to formulate, relate, and act on current goals" (pp.28-29).

Working memory then is involved in the moment-to-moment monitoring, processing and maintenance of information in everyday cognition.

Since formulation of the original model, it has been proposed that both the slave subsystems of working memory can be fractionated. The phonological loop into a passive phonological store (representing information in a phonological code), and an active rehearsal process (refreshing the decaying representations in the phonological store, Baddeley & Logie, 1999). This distinction has been supported by neuroimaging findings (e.g. Smith & Jonides, 1997), neuropsychological data (e.g. Vallar & Baddeley, 1984) and various classes of experimental data (e.g. Baddeley, 1986).

In the same vein, neuropsychological data (e.g. Farah et al., 1988), developmental studies (e.g. Logie & Pearson, 1997), and behavioural studies (e.g. Quinn & McConnell, 1996), have provided evidence for a dissociation between a passive "visual cache", which retains visual patterns, and an active spatially-based mechanism within the visuospatial sketchpad,

known as the "inner scribe", which retains sequences of movements (Logie &

Marchetti, 1991). Deficits in visuospatial function are frequently accompanied by

lesions of the right hemisphere or more specifically, the posterior parietal lobe near

its junction with the occipital lobe (Warrington & James, 1967). This bears close

resemblance to the lesion site Farah and colleagues (1988) recorded when

investigating mental rotation deficits, and subsequently, Turnbull et al. (1997a)

proposed that this area may be necessary for object recognition when viewpoint-

independent means of recognition (in the ventral stream) are insufficient, or for the

binding of viewpoint-dependent and viewpoint-independent information (as

reviewed under the section on picture-plane misorientation).

However, both the visuospatial sketchpad and the phonological loop are

considered slave subsystems to the controller of working memory, the central

executive.

The central executive

As briefly reviewed, the vast majority of previous research has

focussed primarily on the structure and functions of the visuospatial sketchpad

and the phonological loop, and much progress has been made in our

understanding of both the slave subsystems. However, the most complex

component of working memory, the central executive, has received very little

investigation until recent years (Baddeley, 2000). This is the component

working memory which this research aims to investigate in relation to non-optimal view recognition.

From early ablation studies in monkeys (e.g. Fuster, 1980; Mishkin, 1964), it was deduced that short-term memory was one process that appeared to be dependent on an intact prefrontal cortex, and the prefrontal cortex lies at the top of the processing hierarchy, in a position to exert executive control (Rowe & Passingham, 2001). From a neuropsychological perspective, poor judgement, planning, problem-solving and decision making are considered hallmarks of damage to the prefrontal cortex (Robbins, 2000).

It has-been postulated that there are different levels of contribution made by the prefrontal cortex to mnemonic processing. The ventrolateral prefrontal cortex being involved in processes such as active selection and comparison judgements of information held in short term memory, and the mid dorsolateral frontal cortex being involved in monitoring and manipulating information in working memory (Petrides, 1995).

Furthermore, there is plentiful evidence that disorders of executive functions are associated with injury to the frontal lobes of the brain (e.g. Roberts, Robbins & Weiskrantz, 2000; Shallice, 1982; 1988). In investigating the central executive of Baddeley and Hitch's (1974) model, D'Esposito, Detre, Alsop, Shin, Atlas and Grossman (1995) argued that the dorsolateral prefrontal cortex (and cingulate cortex) comprise part of the neuroanatomical circuit of the central executive. Postle, Berger and D'Esposito (1999) have also supported the claim that the central executive is

mediated by the prefrontal cortex. Importantly, the authors demonstrated a double dissociation between central executive processes, subserved by the prefrontal cortex, and working memory storage, subserved by the posterior parietal cortex. More recently, and of pertinence to this research, it has been shown that the prefrontal cortex appears to be involved in processes that include sustained attention to stimuli (D'Esposito, Postle and Rympa, 2000). Interestingly, the authors also argued that prefrontal cortex activity cannot be ascribed to the function of a single, unitary cognitive operation.

In this respect Collette and Van der Linden (2002) have demonstrated that different executive functions, including manipulating and updating of information, and inhibition and shifting processes, recruit various frontal areas (as well as other areas of extrastriate cortex). The authors further hypothesised that executive functions should be understood in terms of different, rather than a specific association between one area and one higher-level cognitive process (Collette & Van der Linden, 2002). Similarly, supportive evidence has recently been offered by Andrés and Van der Linden (2001), who proposed that although the frontal lobe is involved in the executive process of inhibition, other cerebral regions may also sustain executive functions. In this respect, Andrés and Van der Linden (2001), together with Carpenter, Just and Reichle (2000) and Garavan, Ross, Li and Shein (2000) suggested that executive functions implicate a distributed set of neural networks, and was uniquely placed to do so, due to the prefrontal

cortex's "supramodal" connectivity with both cortical and subcortical circuits.

One approach to investigate executive processes has been to study frontal lobe functioning, by employing commonly accepted neuropsychological frontal/executive tasks. It should be noted, however, that many tasks thought to involve executive functioning also involve many other areas of the brain (e.g. Andrés & Van der Linden, 2001;Baddeley, 1990; Collette & Van der Linden, 2002; D'Esposito et al., 2000; Postle et al., 1999). It was for this reason that Baddeley and Wilson (1986) coined the term "dysexecutive syndrome" as a functional description of a pattern of behaviour, which leaves open its anatomical underpinning.

Nonetheless, the prefrontal cortex is the brain region most significantly expanded in humans, compared to other species, and appears to be at the heart of those faculties we consider to be uniquely human, including the execution of complex cognitive behaviours (Cohen, Braver & O'Reilly, 2000). In fact, over forty years ago, it was argued that executive task control and performance monitoring were critical functions of the prefrontal cortex (Luria, 1966).

It cannot be disputed that there is a huge diversity of putative frontal functions (Rabbitt, 1997). Impairments to the frontal lobe can result in: "disturbed attention, increased distractibility, a difficulty in grasping the whole of a complicated state of affairs. . . . Well able to work along routine lines . . . (but) . . . cannot learn to master new types of task" (Rylander, 1939,

pp.20). It is argued, therefore, that the frontal lobes are implicated in the directing and redirecting of processing resources flexibly and appropriately. This, of course, may reflect varying etiology which, in many cases, involves injury to other brain regions apart from the frontal lobes, as previously mentioned (e.g. Collette, Salmon, Van der Linden et al., 1999; Goldman-Rakic, 1993; Hart & Jacobs, 1993; Lezak, 1993; Shallice, 1988). Nonetheless, however vast the diversity among published lists of frontal function, in all descriptions, activities involving the initiation of nonhabitual behaviour, the suppression/inhibition of prepotent responses, and strategic planning, are prominent (Baddeley, 1996).

In support of this view, Rezai, Andreasen, Alliger et al. (1993) used single photon emission computed tomography (SPECT) to demonstrate increased cerebral blood flow in the frontal lobes on several widely used neuropsychological tests, including The Wisconsin Card Sorting Test and the Tower of London Test. Further, PET studies have observed activation of the frontal cortex during cognitive tasks requiring foresight and planning (e.g. Corbetta, Miezin, Dobmeyer, Schulman & Peterson, 1991; Frith, Fristin, Liddle & Frackowaik. 1991). Such monitoring of brain activity offers powerful corroboration of the frontal lobes' role in executive functioning (Della Sala, Spinnler & Trivelli, 1998). The frontal lobes, therefore, have become to be seen, to a major extent, as the neural correlate for executive functioning (e.g. Baddeley, 1986; Della Sala, Gray, Spinnler & Trivelli, 1998; Shallice, 1982; 1988).

The central executive - A homunculus?

It has been proposed that in hypothesising a central control structure,

like the central executive, such a model simply postulates a Homunculus - a

small person who makes all the awkward decisions, in an unspecified

manner, that are beyond the capacity of the two slave systems. On the other

hand, such a concept has allowed for detailed research on the simpler and

more tractable slave systems. Furthermore, it allows for concentrative work

on the concept of a central controlling and regulating mechanism (Baddeley,

1996).[14]

It seems plausible, primarily, to accept the concept of a central

control structure in working memory, in order to systematically analyse the

executive functions it may perform (Baddeley, 1996). Analysis of a range of

such processes would undoubtedly add to our knowledge base, and

potentially throw light on a crucial question in memory research: that of

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It is of note that although several models of working memory explicitly postulate a central control mechanism (e.g. Baddeley & Hitch, 74; Cowan, 1995 and Turner & Engle, 1989), there are "production-system" models which do not postulate such obviously munculus-like constructs (e.g. Lovett et al., 1999; Kieras & Meyer, 1995; Newell, 1990). However, the ACT-R model of Lovett et al. 999), proposes a theory which specifies a fixed computational architecture applicable to all cognitive tasks based on the work of derson, 1993. According to this model, cognitive processing is goal-driven, but the authors do not refer to how these goals are formed the first instance. Similarly, in the Executive-Process/Interactive-Control (EPIC) model (Kieras & Meyer, 1995) it is not specified w the productions that perform executive processes are created. It could further be proposed that one critical feature of the Soar model Newell (1990) is "impasse-driven" learning, but there is no explanation of who/what detects the impasse and creates a new problem ace. In addition, Ericsson and Kintsch (1995) emphasise the importance of "retrieval structures" in the working memory performance experts, once again, however, it is not stipulated who/what carries out and encodes retrieval structures appropriate for incoming muli. It may be argued that the self-regulatory, Interactive Cognitive Subsystems (ICS) model (Barnard, 1985. Banard & Teasdale, 91) most directly avoids the central control problem. The conjecture is that autocontrol arises through reciprocal exchanges among the S subsystems, but Barnard (1999), in introducing the idea of focus of attention, does not offer a clear explanation of how this emerges om interacting subsystems, nor how it can be shifted (Kintsch, Healy, Hegarty, Pennington & Salthouse, 1999).

whether the controlling and regulating component of working memory, the

central executive, is best considered as a monolithic, unitary entity, led by a

single chairperson; or whether it should be considered as directed by an

interacting, though independent, executive committee. These issues continue

to be actively and empirically pursued by researchers in the domain of

working memory, and in recent years, the expansive work of Alan Baddeley

and Randall Engle, amongst several other leading theorists on executive

functioning (e.g. Andrés & Van der Linden, 2001; Carpenter et al., 2000;

Collette & Van der Linden, 2002; Cowan, 1999; Duncan, Burgess & Emslie,

1995; Lehto, 1996; Lovett et al., 1999; Menon, MacKenzie, Rivera & Reiss,

2002; Owen, Schneider & Duncan, 2000; Robbins, Anderson, Barker,

Bradley, Fearneyhough, Henson & Baddeley, 1996; Schneider, 1999), has

been particularly influential.

In postulating some of the functions necessary for any adequate

central executive system Baddeley and Logie (1999) identify: (a) the control

and co-ordination of the two slave systems; and (b) the capacity to focus and

switch attention. Very recently, it has been proposed that the allocation of

attentional resources represents the predominant function of executive

functioning (Baddeley & Wilson, 2002). There are, of course, other high

level cognitive functions that Baddeley and Logie (1999) proposed to be

mediated by the central executive, but these will not be discussed in any great

detail in this review. These functions are discussed below. In the first

section, the dual task paradigm is reviewed, and the second section reviews

purported central executive tasks, with particular reference to random

generation and mental arithmetic, which are of relevance to this research.

The central executive as controller and co-ordinator of the slave

subsystems

The dual task technique (Baddeley & Hitch, 1974) was originally

employed to investigate the then widely held assumption that the short-term

memory store (Atkinson & Shiffrin, 1968) acted as a temporary working

memory, that aids performance on a range of other cognitive tasks. In the

original experiment, the researchers requested subjects to perform a digit

span task, which by definition is a measure of maximum capacity for storage

of a verbal sequence, whilst simultaneously performing tasks such as reading,

comprehension and reasoning, which are assumed to be critically dependent

on working memory. If the assumption was correct, performing the

concurrent short-term memory task would lead to a significant decrease in

performance on the secondary task.

However, Baddeley and Hitch (1974) found that subjects were able to

retain a sequence of up to six digits, with minimal interference on any of the

other tasks. The authors' concluded that both storage and processing could

be performed simultaneously with little mutual interference. It was, of

course, data from this initial series of studies that led Baddeley and Hitch

(1974) to propose the multi-component working memory model and,

importantly, to explore in greater depth the influential dual task technique.

In Baddeley and Hitch's (1974) original model, the central executive

was considered to consist of a pool of general-purpose processing capacity,

available to support either control processes, or supplementary storage.

Since 1974, however, the notion of the central executive's involvement in

storage has been abandoned. Theoretically, the idea of a central controlling

system which in effect imitates the capacities of one, other or both of the

slave systems, is overly flexible and powerful to form a basis for productive

investigation (Baddeley & Logie, 1999). Making a distinction between

storage and control processes in the name of theoretical progress has been

further supported by Cowan (1999) and Engle, Kane and Tuholski (1999), as

proposed earlier. Empirically speaking, revision of Baddeley and Hitch's

(1974) original conceptions regarding the temporary storage capacity of the

central executive, has been severely challenged in recent work, and this is

discussed below.

In attempting to separate the cognitive demands of processing and

storage, Logie and Duff (1996) examined the extent to which increasing

processing demands (involving progressively more difficult arithmetic

verification) reduced performance on a storage task (involving immediate

serial recall of unrelated words). The authors demonstrated that a demanding

storage task had little effect on processing capacity, and processing had little

effect on storage capacity. Such data questions the hypothesis that

processing and storage demands compete for a single capacity resource. The authors argued that whilst serial recall involves a temporary memory store (the phonological loop), the verification task implicated executive resources (the central executive).

Similarly, Engle et al. (1999) found that manipulating the difficulty of a mental arithmetic primary task has very small effects on a concurrent mnemonic task. Further studies attempting to interfere with temporary storage, during expert performance, have also found no reliable effects (e.g. Ericsson & Kintsch, 1995).

A large body of studies, using the dual task approach, demonstrate that performance on laboratory tasks eliciting complex cognitive activities, result in a much smaller degree of interference than would be expected from a central executive with a general-purpose processing capacity. Such cognitive tasks include reasoning (e.g. Kyllonen & Christal, 1990), comprehension (e.g. Wilson & Baddeley, 1988), mental arithmetic (e.g. Logie & Duff, 1996), fluid intelligence (e.g. Kane & Engle, 1998), and the ability to solve novel problems (e.g. Duncan et al., 1995).

Hence, it would appear that skilled performance does not crucially depend on temporary storage. This conjecture is corroborated by Engle et al. (1999), who proposed that working memory is short-term memory (maintenance), plus controlled attention (executive control).

One common theme in a multiple resource theory is that there is a "cost of concurrence" (Navon & Gopher, 1979). It is proposed that when

two tasks performed together mutually interfere, they are competing for the same cognitive resource. Where they do not, they are considered to demand independent resources (Baddeley & Wilson, 1986; Della Sala & Logie, 1993; Farmer, Berman & Fletcher, 1986).

As the visuospatial sketchpad and phonological loop had been shown to be dissociable, some form of co-ordination function would appear paramount. Baddeley, Logie, Bressi, Della Sala and Spinnler (1986), therefore, proposed that if the central executive was involved in the co-ordination of the two slave systems, a central executive impairment should produce an inability to co-ordinate tasks, which involve both the visuospatial sketchpad and the phonological loop, when performed simultaneously.

In this connection, Baddeley et al. (1986) proposed that some of the difficulties experienced by Alzheimer's patients may be due to a central executive impairment. The authors demonstrated that such neurological patients performed equally as well as healthy age-matched individuals on both a visuospatial task (tracking) and a phonological loop task (digit span task), when these were performed alone. However, unlike the control group, the Alzheimer's patients showed a dramatic decrement in performance when requested to perform both tasks concurrently (Baddeley, Bressi, Della Sala, Logie & Spinnler, 1991). The authors concluded that these neurological patients were impaired in the co-ordinating function of the central executive. Subsequently, Baddeley, Della Sala, Papagno and Spinnler (1997) have

demonstrated the same deficit in a specific subsample of patients with frontal lobe damage.

The central executive as an attentional controller

As previously mentioned, the visuospatial sketchpad and the phonological loop appear to be systems specialised for the temporary storage of verbal and visuospatial material. Significantly, Rowe and Passingham (2001) used fMRI to study activations related to the maintenance of spatial items (considered a visuospatial sketchpad process) and the process of selecting between items in memory (considered a central executive process). It was demonstrated that activity related to maintenance was found in the intraparietal cortex, whereas response selection activated the dorsolateral prefrontal cortex. Similarly, Sakai, Rowe and Passingham (2002) demonstrated that this area played a critical role in sustained activity.

Effective cognition, of course, involves the ability to respond to current circumstances, not purely to be tied to those behaviours that have proved previously successful. Naturally, this capacity greatly increases the human capacity for constructive or goal-oriented behaviour, which may be modified on the basis of subsequent information (Roberts et al., 2000).

Of importance to this study, it has been proposed such non-habitual behaviour implicates executive functioning (e.g. Shallice, 1988). One

cognitive task that necessitates inhibition of the tendency to produce 'natural'

patterns is that of random sequence generation (Towse & McLachlan, 1998).

Random Generation

It has been proposed that random generation represents a prototypical

executive task, which fully extends the central executive, as it demands

concentrated effort <u>not</u> to produce well learnt responses. Indeed, there is

abundant evidence that generating random sequences is extremely complex,

which is demonstrated in the production of substantial deviation from

randomness in most data sets (e.g. Baddeley, 1966; Ginsburg & Karpiuk,

1994; Robertson, Hazlewood & Rawson, 1996; Salway, 1991; Towse, 1998;

Towse & McLachlin, 1998; Van der Linden, Breerton & Presenti, 1998;

Vandierendonck, De Vooght & Van der Goten, 1998; Wiegersma, 1982).

Importantly, random generation has been employed as a secondary

task in a large number of studies, in order to disrupt executive functioning.

For example, chess (Robbins et al., 1996), syllogistic reasoning (Gilhooly,

Logie, Wetherick & Wynn, 1993), mental arithmetic (e.g. Aschcraft, Donley,

Halas & Vakali, 1992; Logie, Gilhooly & Wynn, 1994; Menon et al., 2002;

Seitz & Schumann-Hengsteler, 2000), and the acquisition of artificial

grammar (Diennes, Broadbent & Berry, 1991). It should be noted, however,

that random generation, to some degree, also disrupts the functioning of the

phonological loop due to the continuous production of verbal outputs system (Baddeley, 1986).

Random generation may be regarded, therefore, as the "opposite" of automaticity, i.e. processes that are fast, effortless and autonomous (Shiffrin & Schneider, 1977). In contrast, controlled processes are slow, effortful and rely on attentional resources. Hence random generation demands attentional control, even after much practice. It is proposed that the cognitive demands of random generation arise from the necessity to keep track of the frequency with which individual digits/letters have been generated, and involves an active search/retrieval for candidate responses (e.g. Baddeley, 1986), and inhibition of the production of well-learned or stereotyped sequences (e.g. Towse, 1998; Towse & McLachlin, 1998; Van der Linden et al., 1998; Wiegersma, 1982)

It is in this connection that Baddeley (1986) proposed an analogy with the Supervisory Attentional System (Norman & Shallice, 1980). The Supervisory Attentional System is conceptualised as an attentional controller capable of overriding habitual response patterns in order to initiate new behaviour and hence permit flexible responding in novel situations. In agreement with this conjecture, Engle et al. (1999) consider that the central executive represents a limited capacity attentional mechanism, which is conceptually similar to what Posner and Snyder (1975) and Schneider and Shiffrin (1977) referred to as "controlled attention". Moreover, it has been

proposed that the neural system mediating attention can be localised in the

frontal lobes (e.g. Pardo, Fox & Raichle, 1991).

Leclerq, Couillet, Azouvi, Marlier, Martin, Strypstein and Rousseaux

(2000) have demonstrated that patients with prefrontal damage, showed

greater reaction time decrements than controls when performing random

generation. Lesion and imaging studies have also shown that inhibition is a

central function of the prefrontal cortex. For example, the inhibition of

perseverative behaviour (Iverson & Mishkin, 1970), the inhibition of

distracting sensory information (Chao & Knight, 1998), and specifically, the

inhibition of an inappropriate prepotent response in cognitive processes

(Jonides, Smith, Marshuetz, Koeppe & Reuter-Lorenz, 1998).

Mental arithmetic

Another attentionally demanding task, is considered to be counting

and counting backwards. Logie and Baddeley (1987) examined counting

using concurrent articulatory suppression. Articulatory suppression, or

irrelevant speech, is a technique commonly employed to disrupt the operation

of the phonological loop (Miyaki & Shah, 1999). The key finding was that

the central executive played the most important role in counting, whilst the

phonological loop played a minor role in keeping track of the running total.

Similarly, mental arithmetic appears to involve different components

of working memory (Ashcraft, 1995; Lemaire, Abdi & Fayol., 1996; Logie et

al., 1994). Whilst the phonological loop is implicated in temporary storage of partial solutions, the central executive was assumed to be the system that applies algorithms for calculation. The proposal being that the central executive is responsible for selecting and implementing calculational/computation heuristics (Baddeley, 1996).

Early studies in the field of mental arithmetic and working memory resources focussed primarily on addition (e.g. Ashcraft et al., 1992; Hitch, 1978; Logie et al., 1994), and recently on both addition and multiplication (e.g. De Rammelaere, Stuyven & Vandierendonck, 1999; Lemaire et al., 1996; Seitz & Schumann-Hengsteler, 1997). Interestingly, Seitz and Schumann-Hengsteler (2000) proposed that complex multiplication sums require central executive and phonological loop resources, whilst simple multiplication requires only executive resources.

Latterly, and of pertinence to this research, imaging studies have implicated both prefrontal and parietal cortices in the arithmetic process (e.g. Dehaene, Spelke, Pinel, Stanescu & Tsivkin, 1999; Menon, Rivera, White, Eliez, Glover & Reiss, 2000). Very recently, Menon et al. (2002) have demonstrated that the dorsolateral prefrontal cortex region is involved in overall arithmetic processing, but it is selectively involved in the processing of incorrect, as opposed to correct, responses. The authors have argued that incorrect response involve the inhibition of conflicting information, and the selection of an appropriate response. It is now accepted that the parietal cortex also plays a role in arithmetic computations, what that role is, has yet

to be fully specified. Menon et al. (2002), however, have proposed a left

parietal contribution to calculation, in the processing of correct responses.

Secondary tasks have been the prime means for analysis of working

memory's components to target tasks (e.g. Cowan, 1999; Engle et al., 1999;

Logie & Duff, 1996; Rowe & Passingham, 2001, Sakai et al., 2002; Seitz &

Schumann-Hengsteler, 2000). Concurrent articulation, for example repeating

'the the the' continuously, and concurrent spatial activity, for example

tapping in a pre-defined pattern, are seen as loading the phonological loop

and the visuospatial sketchpad, respectively. Whilst random generation and

mental arithmetic appear predominantly as secondary tasks in the

investigation of executive function.

The debate concerning precise specification of the different executive

functions continues to date. Nonetheless, those functions often mentioned

referred to are: focusing on one stream of information, whilst inhibiting a

stream of irrelevant information, alternating attention from one source to

another, and mental sets (Rogers & Mansell, 1995); active inhibition or

suppression of prepotent responses (Roberts, Hager & Heron, 1994); and

monitoring and updating the contents of working memory (Van der Linden,

Bredard & Beerten, 1994). It is not, however, suggested that those functions

referred to constitute the only functions served by the central executive. This

is a question that remains open to empirical investigation. As does the

question of whether they should be considered as separate functions or rather,

reflect different operations of a smaller number of underlying control

processes (Baddeley & Logie, 1999).

Summary

The dual task technique (Baddeley & Hitch, 1974) was originally

employed to investigate the then widely held assumption that the short-term

memory store (Atkinson & Shiffrin, 1968) acted as a temporary working

memory that aids performance on a range of other cognitive tasks. The

findings of the original experiment (Baddeley & Hitch, 1974) demonstrated

that both storage (in the form of a digit span task), and processing (in this

case reading, comprehension and reasoning), could be performed

simultaneously with little mutual interference. Data from this seminal study

initiated exploration of the influential dual task technique.

A large body of work has employed this paradigm to disrupt

executive behaviour across a range of cognitive tasks (e.g. Ashcraft et al.,

1992; Diennes et al., 1991; Gilhooly et al., 1993; Logie et al., 1994; Robbins

et al., 1996; Seitz & Schumann-Hengsteler, 2000). Where performance on

one task does not interfere with performance on the concurrent second task, it

is proposed that they demand independent resources. Alternatively, if

simultaneous execution results in impaired performance, it is considered that

the two tasks are dependent upon the same resources (e.g. Baddeley, Emslie,

Kolodny & Duncan, 1998; Baddeley & Wilson, 1986; Della Sala & Logie, 1993; Farmer et al., 1986).

The employment of dual task methodology continues to be a useful tool, and represents a reliable method of studying whether two functions rely on the same cognitive resource (Baddeley et al., 1998). The dual task technique, employed in the present study, therefore, represents an appropriate paradigm for studying whether non-optimal view, but not optimal view recognition, is dependent upon executive resources, and it is employed in a series of investigations with neurologically normal individuals.

Additionally, as already proposed, executive function may not necessarily be considered as a unitary construct, and different tests of executive function do not consistently inter-correlate to a high degree (e.g. Andrés & Van der Linden, 2000, 2001; Collette & Van der Linden, 2002; Carpenter et al., 2000; Duncan et al., 1995; Garavan et al., 2000; Lehto, 1996; Schneider, 1999). In line with recent research, as discussed earlier, it may be suggested that some components of central executive function are more directly involved in non-optimal view recognition than others. The dual task paradigm, therefore, also offers the possibility of custom-designing secondary tasks which target specific aspects of central executive function, and affords the opportunity to test this hypothesis more directly. This question is addressed in Chapter 6. To the best of the author's knowledge, no other studies have employed this procedure to selectively influence object recognition from non-optimal views. There are a number of issues which

arise when using dual task methodology, however, and these will be considered after outlining the basic experimental paradigm.

Basic experimental design for the present study

Participants

All participants were recruited from the Bangor University student pool. Each received a course credit for participation. No participants over 40, or under 18, years of age were recruited. All had normal or corrected-to-normal visual acuity, were not dyslexic by self-report, and spoke English as a first language. Each participant signed an informed consent form, and all were naive as to the purpose of the experiment, but were fully debriefed at the conclusion of the study. In all cases participants confirmed their understanding of the tasks required of them, and practice sessions corroborated this.

Apparatus

Primary Task

Testing was carried out using a Power Macintosh 4400/160 with a screen measuring 33cm by 25 cm. Stimuli were generated using the

PsyScope (Version 2.1.1) software programme. Responses were made using

keys on a QWERTY keyboard. Each picture was sized to 3.5 cm square for

presentation, subtending a visual angle of 2.7°. The font size for words was

Helvetica 48 points. Participants sat at a viewing distance of 55 cm and an

adjustable chin rest ensured that their eyes remained level with the centre of

the computer screen. All stimuli were black and presented on a white

background.

Secondary Task

Secondary tasks had an auditory input, where appropriate, and a

verbal output. Where relevant, auditory stimuli were pre-recorded on a

Steepletone Portable Cassette Recorder (SCR 805), and participants listened

to the stimuli using Philips (SCB 3174) headphones. All verbal responses

were recorded on tape, using a Sony Walkman Stereo Cassette Corder (WM-

D6c).

Method

Primary task

The commencement of each trial was signalled by a fixation point

(which remained on screen for 500 msec), followed by a blank screen (500

msec), after which one word was presented corresponding to the name of one

of the 20 objects used in the experimental trials (750 msec), this was again

followed by a blank screen (500 msec), and finally a line drawing from the

Birmingham Object Recognition Battery (BORB)[15] (Riddoch & Humphreys,

1993) was displayed until a response was made by way of a marked

keyboard button (see Figure 2.2). Participants responded with their left or

right hand, as preferred.
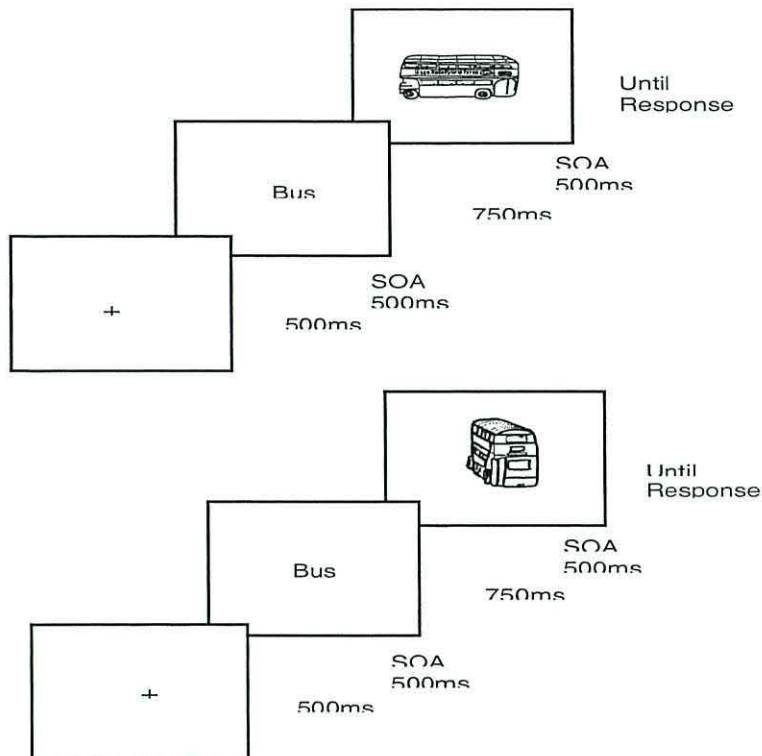
Figure 2.2: Example of a same optimal and same non-optimal trial.

The BORB consists of 14 separate subtests designed to assess particular aspects of visual processing and visual object recognition.
ORB was designed to be a resource for cognitive and clinical neuropsychologists who wish to assess whether the processes of
sual recognition are intact following brain damage. Object constancy is assessed in two matching tests, minimal features (Test 7,
101) and foreshortened views (Test 8, p. 128). In the foreshortened view task, the main identifying feature of the object is
aintained in the unusual/non-optimal view. However, the main axis of the object is distorted as a result of rotating the object in
pth. In the minimal feature view task, the main identifying feature of the object, rated from the standard/optimal view, is
scured.

In Experiments 7 and 8, however, as well as BORB base level

stimuli, it was necessary to use subordinate level picture stimuli, and this is

described in more detail in Chapter 4 (see Figure 2.3).
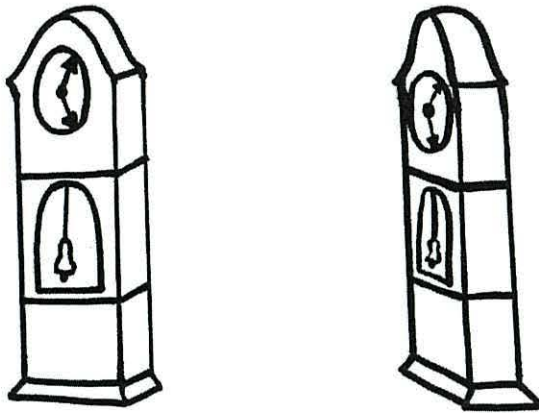
Figure 2.3: Example of an optimal and non-optimal view of a grandfather clock (subordinate stimuli), employed in Experiments 7 and 8.

One keyboard button coloured red ('m' on the keyboard) was pressed

if the word and the object were the same, and another button coloured blue

('b' on the keyboard), if they were different. Word/picture verification tasks

were employed to ensure that participants accessed stored knowledge (i.e.

recognition), and did not match purely on perceptual constancies, as would

be the case picture/picture verification, for example. Instructions to the

participants placed emphasis on both speed and accuracy of responses.

The BORB stimuli consisted of a bus, car, corkscrew, razor, cup, jug, digger (see Figure 2.4), shoe, elephant, rhino, fork, spoon, glasses watch, horse, pig, nailbrush, paintbrush, scissors and peg (see Appendix A).

All stimuli were presented in the centre of the screen, and participants were given the chance to complete as many practice sessions as they required both for primary and secondary tasks, individually and concurrently performed. During the practice session the experimenter remained within the laboratory. The stimuli employed in the practice trials were different to those used in the experimental trials (see Appendix B). On the "different" response trials, where possible the stimuli were visually similar and/or semantically related to the object referred to in the word comparison, as outlined in the BORB (1993, p. 128).
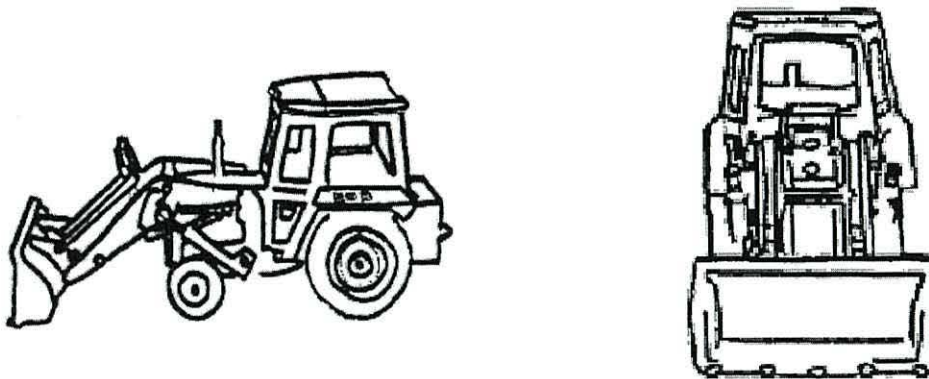
Figure 2.4: Example of an optimal and non-optimal view of a digger.

There were four conditions in each experimental trial: same and optimal view; same and non-optimal view; different and optimal view; and different and non-optimal view (See Appendix A). 50% of the trials in each block were same trials (where word and picture matched) and 50% were different (where word and picture did not match), 50% were optimal, and 50% were non-optimal views. Each block contained identical stimuli, but the order of the 80 trials within each block was pseudo-randomised, to ensure that "same" and "different" views were not seen on more than three consecutive trials. The order of presentation of blocks and conditions was counter-balanced across participants using a Latin Square design. The dependent measures were reaction time (msec) and percentage errors, which were recorded by computer. The trials of interest were those were the word and the picture matched (i.e. the "same" trials). The commencement of experimental trials for both primary and secondary tasks was initiated by the researcher. There were breaks between blocks, and each participant was tested on all blocks. The duration of each experiment was approximately 45 minutes, with the exception of Experiments 3 and 4 which lasted approximately 30 minutes.

Secondary Task

Where random generation was employed as the secondary task, participants were required to verbally generate a string of digits. Instructions

were given to "imagine pulling numbers from a hat", and in doing so, "to

avoid generating numbers outside of the instructed set", "to avoid any

particular patterns, for example, 3, 4, 5, or well known sequences, for

example, 999 or 1471" and to attempt "not to repeat sequences of numbers,

for example, 1, 7, 5 and 1, 7, 5 ….". In these experiments, a metronome,

set at one beat per second, ensured that participants randomly generated

digits at a consistent pace throughout each experimental block. Participants

commenced random generation immediately prior to commencing each block

of the primary object recognition task. Participants were given no indication

that one task was "secondary" to the other, and were encouraged to approach

both the object recognition task and secondary task as equally important. In

those experiments where random digit generation was not employed as a

secondary task, the specific methodology is discussed in the relevant section.

Data Analysis

Primary Task

SPSS Version 6.1 software programme was used for data analysis.

Analysis was restricted to "same" trials. All "different" responses, and all

incorrect responses, were removed from the analysis. Repeated measures

analysis of variance (ANOVA) was performed on the data, together with

paired sample 't' tests (with Bonferroni adaption) for post-hoc comparisons, where appropriate. ANOVA was also performed on the error scores.

Data from participants with overall mean error rates of 30% or more were excluded from analyses (to ensure that participants were not purely choosing one of two possible responses), as were the response times of those participants who were two or more standard deviations (SDs) away from the sample mean. Reaction times under 300msec or over 2000msec were also removed from the analyses, as the responses were considered to be either too quick or too slow, and, therefore, participants' responses were more likely to have been guesses.

Secondary tasks

Each primary task trial lasted approximately three seconds (including participants' responses), and therefore, each experimental block (i.e. 80 trials) produced approximately 240 randomly generated responses per participant (i.e. one per second). As there were two blocks per experimental condition in all studies, 50 responses were analysed from the middle portion of each relevant block. Therefore, one hundred randomly generated responses from each participant were analysed in each condition, providing a percentage error rate per experimental condition.

As with the primary task, data from participants with overall mean error rates of 30% or more were excluded from analyses. Error criteria for

the secondary task included: (a) missing a response altogether; (b) patterning or sequencing (e.g. 2, 4, 6); (c) repeating a number (e.g. 2, 4, 6, 6); and (d) responding with a number outside of the stated set (e.g. if instructed to generate randomly between 1 and 20, responding with 29 etc.). Across all experiments using random generation as a secondary task criterion (a), missing a response, produced the highest percentage error rate, and responding with a number outside of the stated set, produced the least errors.[16] Error criterion for Experiments 9 to 12 are outlined in the relevant sections.

Issues arising in the employment of the dual task paradigm

One consideration when using dual task methodology is the processing cost in co-ordinating multiple tasks, which has been referred to as the "cost for concurrence" (Navon & Gopher, 1979, p. 232). This extra resource load has also been described, in previous literature, as a "dual task overhead" (e.g. Baddeley et al., 1991; Baddeley et al., 1986; Logie et al., 1990). It has been suggested that this overhead is responsible for decrements in performance of approximately 15% (Duff, 2000, p. 15). Clearly, there is a cost in performing dual tasks, and this decrement is caused by having to co-ordinate two activities in synchrony. With regard to the series of studies in

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[16] Across all relevant experiments, missing a response constituted 28% of random generation errors; patterning or sequencing 27%; repeating a number 25%, and responding with a number outside of the stated set, 20%.

this research, if uniform decremental effects were to be seen when combining

performance on both optimal and non-optimal view recognition with the

same concurrent secondary task, it would be feasible to suggest that the dual

task overhead alone is responsible for the drop in performance. For example,

in Figure 2.1, compare No Secondary Task in optimal and non-optimal views

with Secondary Task – No Selective interference. There is no interaction

between these two conditions, and non-optimal view recognition is not

selectively effected by the secondary task, that is, both optimal and non-

optimal views show equal decrements when performed with a secondary

task. However, if effects are seen over and above a dual task overhead when

combining performance on non-optimal, but not on optimal views, it is

plausible to infer that this constitutes a selective interference effect per se. In

Figure 2.1, for example, there is an interaction between No Secondary Task

and Secondary Task – Selective Interference, whereby performance of the

secondary task selectively interferes with non-optimal view recognition.

Consequently, non-optimal view recognition and the concurrent secondary

task may be reliant on a common cognitive resource, as this viewing

condition alone is selectively disrupted.
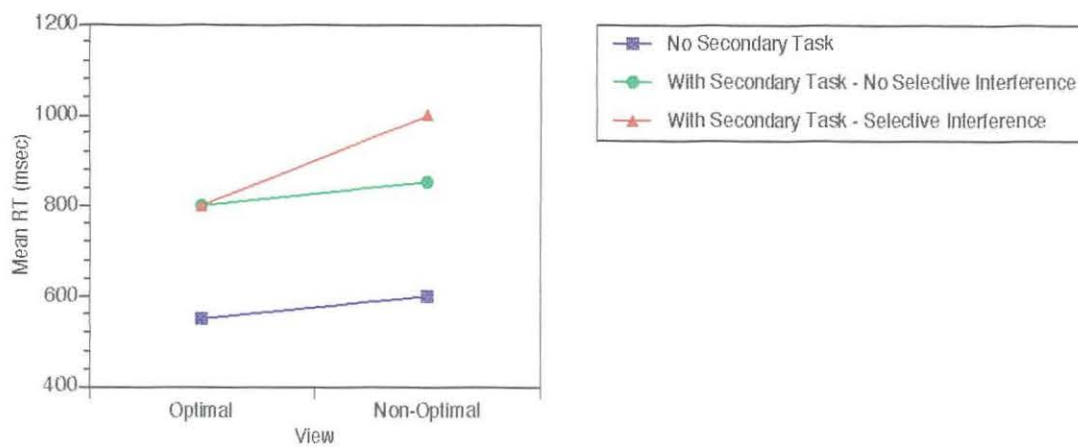
Figure 2.1: Example chart showing the effects of a secondary task with and without selective interference in non-optimal view recognition.

An additional issue with regard to the dual task paradigm is selection of

suitable tasks. It is imperative, to ensure, for example, that interference is not a

result of competition between input modality or mode of response (e.g. Hegarty et

al., 2000; Lemaire et al., 1996; Spelke, Hirst & Neisser, 1976). In this respect, the

primary object recognition task, for all experiments in this study, has a visual input

and a motor output, and the secondary task has an auditory input, where

appropriate, and a verbal output.

A further complicating factor concerns the extent to which the

primary and the secondary tasks are "interleaved", raising the question of a

possible trade-off between primary and secondary task performance

(e.g. Ruthruff, Pashler & Klaassen, 2001; Schumacher, Seymour, Glass,

Fencsik, Lauber, Kieras & Meyer, 2000). In the present study, this issue has

been addressed by having participants generate secondary task

verbal responses at a consistent rate throughout each block of trials (in the majority of cases by mean of a metronome), whilst concurrently performing the primary object recognition task. It is proposed that the necessity for this constant intervention engages executive resources consistently throughout each block of experimental trials. Primary task viewing conditions were randomised throughout blocks, and both primary and secondary tasks were analysed (with the one exception of Experiment 2). If participants were performing either task at the expense of the other, reaction times in the primary task, and errors in the secondary task, would verify any trade-off between tasks. Such a trade-off was not found in any of the experiments described in the study (with the exception of Experiment 2, where it was impossible to ascertain if this was the case).

In conclusion, previous work using dual task methodology has convincingly shown that this technique can be used to selectively disrupt the operation of one component part of the working memory apparatus (as detailed earlier). The rationale for the use of this methodology, in the present study, is based on the hypothesis that the recognition of objects from non-optimal, but not optimal views, implicates the central executive of working memory. In this instance, the secondary tasks acts as a 'functional' lesion in normal subjects, to selectively disrupt non-optimal object recognition.

The present study presents a series of twelve experiments in which the above method, in some cases with minor variations (detailed in the

relevant section), was applied to investigate the role of the central executive

in object recognition. Reference will be made to this chapter when

describing each experiment.

CHAPTER 3: EXPERIMENTS 1 - 4: NON-OPTIMAL VIEW RECOGNITION: PRIMARY TASK AND WITH A CENTRAL EXECUTIVE SECONDARY TASK[1]

As discussed in Chapter 1, changes in viewpoint can affect our ability to recognise objects, most notably when rotated in depth, being when the principal axis of elongation is foreshortened (e.g. Christou & Bülthoff, 2000; Edelman & Intrator, 2000; Hummel, 2000; Hayward & Tarr, 1997; Humphrey & Jolicoeur, 1993; Jolicoeur & Humphreys, 1998; Lawson & Humphreys, 1996, 1998; Marr, 1982; Marr & Nishihara, 1982; Riesenhuber & Poggio, 1999; Srinivas, 1993, 1995; Zourtzi & Shiffrar, 1999). Such changes in viewpoint have been a key variable in a substantial proportion of neuropsychological research (e.g. Caterini et al., 2002; Humphreys & Riddoch, 1984; Kosslyn et al., 1990, 1994; Leek et al., 1996; Riddoch & Humphreys, 1987; Turnbull et al., 1999, 2002; Warrington & James, 1986; Warrington & Taylor, 1973, 1978), and neurophysiological research on object recognition (e.g. Grafton et al., 1997; Sakata & Tiara, 1994; Sugio et al., 1999; Vogels et al., 2001).

Experiment 1 investigates the effects of depth rotation on object recognition, piloting the BORB (Riddoch & Humphreys, 1993) stimuli in a reaction time task. A word/picture matching paradigm is employed, and stimuli

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[1] Baragwanath, B.A. & Turnbull, O.H. (2002). Central Executive secondary tasks in object recognition: An

are presented over repeated blocks. Experiments 2, 3, and 4 involve the putative

central executive secondary tasks of serial subtraction and random generation, in

the employment of the influential dual task paradigm, which has been so

constructively employed in the working memory literature (e.g. Baddeley, 1996;

Baddeley & Hitch, 1974; Logie, 1995).

Experiment 1: Optimal versus Non-optimal recognition

As discussed in Chapter 1, increasing the picture plane misorientation of

pictures of familiar objects, correspondingly increases response latencies

(Jolicoeur, 1985, 1990; Jolicoeur et al., 1998; Jolicoeur & Milliken, 1989;

McMullen & Jolicoeur, 1990; Murray, 1995, 1997; Tarr & Pinker, 1990). It has

also been proposed that depth rotation influences object recognition, in that

performance on foreshortened views is slower and less accurate than on canonical

view recognition (Humphrey & Jolicoeur, 1993; Lawson & Humphreys, 1996,

1998, 1999; Warrington & James, 1986, 1991). In contradiction, however,

Biederman and Gerhardstein (1993, 1995) have argued that recognition of

familiar objects is largely invariant to depth rotation (see Chapter 1).

The initial study is a variation of the chronometric recognition task of

Jolicoeur (1985), being an investigation into recognition of misoriented objects in

normal subjects, across multiple blocks of repeated presentation. In Jolicoeur's

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Analogue of the unusual Views Deficit in the neurologically normal? Brain and Cognition, 48, 268-272.

(1985) study, participants were requested to name line drawings of natural objects

rotated in the picture plane. However, in the present study participants responded

to a word/picture matching task, using stimuli taken from the BORB (Riddoch &

Humphreys, 1993), specifically a series of common objects rotated in the depth

plane, constituting images that have a foreshortened principal axis. Furthermore,

unlike Jolicoeur (1985), who presented each stimulus at six orientations (in 60°

rotational steps), in this study only two views of the stimuli are presented, an

optimal and a non-optimal view. The central concern of Experiment 1 is to

replicate previous findings, in that a non-optimal view is significantly more

difficult to recognise in terms of error and reaction time, than an optimal view.

Experiment 1 also investigates the effect of practice, revealed by the results on the

second and subsequent blocks of trials, in order to ascertain whether such effects

remain present over multiple blocks of repeated presentation.

It is hypothesised that: (a) Non-optimal views will increase response

latencies relative to optimal views across all blocks, and (b) the error rate for non-

optimal views will exceed that of optimal views.

Method

Participants

Seventeen volunteers (10 female) were recruited from the Bangor

University student pool. Each received a course credit for participation. The age

of participants ranged from 18 to 37 years ($M = 22.6$ years), and all matched the

inclusion criteria as outlined in Chapter 2. One participant was

subsequently discarded from analysis, as data did not meet the criteria for

inclusion (see Chapter 2), in this instance, the data were more than two SDs below

the sample mean.

Stimuli and Apparatus

The stimuli consisted of 20 line drawings of common objects (see below),

each was presented from a optimal and non-optimal perspective (i.e. with a

foreshortened principal axis). These perspectives are referred to as "standard"

and "unusual" respectively in the BORB (Riddoch & Humphreys, 1993, p. 128).

See Chapter 2 for further details of stimuli and apparatus for the primary task.

Design

See Chapter 2 for details of the primary task.

Procedure

Six blocks were presented to all subjects, each containing 80 trials, plus a

block of practice trials, using different stimuli taken from the BORB (Riddoch &

Humphreys, 1993). See Chapter 2 for further details of the procedure.

Results

Analysis of the data was consistent with that outlined in Chapter 2.

Overall mean reaction time was 762.3 msec (SD 125.5 msec), with the mean

reaction time for block 1, optimal view was 823.4 msec (SD 179.9 msec),

compared to non-optimal view, 1037.6 msec (SD 296.9 msec) (see Table 3.1).

Mean overall errors were 5.5% (range 0.8% to 9.9%). Overall errors never

exceeded 10% for any participant, clearly participants made few mistakes in the

recognition process in either viewing condition. Importantly, and consistent with

the RT data, mean errors for non-optimal views were 7.1% (range 0 – 25%),

exceeding those for optimal views, 3.9% (range 0 – 20%) (see Figure 3.1).

**Table 3.1: Mean Reaction Time (and standard deviation) in msec for Blocks
1 to 6 in optimal and non-optimal view conditions**

Blocks	Optimal View	Non-optimal View
1	823.4 (179.9)	1037.6 (196.9)
2	792.6 (242.2)	833.4 (235.5)
3	761.9 (235.6)	798.6 (220.9)
4	695.4 (139.1)	759.71 (159.0)
5	728.7 (185.7)	753.5 (222.4)
6	659.4 (122.4)	703.6 (131.1)

A 2 x 6 repeated measures ANOVA showed an overall significant main effect of view, $F(1,15) = 48.06$, $p<0.001$, demonstrating that participants took significantly longer to recognise non-optimal views, compared to optimal views, and blocks, $F(5,75) = 11.41$, $p<0.001$, indicating that recognition on the initial block was faster than that on the last block, in both viewing conditions. There was also an interaction between blocks and view, $F(5,75) = 6.47$, $p<0.001$ (see Figure 3.1). Both optimal and non-optimal view recognition was influenced by blocks.

Paired sample 't' tests were used to compare the mean reaction times for optimal and non-optimal views in the first block and all subsequent blocks. It was found that the effect of view was significant for block 1, $t(15) = 4.04$, $p < 0.001$, block 3, $t(15) = 2.37$, $p< 0.05$, block 4, $t(15) = 3.92$, $p< 0.001$, and block 6, $t(15) = 2.67$, $p<0.05$, showing that participants' responses across these blocks were much slower in the non-optimal viewing condition. This was also the case for blocks 2 and 5, but statistically the difference was not significant.

A repeated measures ANOVA on error data showed a main effect of both view and block, $F(1,15) = 46.54$, $p<0.0 01$ and $F(5,75) = 5.45$, $p<0.001$ respectively, together with a significant interaction, $F(5,75) = 2.70$, $p<0.05$, participants made more errors in the recognition of non-optimal views.
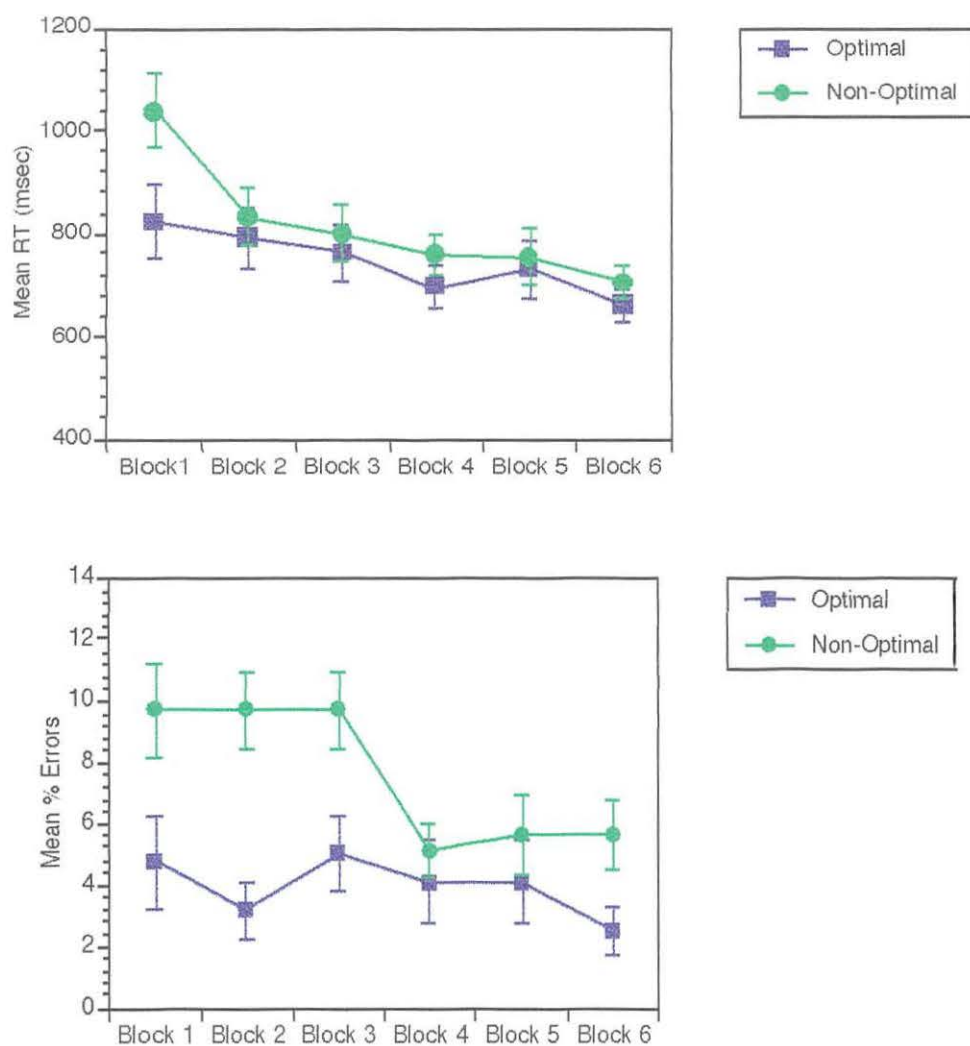
Figure 3.1: Mean reaction times and percentage errors for optimal and non-optimal views; Error Bars = ± 1 standard error *(SE)*.

Comment

Experiment 1 shows that on the first block of trials there was a highly significant effect of view, with non-optimal views increasing reaction times substantially. As predicted, on second and subsequent blocks the effect of view was reduced, but remained, showing a significant effect in the majority of cases, and increased reaction times on all blocks. Participants' performance thus improved with experience with the stimuli, even in block 6, however, non-optimal views still took significantly longer to recognise than optimal views. These findings demonstrate that the non-optimal view effect can be found over six blocks of repeated presentation, which is a replication of the seminal work on object constancy by Jolicoeur and colleagues (1985, 1988, 1990), with the exception that in this study line drawings of familiar objects were rotated in depth. In this respect, the findings also replicate those Hayward & Tarr (1997); Humphrey & Jolicoeur (1993); Lawson & Humphreys (1996, 1998, 1999); Newell & Findlay (1997); Srinivas (1993, 1995), indicating that stimuli with a foreshortened principal axis are significantly more difficult to recognise than optimal views. The data add support for the hypothesis that practice improves performance, but does not entirely eliminate the effects of depth rotation (e.g. Lawson et al., 2000). In concurrence with the hypothesis of this study, the data also reveal that error rates are appreciably higher for non-optimal, compared to optimal views.

In conclusion, the multiple presentation of objects with foreshortened principal axes of elongation, as employed in the BORB, appear to be appropriate for investigating non-optimal view recognition. This experiment forms the basis for further studies and is employed as the primary task in Experiment 2. Subsequent studies will also involve a central executive secondary task.

Experiment 2: Non-optimal view recognition with serial subtraction as a central executive secondary task

As discussed in the previous chapter, the dual task paradigm represents a well established tool for studying if two processes rely on the same resource, such that simultaneous use of this component of the cognitive apparatus will result in impaired performance (Baddeley et al., 1998). If the central executive is an additional resource used only in non-optimal view recognition, but not in optimal view recognition, then it should be possible to selectively disrupt non-optimal recognition by disrupting the central executive. Experiment 2 employs serial subtraction as a central executive secondary task to investigate this proposal.

As discussed in Chapter 2, serial (or continuous) subtraction, whereby participants count down in threes from a three digit number (e.g. Ashcraft, 1992; Logie & Baddeley, 1987), is employed as a central executive secondary task in this study. Experiment 2 investigates the contribution to object recognition of two

components of the Baddeley and Hitch (1974) working memory model - the phonological loop and the central executive.

It is hypothesised that: (a) serial subtraction (as a central executive secondary task) will selectively disrupt non-optimal view recognition, compared to optimal view recognition; and (b) articulatory suppression (phonological loop task) will not significantly interfere with either viewing condition.

Method

Participants

Twenty one participants (11 female) were recruited from the Bangor University student pool. Each received a course credit for participation. Participants' ages ranged from 18 – 39 years ($M = 27.8$ years), and all complied with the inclusion criteria in Chapter 2. The data from five participants were subsequently discarded. One having exceeded the error criteria, and a further four participants' performing at more than two SDs below the sample mean.

Stimuli and Apparatus

The stimuli and apparatus for the primary object recognition task were identical to those used in Experiment 1 (see Chapter 2 for details).

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

identical to those employed in Experiment 1. Conditions and trials for the

primary task followed the same format as those in Experiment 1. For two blocks,

participants performed the object recognition task alone (no task condition).

During two of the six experimental blocks, however, participants were requested

to repeat "3, 2, 1, 3, 2, 1 ….." (i.e. articulatory suppression) continuously

throughout each of the two experimental blocks (phonological loop condition),

whilst simultaneously performing the object recognition task. For a further two

blocks, participants were required to count backwards in threes (serial

subtraction), from a number specified by the experimenter (central executive

condition).

Results

Analysis was collapsed across blocks. Mean overall errors were 9.7%

(range 2.5% - 19.1%). Mean errors for the no secondary task condition were

6.3% (range 0% - 22.5%), for the phonological loop condition were 6.6% (range

0% - 17.5%), and for the central executive condition were 16.3% (range 2.5% -

47.5%). Mean overall errors for non-optimal views were 11.1% (range 0% -

47.5%), exceeding those for optimal views, which were 8.4% (range 0% - 47.5%)

(see Figure 3.2).

A 2 x 3 repeated measures ANOVA was performed on the RT data.

Analysis showed a significant effect of view, $F(1,15) = 20.43$, $p<0.001$, showing

that non-optimal views were significantly slower to be recognised than optimal

views, and also task condition, $F(2,30) = 22.06$, $p<0.001$, demonstrating that

responses were significantly slower when performing both primary and secondary

task, compared to when performing primary task alone. However, there was no

significant interaction between the two conditions, indicating that non-optimal

view recognition was not selectively disrupted when employing serial subtraction

as a secondary task (see Figure 3.2). However, statistical analysis in the no

secondary task condition showed that there was a significant difference between

optimal and non-optimal view recognition, $t(15) = 6.79$, $p<0.001$.

An ANOVA on the error data showed a main effect of both view and task

condition, $F(1,15) = 9.82$, $p<0.05$ and $F(2,30) = 11.37$, $p<0.05$, respectively.

There was no interaction (see Figure 3.2). Participants made significantly more

errors in the non-optimal view condition, compared to the optimal view condition,

and also made more object recognition errors whilst concurrently performing the

primary and secondary tasks, compared to when performing the primary task

alone.
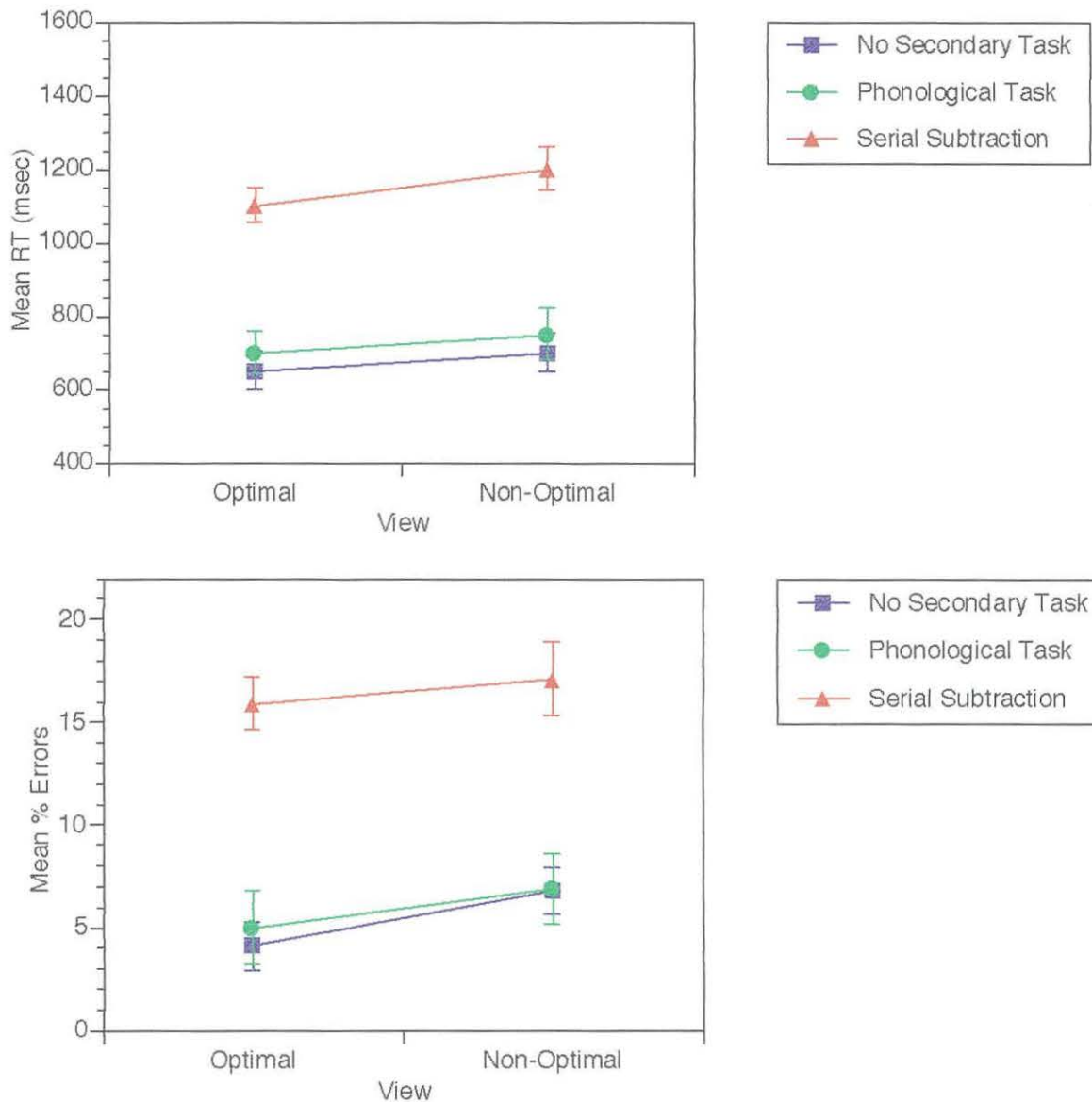
Figure 3.2: Mean reaction times and percentage errors for optimal and non-optimal views with no secondary task, with serial subtraction as a secondary central executive task, and articulatory suppression as secondary phonological loop task; Error Bars = ± 1 standard error *(SE).*

Comment

The results indicate that subjects found it more difficult to recognise objects seen from non-optimal perspectives, even in the absence of a secondary task. This finding is a replication of Experiment 1. Articulatory suppression resulted in no appreciable difference in performance when compared to the no secondary task condition, suggesting that this task does not influence object recognition under either viewing condition. In this condition the cost to object recognition was minimal, which adds support for the hypothesis that the verbal repetition of a well-learnt sequence (i.e. 3, 2, 1) is an automatically generated response, which does not involve executive resources (see Shiffrin & Schneider, 1977), and does not interfere, to any great extent, with the achievement of object constancy. On the other hand, data demonstrate that serial subtraction increases reaction times significantly across both viewing conditions, but has no selective effect on non-optimal views, and, therefore, the findings are not consistent with the stated hypothesis.

It may be contended that the lack of an interaction, together with a significant increase in reaction times, may be explained as a "dual-task overhead" (Baddeley et al., 1991; Baddeley et al., 1986; Logie et al., 1990; Engle et al., 1999).

Moreover, in Experiment 2 there was no control over the pace at which serial subtraction was performed. The rate of responding was left entirely up to the participants, which may have resulted in minimal competition for common

central executive resources (Hicks, 1998). Consequently, participants may not have performed the primary and secondary tasks concurrently, which may have resulted in a trade-off between the tasks, as discussed in Chapter 2.

Also, it may be argued that the specific components of executive function, involved in serial subtraction, do not equate to those executive components contributing to non-optimal view recognition, making this an unsuitable secondary task with which to examine the executive resources implicated in non-optimal view recognition. As discussed, the fractionation of executive resources is currently the subject of extensive research (e.g. Baddeley & Logie, 1999; Schneider, 1999; Towse & McLaughlin,1999; Van der Linden et al., 1998). It is, therefore, plausible to suggest that certain aspects of executive function may be more directly involved in non-optimal view recognition than others.

With this in mind, Experiment 3 employs random generation as a central executive secondary task. Random generation is purported to encompass the inhibition of prepotent patterns (Towse & McLaughlin, 1999; Van der Linden et al., 1998), and the active search for candidate responses (Baddeley, 1986). Of importance, it has been proposed that these two specific components of executive function may also be directly involved in object recognition (see Hummel, 2000 in Chapter 1). Rate of response, and the possibility of a trade-off between primary and secondary task performance, are controlled for in Experiment 3.

Experiment 3: Non-optimal view recognition with random generation (1-10)

as a central executive secondary task

Experiment 3 involves random digit generation as a central executive

secondary task, in order to load the central executive and simulate the Unusual

Views Deficit (Warrington & Taylor, 1973, 1978) in neurologically normal

subjects. As detailed, random generation has proved highly successful in

disrupting executive behaviour across a range of cognitive tasks (e.g.Robbins et

al., 1996, Logie et al., 1994, Diennes et al., 1991, Gilhooly et al., 1993).

Additionally, in the neuropsychological population, patients with Alzheimer's

disease (Brugger, Monsch, Salmon & Butters, 1996), Korsakoff's syndrome and

schizophrenia (Rosenberg et al., 1990), Parkinson's disease (Spatt & Goldenberg,

1993), and patients with frontal lobe lesions (Spatt & Goldenberg, 1993),

demonstrate severe deficits in random generation performance compared to aged-

matched controls. It has been suggested that the main difference between patients

with frontal lobe dysfunction and control subjects, is the persistence of a single

production strategy that is most likely to result in a reduced inability to inhibit

overlearned schemas (e.g. Van der Linden et al., 1998).

Baddeley (1986) proposed that individuals tend to generate digits based on

overlearned habits, e.g. 4, 5, 6 etc., and suggested that the avoidance of such

behaviour demands the constant intervention of a 'filtering' device (the central

executive) to screen out automatically generated responses. It is considered,

therefore, that random generation fully utilises the resources of a limited-capacity central executive in the active search for candidate responses and the inhibition of responses that lead to well learnt sequences (Baddeley, 1986).

If we are to conclude that the executive resources of a limited-capacity working memory contribute to non-optimal, but not optimal view recognition, it is necessary to demonstrate that random generation preferentially disrupts non-optimal views and leaves optimal views more or less unaffected. Such a finding would lend support for the view that non-optimal recognition and random generation may be dependent on a common resource.

It is hypothesised that random generation will: (a) Selectively interfere with performance on non-optimal views; and (b) that participants will produce a significant increase in reaction times to non-optimal, compared to optimal, views. This hypothesis was tested in Experiment 3.

Method

Participants

Twenty two participants (11 female) were recruited from Bangor University community pool, and each received £5 for participation. Mean age 21.8 years (range 18-31 years), and all complied with the criteria outlined in Chapter 2. The data of six participants were subsequently discarded. In the

primary task, two participants had more than 30% errors, and the mean reaction

time of a further two participants was more than two SDs away from the sample

mean. Two further sets of data were discarded as they had more than 30% errors

in the secondary task.

Stimuli and Apparatus

Primary task

Apparatus and stimuli for the primary object recognition task were

identical to those employed in the previous experiment.

Secondary task

All random sequences were recorded on tape (see Chapter 2).

Design/Procedure

Four blocks of experimental trials were presented to all participants, being

blocks 1, 2, 3, and 4 in Experiment 1. Conditions and trials for the primary task

followed the same format as those in previous experiments (see Chapter 2). For

two blocks, participants performed the object recognition task alone (no task

condition). During two of the four experimental blocks, however, participants were requested to randomly generate digits between 1 and 10 (secondary task condition) in accordance with the criteria described in Chapter 2. This task was performed concurrently with the primary task.

Results

Primary task

Mean overall errors were 9.8% (range 2.5% - 18.7%). Mean errors for the no secondary task condition were 5.9% (range 0% - 17.5%), and mean errors for the secondary task (random generation) condition were 13.6% (range 0% - 35%). In the no secondary task condition, mean errors for the optimal view were 4.2% (range 0% - 10%), and the non-optimal view 7.6% (range 2.5% - 17.5%). In the secondary task condition (random generation), mean errors for the optimal view were 12.8% (range 0% - 35%), and the non-optimal view 14.5% (range 0% - 35%).

As in Experiment 2, a 2 x 2 repeated measures ANOVA showed a significant effect of view, $F(1,15) = 26.69$, $p<0.001$, and also task condition, $F(1,15) = 35.14$, $p<0.001$. In addition, however, and in contrast to Experiment 2, there was a significant interaction between the two conditions, $F(1,15) = 4.70$, $p<0.05$. Hence, non-optimal view recognition was selectively disrupted by the

concurrent performance of random generation, above and beyond a dual task

overhead (see Figure 3.3A). Statistical analysis in the no secondary task

condition showed that there was a significant difference between optimal and

non-optimal view recognition, $t(15) = 8.34$, $p<0.001$.

An ANOVA on the error data showed a main effect of both view and task

condition, $F(1,5) = 4.84$, $p<0.05$, and $F(1,15) = 10.05$, $p<0.05$ respectively, but no

interaction (see Figure 3.3B). Participants, therefore, once again made

significantly more errors in the non-optimal view condition, compared to the

optimal view condition, and also made more object recognition errors whilst

concurrently performing the primary and secondary tasks, compared to when

performing the primary task alone.
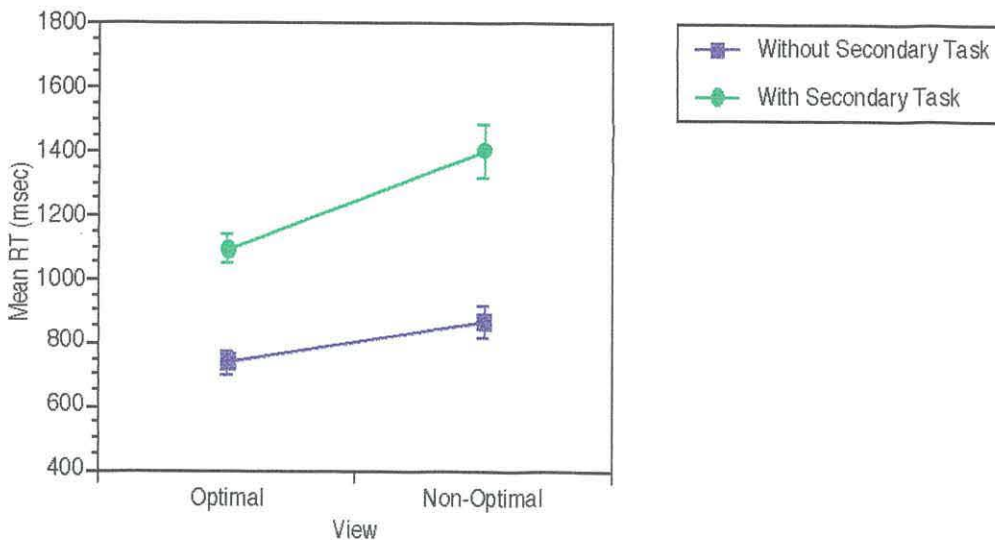
Figure 3.3A: Mean reaction times for optimal and non-optimal views when using random generation (1-10) as a central executive secondary task; Error Bars $= \pm$ 1 standard error *(SE)*.
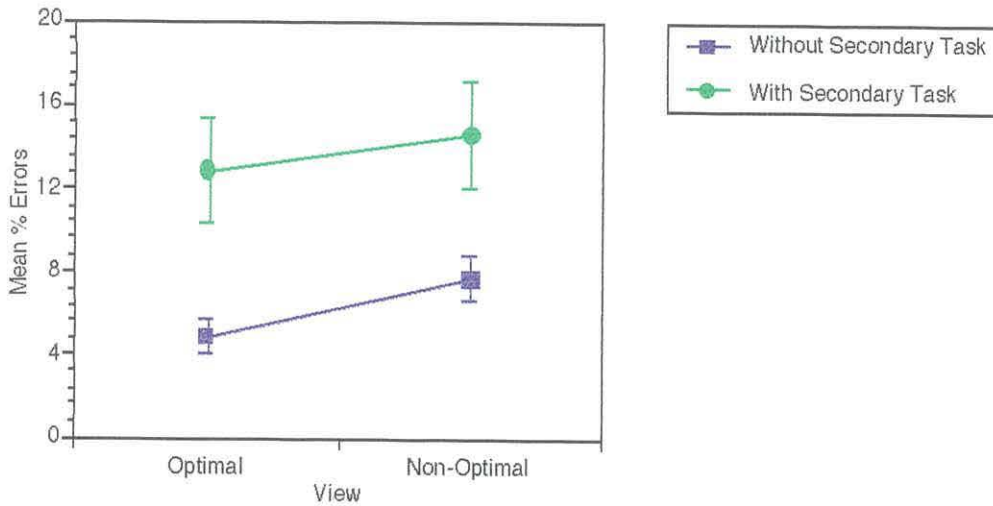
Figure 3.3B: Mean percentage errors for optimal and non-optimal views when using random generation (1-10) as a central executive secondary task; Error Bars = ± 1 standard error (SE).

Secondary task

Mean overall errors in random digit generation ranged from $4 - 27\%$, ($M = 14.5\%$).

Comment

As in the previous experiments, analysis of both the reaction time and error data show the consistent finding of significantly increased response latencies and error rates for non-optimal view recognition. It was predicted that disruption of the central executive system would produce a decrement in recognition performance selectively for non-optimal view stimuli. This was confirmed by the significant interaction between task and view in Experiment 3, and indicates that

specific central executive resources may contribute in the recognition of non-optimal views, but not optimal views.

Although the results of Experiment 3 support the proposed hypothesis, it could be argued that the interaction between view and task was only marginally significant ($p = 0.047$). The theoretical basis for Experiment 3 was the proposal that random generation involves both the active search of candidate responses and the inhibition of "natural" patterns. In consideration of this, it might be argued that an increase in the number of digits to be randomised (the set size) would influence performance. In this respect, Towse (1998) proposed that where there are more candidate responses, there are consequently more responses to be inhibited. Furthermore, the author proposed that the mental retrieval/search for candidate responses, from the total number of possibilities, may constitute an additional and independent source of central executive involvement. Several studies have in fact shown that random generation performance is mediated by set size (e.g. Towse & McLachlan, 1999; Towse & Valentine, 1997; Vandierendonck, 2000; Warren & Morin, 1965; Wiegersma, 1976). Experiment 4, therefore, replicates Experiment 3, but increases set size for random generation from 1-10 to 1-20, with the aim of loading the central executive more heavily.

Experiment 4: Non-optimal view recognition with random generation (1-20)

as central executive secondary task

Experiment 4 retains many of the features of Experiment 3, in that it employs the same stimulus set in the primary task, and random generation as a secondary task. However, in this study the set size for random generation was increased and participants were required to randomly generate digits from 1-20, as opposed to 1-10 as in Experiment 2. The aim of the study is to add support the findings of the previous experiment, and has, therefore, the same hypotheses, which are: (a) that random generation will selectively interfere with performance on non-optimal views, and (b) that participants will produce a significant increase in reaction times to non-optimal, compared to optimal, views.

Method

Participants

Twenty three participants (10 female) were recruited from the Bangor University student pool and each received a course credit for participation. Mean age was 22.5 years (range 18 to 38 years). The data of seven participants were subsequently discarded, using Chapter 2 criterion. Two participants, as they had more than 30% errors, and a further two participants' mean reaction times being

more than two SDs away from the sample mean in the primary task. Three

participants exceeded 30% errors in the secondary task.

Design/Procedure

All stimuli, apparatus, conditions and trials followed the same format as

those in Experiment 3, with the exception that all participants were requested to

randomly generate digits between 1 and 20.

Results

Primary task

Mean overall errors were 7.3% (range 0% - 19.5%). Mean errors for the

no secondary task condition were 6.9% (range 0% - 22.5%), and mean errors for

the secondary task condition were 12.9% (range 0% - 32.5%). In the no

secondary task condition, mean errors for the optimal view were 5% (range 0% -

15%), and the non-optimal view 8.9% (range 0% - 22.5%). In the secondary task

(random generation) condition, mean errors for the optimal view were 11.4%

(range 0% - 32.5%), and the non-optimal view 14.5% (range 5% - 27.5%) (see

Figure 3.4).

As in Experiment 3, there was a significant effect of view, $F(1,15) =$

50.40, $p<0.001$, and also task condition, $F(1,15) = 49.03$, $p<0.001$. In addition,

there was a significant interaction between the two conditions, $F(1,15) = 6.95$, $p<0.05$ (0.019). Hence, non-optimal view recognition was selectively disrupted by the concurrent performance of random generation, above and beyond a dual task cost (Baddeley, 1996) (see Figure 3.4). Statistical analysis in the no secondary task condition showed that there was a significant difference between optimal and non-optimal view recognition, $t(15) = 9.62$, $p<0.001$.

An ANOVA on the error data, also consistent with the findings of Experiment 3, showed a main effect of both view and task condition, $F(1,15) = 8.10$, $p<0.05$, and $F(1,15) = 18.63$, $p<0.01$ respectively, but no interaction (see Figure 3.4).

Secondary task

The mean overall errors in random digit generation were 15% (range 6 – 28%).
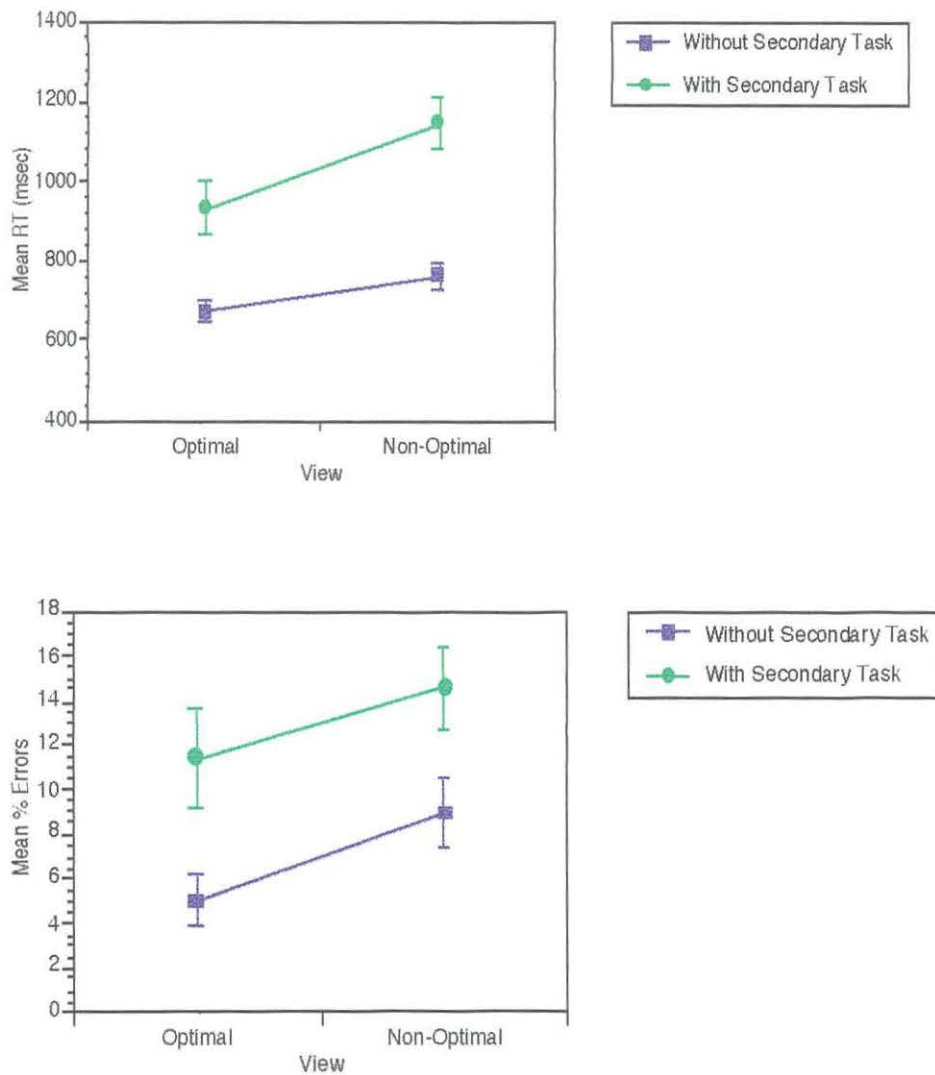
Figure 3.4: Mean reaction time and percentage errors for optimal and non-optimal views when using random generation of digits (1-20) as a central executive secondary task; Error Bars = ± 1 standard error (SE).

Comment

As with Experiment 3, analysis of both the reaction time and error data show the consistent finding of significantly increased response latencies and error rates for non-optimal, compared to optimal, view recognition. It was predicted that disruption of the central executive system would produce a decrement in recognition performance selectively for non-optimal view stimuli, and this was confirmed by the significant interaction between task and view. The results of Experiment 4 add support for those of Experiment 3. Experiment 4, however, demonstrated a more robust level of interaction significance ($p = 0.019$).

The findings of Experiments 3 and 4 suggest that random generation, as a central executive secondary task, selectively disrupts non-optimal view recognition, leading to the proposal that executive resources may be implicated in such recognition.

Experiments 1 – 4: General discussion

The findings of Experiment 1 demonstrate that there is a consistent decrement in performance for non-optimal, compared to optimal, view recognition, even over repeated blocks of presentation. This finding appears to be consistent with Jolicoeur (1985, 1990); Jolicoeur et al. (1998); Jolicoeur and Milliken (1989); Hayward and Tarr (1997); Humphrey and Jolicoeur (1993); Lawson and Humphreys

(1996, 1998, 1999); Newell & Findlay (1997); Srinivas (1993, 1995), who propose a viewpoint-dependent theory of object recognition, but appear to contradict Biederman (1987, 2000); Biederman and Bar (1999); Biederman and Cooper (1992); Biederman and Gerhardstein (1993); and Hummel and Biederman (1992), who propose a viewpoint-independent theory of object recognition, and have suggested that there maybe no orientation effects in recognising depth rotated familiar objects. However, the latter researchers also proposed that there would be costs on recognition if distinctive GSDs were altered by occlusion or accretion. It has been contended that when objects are rotated in depth, as they were in all four reported experiments, this would indeed be the case (e.g. Hummel, 2001), but is not, of course, the case when objects are viewed from an optimal perspective.

Experiment 3, using the dual task paradigm, with a random generation secondary task, also demonstrates the consistent finding of slower responses and higher error rates in non-optimal view recognition. It was predicted that disruption of the central executive system would produce a decrement in recognition performance selectively for non-optimal view stimuli, and this was confirmed by the significant interaction between task and view in the experiment. Experiment 4 replicated and extended the results of Experiment 3, by investigating whether an increased set size in random generation modulated the combined effect or primary and secondary task, and this was found to be the case.

It is considered that this finding may be regarded as akin to the Unusual Views Deficits seen in neurological patients, where the secondary task acts as a "functional" lesion, selectively disrupting non-optimal recognition, and, therefore, simulating the unusual Views Deficit in the neurologically normal. Furthermore, the data add support for suggestions from the neurological lesion literature (e.g. Farah, 1990; Turnbull & McCarthy, 1996), as well as the functional imaging literature (e.g. Alivisatos & Petrides, 1997; Kosslyn et al., 1994; Sugio et al., 1999), that the central executive and/or frontal lobes may be selectively involved in the recognition of objects from non-optimal views.

In summary, the pattern of results in Chapter 3 support the conclusions that: (a) the BORB stimuli are useful for investigating non-optimal object recognition; (b) the dual task paradigm appears to be a valid tool for the investigation of the role of central executive resources in object recognition; and (c) random digit generation, involving both inhibition and search aspects of executive function, appears to selectively disrupt non-optimal views.

However, all the non-optimal views in Chapter 3 were depth-rotated objects, i.e. objects with a foreshortened principal axis of elongation, which raises the question as to whether there is a central executive contribution in other forms of non-optimal view recognition. Chapter 4, therefore, investigates the effects of random digit generation on two different types of non-optimal views. Those being: (i) picture plane misorientation; and (ii) stimuli with an occluded critical feature.

All the primary tasks in Chapter 4 employ the BORB (Riddoch &

Humphreys, 1993) stimuli. Based on the results of Experiments 3 and 4

(Baragwanath & Turnbull, 2002), random generation is used as the central

executive secondary task in the following two experiments.

CHAPTER 4: EXPERIMENTS 5 & 6: THE CENTRAL EXECUTIVE AND THE RECOGNITION OF PICTURE-PLANE ROTATED, AND MINIMAL FEATURES, STIMULI

On the basis of the findings in Chapter 3, it may be proposed that the central executive is involved in recognition of objects rotated in the depth plane (Baragwanath & Turnbull, 2002). However, a number of important issues have arisen in the literature on object constancy, and the role of the central executive in each of these has yet to be assessed. The two issues this chapter will focus on are: (a) picture versus depth plane rotation; and (b) axis- versus feature-based accounts of object recognition.

Clearly, an image varies following both plane and depth rotations. In the case of depth rotations, an object may differ in size, outline shape and through the presence/absence of distinctive parts/features. However, this is not the case for picture plane rotation, where size, outline shape and spatial relations between the parts/features, remain constant (e.g. Biederman, 1987; Hayward, 1998; Hummel, 2000; Lawson, 1999; Lawson & Humphreys, 1998, 1999; Lawson et al., 2000; Stringer & Rolls, 2002). Experiment 5 addresses the question of a potential central executive contribution to picture-plane rotated stimuli.

A second issue concerns the question of whether object constancy is achieved by the "holistic"/global properties of shape or by distinguishing local

features. Experiment 6 investigates the potential role of executive resources in a
study addressing the effect of a central executive secondary task on minimal
features, compared to depth rotated, stimuli.

Experiment 5: Picture versus depth plane misorientation

It has been suggested that objects rotated in the picture plane and in the
depth plane show no differential performance, and that the visual system may
compensate for both in the same manner, (e.g. Cooper & Shepard, 1973, 1975;
Hock & Tromley, 1978; Humphrey & Jolicoeur, 1988, 1993; Shepard, 1984;
Shepard & Judd, 1976; Shepard & Metzler, 1971), although this is not widely
accepted (e.g. Hummel, 2000, 2001; Hummel & Biederman, 1992 Lawson, 1999;
Lawson et al., 1999, 2000). The models of Hummel and Biederman (1992) and
Biederman and Gerhardstein (1993), as previously reviewed, proposed that
picture plane rotation produces deficits in performance, whilst the recognition of
depth-rotated stimuli, to some degree, is viewpoint-invariant.

A commonly held assumption is that a mental rotation process is used by
participants to recognise picture plane rotated pictures (e.g. Jolicoeur, 1985, 1990;
Lawson, 1999; Murray, 1997; Tarr & Pinker, 1989). As discussed in Chapter 1,
deficits in this visuospatial function are frequently associated with lesions of the
posterior parietal lobe (e.g. Alivisatos & Petrides, 1997; Carlesimno et al., 2001;
Caterini et al., 2002; Harris et al., 2000, 2001; Just et al., 2001).

If we are to assume that mental rotation (purported to take place in the parietal regions), is implicated in the recognition of stimuli rotated in the picture plane, whilst executive resources (purported to take place in the frontal lobe), play a role in the recognition of depth rotated stimuli, this leads to a clear prediction: the concurrent performance of a central executive secondary task would disrupt non-optimal view recognition when objects are rotated in the depth plane, but not when objects are rotated in the picture plane.

On the basis of this prediction, Experiment 5 manipulated the primary task stimuli. BORB stimuli were employed, as in previous experiments, for both optimal and non-optimal viewing conditions. In the non-optimal viewing conditions, stimuli were rotated either in the depth, or the picture plane. The secondary central executive task was the random generation of numbers between 1 and 20, as described in Chapter 3.

It is hypothesised that: (a) non-optimal, but not optimal, view recognition would be selectively disrupted by a central executive secondary task, when objects are rotated in the depth plane, and (b) non-optimal view recognition would show no selective effects over optimal views, with the concurrent performance of a central executive secondary task, when objects are rotated in the picture plane.

Method

Participants

Twenty one volunteers (13 female) were recruited from Bangor University student pool. Each received a course credit for participation. The age of participants ranged from $18 - 25$ years ($M = 20.3$ years). The data of five participants was discarded, three exceeding the error criteria for the primary task as outlined in Chapter 2, and two exceeding the error criteria for the secondary task.

Stimuli and Apparatus

Primary task

All stimuli and apparatus for the primary object recognition task were identical to those used in previous experiments.

Secondary Task

As described in Chapter 2.

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

identical to those employed in Experiment 1. Conditions and trials for the

primary task followed the same format as outlined in Chapter 2. For two blocks,

participants performed the object recognition task alone in both picture plane and

depth rotation (no task condition). During the remaining experimental blocks,

however, participants were requested to randomly generate digits between 1 and

20, in accordance with the criteria described in Chapter 2, concurrently with the

primary task. In the picture plane condition, stimuli were optimal views of

objects from the BORB set, rotated at 120° and 240°[1] (see Figure 4.1, & Appendix

C). In the depth plane condition, the objects had a foreshortened principal axis, as

in all previous experiments.

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[1] This set of orientations were chosen for the primary task as it has been demonstrated that a monotonic
function is produced from 0 – 120° and inversely from 240° – 360° (e.g. Murray. 1997; Jolicoeur, 1985,
1990) when recognising objects rotated in the picture plane. Lawson (1999, pp.227) argues that the most
severe performance deficits are at 120° and 240°. Statistical analysis of data showed no significant
difference in mean RTs for those objects presented at 120° and 240° rotations (t(9) = -1.57, p > 0.05).
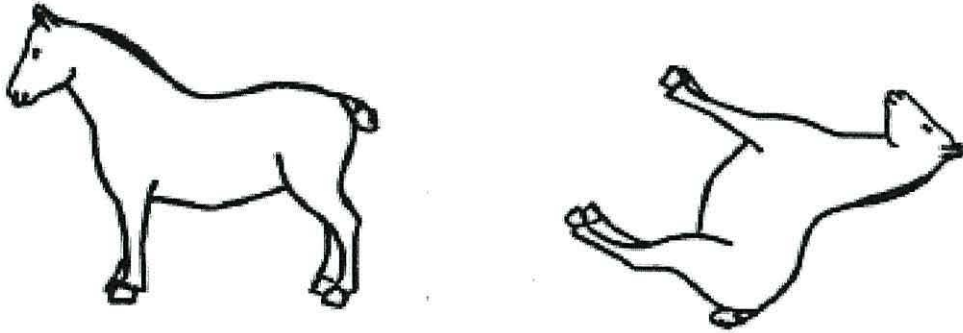
Figure 4:1: Example of an optimal and picture plane view (120°) of a horse.

Results

Primary task

Mean percentage errors and range for optimal and non-optimal views in all conditions were calculated for analysis (see Table 4.1). On inspection, overall errors for non-optimal views exceeded those for optimal views, and this was a consistent finding in all conditions. Mean error rates were also higher when participants were concurrently performing the secondary task.

**Table 4.1: Mean percentage error, range and standard deviation for optimal
and non-optimal views, with and without a central executive secondary task
in both picture and depth plane conditions**

	Mean (%)	Range (%)	Standard Deviation (%)
Overall errors	10.7	9.6 – 18.8	7.3
Overall errors Non-optimal	14.5	0 - 35	7.4
Overall errors Optimal	10.9	0 – 27.5	6.8
Overall errors: No secondary task – picture plane rotation	8.1	5 - 25	7.1
Overall errors: No secondary task – depth plane rotation	9.3	0 - 25	6.2
Overall errors: Secondary task – picture plane	15.9	5 – 27.5	4.7
Overall errors: Secondary task – depth plane	17.4	5 – 35	6.3
No Secondary Task: Optimal – picture plane	5.9	0 - 15	5.8
No Secondary Task: Optimal – depth plane	6.4	0 – 15	4.4
No Secondary Task: Non-optimal – picture plane	10.3	10 – 25	7.8
No Secondary Task: Non-optimal – depth plane	12.	0 – 25	6.5
Secondary Task: Optimal – picture plane	14.7	10 – 27.5	4.9
Secondary Task: Optimal – depth plane	16.7	5 – 20	4.7
Secondary Task: Non-optimal – picture plane	17.2	5 – 22.5	4.6
Secondary Task: Non-optimal – depth plane	18.1	7.5 - 35	7.8

A 2 x 4 repeated measures ANOVA performed on the reaction time data showed a significant effect of view, $F(1,15) = 539.94$, $p<0.001$, in that non-optimal views were significantly slower to recognise than optimal views in all task conditions. There was also a main effect of task, $F(3,45) = 76.31$, $p<0.001$, demonstrating that responses were significantly slower when performing primary and secondary tasks together, than when performing the primary task alone. There was also a significant interaction between view and task, $F(3,45) = 73.36$. $p<0.001$. There was no interaction between no task and secondary task in the picture plane, however, there was an interaction between no task and secondary task in the depth plane condition ($F(1,15) = 42.48$, $p<.001$). Participants took relatively longer in the non-optimal view condition when performing random generation concurrently with the recognition of depth rotated stimuli, than when they performing concurrent random generation in the same viewing condition, with picture plane rotated stimuli (see Figure 4.2). Statistical analysis in the no secondary task condition showed that there was a significant difference between optimal and non-optimal view recognition for picture plane stimuli, $t(15) = 7.89$, $p<0.001$, and for depth plane stimuli, $t(15) = 9.51$, $p<0.001$.

Analysis of errors showed a significant main effect of both view, $F(1,15) = 11.04$, $p<0.05$, and task, $F(3,45) = 14.51$, $p<0.05$. There was no interaction between factors. Participants made more errors in non-optimal view recognition, compared to optimal view recognition and more errors in object recognition

whilst concurrently performing the two tasks together, compared to performing

object recognition alone (see Figure 4.2).
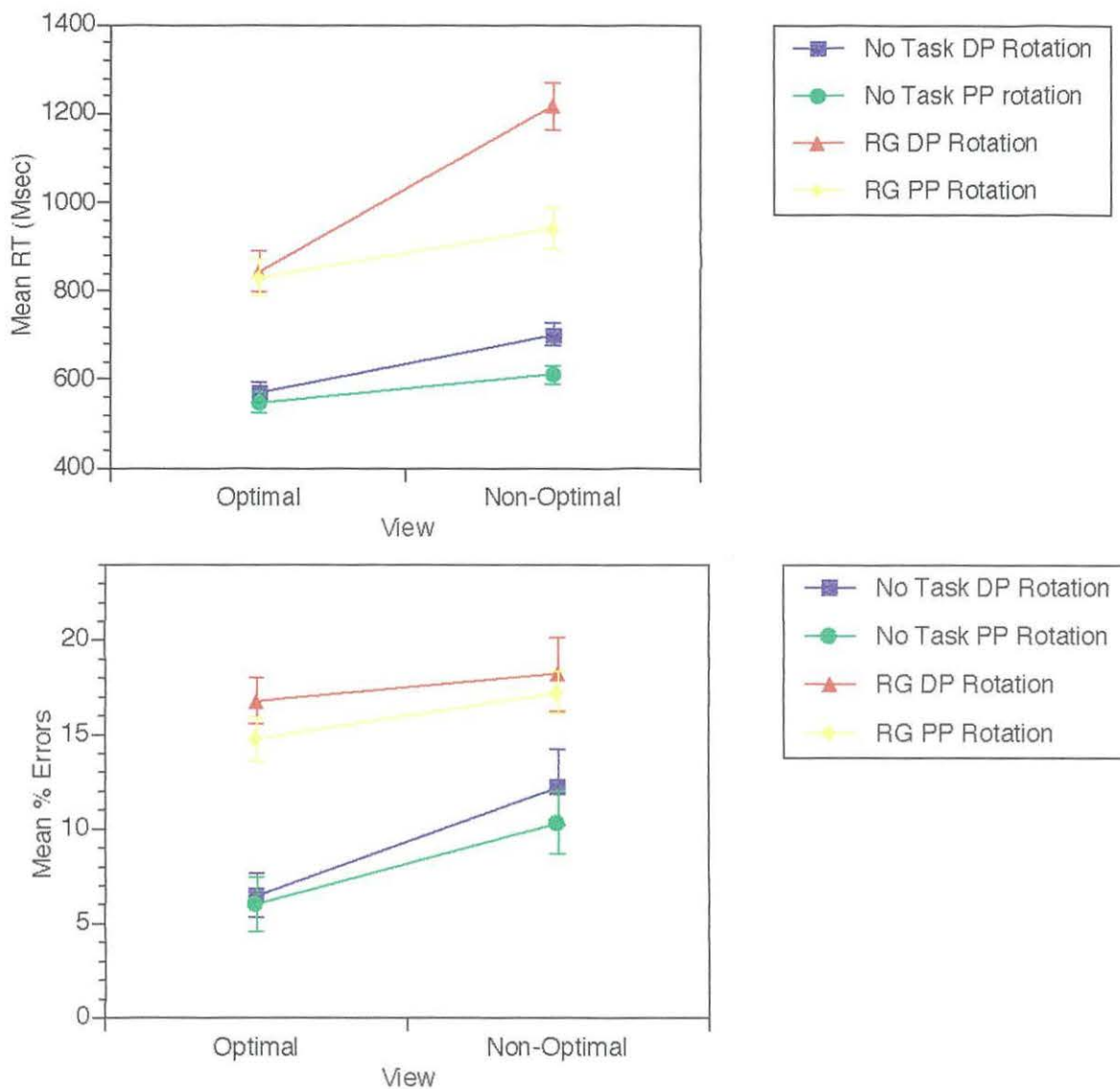
Figure 4.2: Mean reaction time and percentage errors for optimal and non-optimal views (PP – picture plane; DP – depth plane), using random generation (1-20) as a central executive secondary task (RG) ; Error Bars = ± 1 standard error *(SE)*.

Secondary Task

Mean overall errors in random digit generation ranged from 5% - 26% (M

= 16.6%). Mean errors in the depth rotated condition were 17.1% (range, 5% -

26%), marginally exceeding those in the picture plane condition, which ranged

from 6% - 22% (M = 16.2%).

Comment

Analysis of both reaction time and error data show the consistent finding of

significantly increased response latencies and error rates for non-optimal view

recognition. The prediction was that disruption of the central executive system

would produce a selective decrement in the recognition of depth rotated stimuli, as

previously, but not picture plane rotated stimuli, and this was confirmed by the data.

These findings consolidate the findings of Experiments 3 and 4, whereby

recognition of foreshortened principal axis stimuli appear to involve executive

resources. The data appear to run counter to those of Shepard and Metzler (1971),

Cooper and Shepard (1973, 1975), Hock and Tromley (1978); Humphrey and Jolicoeur

(1988, 1993), Shepard, (1984), and Shepard and Judd (1976), who proposed that the

same processes are involved in picture and depth plane recognition, but are supportive

of Lawson (1999) and Lawson et al. (1999, 2000), who proposed different

compensatory processes for the recognition of picture and depth rotated stimuli. The

data from Experiment 5 suggest that the processing of two-dimensional

misorientations and the processing of three-dimensional misorientations may be
functionally distinct.

Experiment 6: Minimal features versus depth plane misorientation

Abundant research (e.g. Hayward & Tarr, 1997; Hayward, 1998;
Humphrey & Jolicoeur; Lawson, 1999; Lawson & Humphreys, 1996, 1998, 1999,
Lawson et al., 2000, 2002; Newell & Findlay, 1997; Srinivas, 1992, 1995;
Stringer & Rolls, 2002), has demonstrated that the identification of line drawings
is noticeably disrupted when the main axis is foreshortened, supporting the
hypothesis that object recognition may be considered axis-based. It has also been
suggested, however, that the visibility of salient features are of crucial importance
when recognising and object from non-optimal views (e.g. Jolicoeur, 1990, 1992;
Murray et al., 1993; Warrington & James, 1986). Additionally, several authors
(e.g. Palmer et al., 1981, Humphreys & Riddoch, 1984, Riddoch & Humphreys,
1987) have reported that both the occlusion of distinctive features and a
foreshortened principal axis principal produce deficits in performance. In this
connection, it has been demonstrated that the processing of principal axes can be
dissociated from the processing of local features (e.g. Humphrey & Joliceour,
1993; Humphreys & Riddoch, 1984; Riddoch & Humphreys, 1987; Jolicoeur,
1990).

If there are functionally-distinct, feature- and axis-based routes for object

recognition, and based on the previous findings of a potential central executive

role in the recognition of stimuli with a foreshortened principal axis, it is feasible

to propose that recognition of objects with critical features occluded may not

involve executive resources.

The issue of axis-based versus feature-based recognition is investigated in

Experiment 6. The BORB (Riddoch & Humphreys, 1993) stimuli were

employed, as in previous experiments, to represent optimal and non-optimal

views. In the non-optimal viewing conditions stimuli were rotated either in depth,

as previously (i.e. with a foreshortened principal axis of elongation), or where

critical features were occluded (see Figure 4.3). The secondary central executive

task was random digit generation (1-20) as described in Chapter 3. It was

hypothesised that: (a) Non-optimal, but not optimal, view recognition would be

selectively disrupted when objects were rotated in the depth plane, and (b) non-

optimal view recognition would show no selective effects over optimal views

when critical features were occluded.
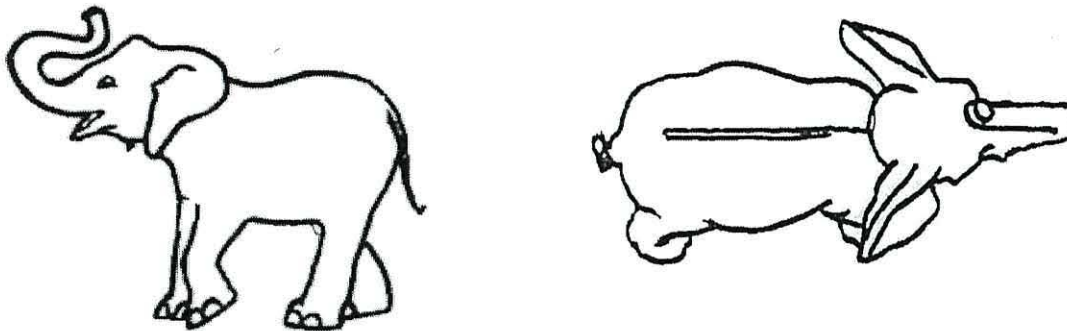
**Figure 4.3: Example of an optimal and minimal features view of an elephant,
taken from the BORB (Riddoch & Humphreys, 1993).**

Method

Participants

Twenty two volunteers (15 female) were recruited from Bangor University

student pool. Each received a course credit for participation. The age of

participants ranged from 18 – 36 years ($M = 21.2$ years). The data of six

participants was discarded, four exceeding the error criteria for the primary task,

and two exceeding the error criteria for the secondary task (outlined in Chapter 2).

Stimuli and Apparatus

Primary task

All stimuli and apparatus for the primary object recognition task were

identical to those used in Experiment 5.

Secondary Task

As described in Chapter 2.

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

blocks 1 to 6 in Experiment 1. Conditions and trials for the primary task followed

the same format as outlined in Chapter 2. For two blocks, participants performed

the object recognition task alone in both the minimal features and depth rotation

conditions (no task condition). During the remaining experimental blocks,

however, participants were requested to randomly generate digits between 1 and

20, in accordance with the criteria described in Chapter 2, concurrently with the

primary task. In the minimal features condition, stimuli were taken from the

BORB (see Figure 4.3). In the depth plane condition, the objects had a

foreshortened principal axis, as in all previous experiments.

Results

Mean percentage errors and range for optimal and non-optimal views in

all condition were calculated for analysis. Once again, overall errors for non-

optimal views exceeded those for optimal views, and this was a consistent finding

in all conditions. Mean error rates were also higher when participants were

concurrently performing the secondary task (see Table 4.2).

**Table 4.2: Mean percentage error, range and standard deviation for optimal
and non-optimal views, with and without a central executive secondary task
in both minimal feature and depth conditions**

	Mean (%)	Range (%)	Standard Deviation (%)
Overall errors	10.9	4.5 – 19.5	10.8
Overall errors Non-optimal	13.6	0 - 35	9.0
Overall errors Optimal	8.3	0 – 35	7.7
Overall errors: No secondary task – minimal features	5.0	0 - 15	4.7
Overall errors: No secondary task – depth plane rotation	11.5	0 - 35	10.2
Overall errors: Secondary task – minimal features	13.4	0 – 35	8.5
Overall errors: Secondary task – depth plane	13.9	5 – 32.5	8.1
No Secondary Task: Optimal – minimal features	3.2	0 - 10	3.7
No Secondary Task: Optimal – depth plane	7.5	0 – 25	10.4
No Secondary Task: Non-optimal – minimal features	6.7	0 – 15	5.0
No Secondary Task: Non-optimal – depth plane	15.4	5 – 35	8.4
Secondary Task: Optimal – minimal features	10.9	0 – 22.5	6.1
Secondary Task: Optimal – depth plane	11.5	5 – 30	6.7
Secondary Task: Non-optimal – minimal features	15.9	5 - 35	10.0
Secondary Task: Non-optimal – depth plane	16.4	5 – 32.5	7.8

A 2 x 4 repeated measures ANOVA performed on the reaction time data

showed a significant effect of view, $F(1,15) = 453.9$, $p<0.001$, indicating that

participants were significantly slower at recognising non-optimal, compared to optimal, views. There was also a main effect of task, $F(3,45) = 24.67$, $p<0.001$, in that responses were slower when performing the primary and secondary tasks together, than when performing the primary task alone. There was also a significant interaction between view and task, $F(3,45) = 41.8$, $p<0.001$. Figure 4.4 shows that there was no interaction between no task and random generation in the minimal features condition, but there was an interaction between no task and random generation in the depth rotation condition ($F(1,15) = 11.95$, $p<.005$). It was found that participants took relatively longer in the non-optimal view condition when performing random generation with depth rotated stimuli, than they did when performing concurrent random generation in the same viewing condition, with minimal features stimuli (see Figure 4.4). Statistical analysis in the no secondary task condition showed that there was a significant difference between optimal and non-optimal view recognition for minimal features stimuli, $t(15) = 8.24$, $p<0.001$, and for depth plane stimuli, $t(15) = 15.69$, $p<0.001$.

Analysis of errors showed a significant effect of both view, $F(1,15) = 64.22$, $p<0.001$, and task, $F(3,45) = 6.28$, $p<0.01$. There was no interaction between factors. Participants made more errors in non-optimal view recognition, compared to optimal view recognition and more errors in object recognition whilst concurrently performing the two tasks together, compared to performing object recognition alone.
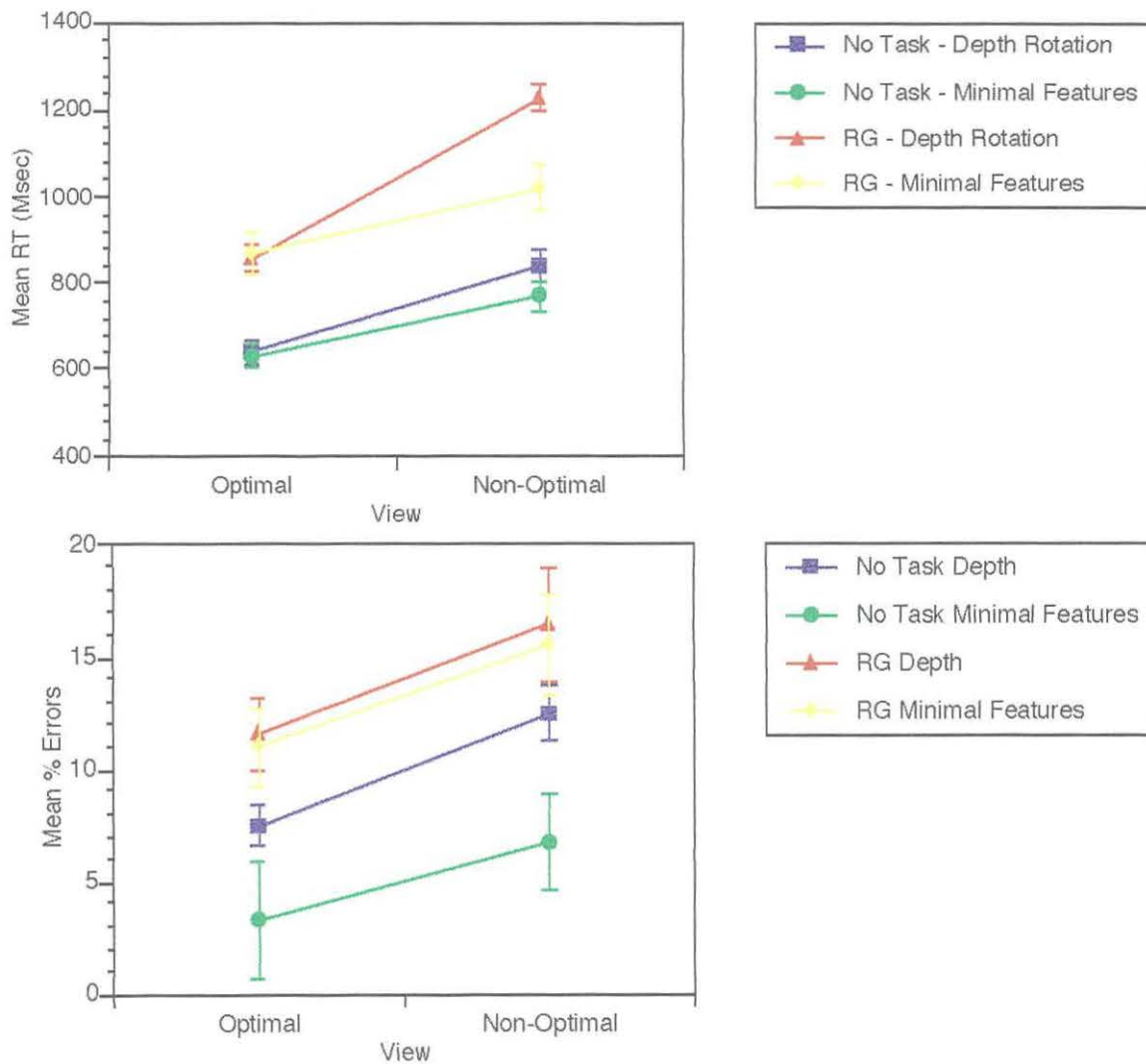
Figure 4.4: Mean reaction time and percentage errors for optimal and non-optimal views (Depth and Minimal Features), using random generation (RG) (1-20) as a central executive secondary task; Error Bars = ± 1 standard error *(SE)*.

Secondary Task

Mean overall errors in random digit generation ranged from 4% - 28% (M = 18.1%). Mean errors in the depth rotated condition were 17.3% (range, 4% - 26%), and in the minimal features condition ranged from 4% - 28% (M = 19%).

Comment

Data, once again, show a significant increase in reaction times and errors for non-optimal views. However, results indicate that, although recognition of stimuli with a foreshortened principal axis may involve executive resources (Baragwanath & Turnbull, 2002), this does not appear to be the case for minimal feature stimuli. The findings, therefore, confirm the stated hypotheses. These results concur with Jolicoeur (1990), Palmer et al. (1981) and Humphreys and colleagues (1984, 1986), in that it appears that the processing of minimal feature and foreshortened principal axis recognition may be functionally distinct.

Experiments 5 & 6: General Discussion

As with all the experiments in Chapter 3, the experiments in Chapter 4 show a consistent increase in response latencies and errors from optimal to non-optimal views, indicating that non-optimal view recognition may require some

form of additional processing (Farah, 1990; Turnbull et al., 1997; Turnbull & McCarthy, 1996). It was proposed in Chapter 3 that this resource may be considered to be the central executive of working memory (Logie, 1995).

However, in Chapter 3 all the non-optimal views were objects rotated in the depth plane (i.e. with a foreshortened principal axis), and Chapter 4 investigated the question of what other types of non-optimal recognition may enrol executive resources.

The results of Experiment 5 indicate that the processing of picture plane misorientation does not involve such resources. This was also the case for minimal feature stimuli, inferred by the results of Experiment 6.

Basic level categories, using the BORB inventory, have been employed in all previous experiments in this study. Discussions of conceptual hierarchies propose that the most psychologically fundamental level is that of the so called "basic" level category (Tanaka & Taylor, 1991). To further explore this issue, Experiments 7 and 8 address the question of the role of the central executive in subordinate category object constancy.

CHAPTER 5: EXPERIMENTS 7 & 8: THE

CENTRAL EXECUTIVE AND LEVEL OF

CATEGORISATION

Chapter 5 investigates the category level of an object, and the effect this has on the recognition process. Before presenting the experimental data related to this issue, the literature on categorisation is briefly reviewed.

Basic level categorisation: An extremely influential concept in visual categorisation is the hierarchy of three levels of object classification posited by Rosch, Mervis, Gray, Johnson and Boyes-Braem (1976): (1) basic; (2) superordinate; and (3) subordinate. "Basic" level may be considered as the classification that both adults and children spontaneously employ to name an object, for example, dog. Superordinate refers to the category to which the basic level word belongs, i.e. animal, and the subordinate level increases the specificity of the basic level name by defining the object, i.e. terrier.

The underlying principle of this hierarchical structure is that of class inclusion. The superordinate class includes all objects in the basic and subordinate levels. In this way, basic level categories are at an intermediate level of a general-to-specific hierarchy, i.e. animal, dog, terrier. Generalisation proceeds "upwards" from the basic level, and specialisation proceeds "downwards" (Lakoff, 1987).

The basic level was shown by Rosch and her colleagues (1976) to be the labels that are first learned by children, and those that are the most inclusive at which a generalised shape of category exemplar is identifiable and imaginable, i.e. the most psychologically fundamental (Tanaka & Taylor, 1991). The authors demonstrated the special status of basic level for object recognition in both free naming and category verification tasks. Rosch et al.'s (1976) findings were interpreted as indicative that subjects first identify objects at the basic level and then access the corresponding superordinate or subordinate categories. The initial contact between the percept and the semantic representation has been referred to as "primal access" or "entry point"[1] (Biederman, 1987).

It has been proposed that basic level categories maximise the number of shared attributes of its members and minimise the number of attributes shared with members of other categories, i.e. it maximises the distinctiveness between classes and the informativeness within classes (Biederman, Subramaniam, Bar, Kalocsai & Fiser, 1999). Whilst basic level categories achieve this criterion, superordinate and subordinate categories do not (Rosch, 1978). For example, the attributes of members of the basic category of car provide enough information to distinguish them from members of the categories of boat or train. All members of the category car have similar attributes, whilst few of these attributes are shared with boats or trains. Conversely, the number of shared attributes between members of the superordinate category vehicle, are minimal. Similarly, many

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[1] Jolicoeur et al. (1984) used the term entry-point level as constituting the basic level for many objects, with the exception of distinctive or atypical exemplars of a basic level category, which have their own entry

attributes of the subordinate categories of Ford or Toyota are shared, and thus these categories are less distinguishable from each other.

It is, therefore, necessary to have knowledge of the defining characteristics or features of a category in order to categorise stimuli (Slater, 1998). Slater (1998) proposed that when we categorise our perceptions we allocate them by way of the absence or presence of invariant information or features that define that category. Rosch and Mervis (1975) demonstrated that the more attributes an object has in common with other members of the category, and the fewer it has in common with contrasting categories, the more it is judged to be prototypical of a category. Hence, in the vast majority of cases, we can define a prototype as being an average or typical member of a category. Prototypes may be accessed to allocate new members to the category, as well as to organise, and define other members within that specific category (Rosch & Mervis, 1975).

The multiple features theory of categorisation (Fersen & Lea, 1990: Huber & Lenz, 1996, Jitsumari & Yoshihara, 1997) proposes that no single feature is necessary or sufficient to determine category membership, but suggests that if an object contains enough features to be associated with a particular category, then classification to that category will ensue. For example, the features of a tree may comprise a shape that is smaller at the bottom than the top, a roughly-textured trunk that meets the ground from which there are protruding branches, and with green leaves attached to those branches. Not all trees will conform to all these criteria, but objects containing a subset, as opposed to those that contain none of

point into semantic memory defined at a subordinate level, to be discussed later.

the features, are more likely to classified as trees (Peissig, Wasserman, Young &

Biederman, 2002).

Subordinate level categorisation: The literature on categorisation posits

then that only subordinate level is less abstract than basic level classification

(Biederman et al., 1999), and several experiments, using the word/picture

verification paradigm, have shown that typical members of basic level categories

represent the particular level of abstraction to which objects are first identified

(Brownell, 1978; Gellatly & Gregg, 1975; Hutcheon, 1970; Murphy & Smith,

1982; Rosch et al., 1976; Smith et al., 1978). This has also been shown to be the

case when using the naming paradigm (Gellatly & Gregg, 1975; Hutcheon, 1970;

Segui & Fraise, 1968; Smith, Balzano & Walker, 1978).

Jolicoeur, Gluck and Kosslyn (1984), suggested that subordinate level

recognition required more detailed perceptual analysis, together with a more

detailed search through semantic memory to provide more specific names.

Concurring with Jolicoeur et al. (1984) and Rosch et al. (1976), Humphreys et al.

(1988) proposed that basic level recognition occurs prior to subordinate level

categorisation. Humphreys et al. (1988) suggested, however, that it was animate,

but not inanimate objects, that required additional processing. This prediction

was based on the fact that category members of animate objects have similar

perceptual structures, and hence activate competition between numerous

candidate representations. It was proposed that perceptual overlap combines with

semantic overlap and produces decrements in performance, and it was contended

that inanimate categories were less structurally similar than animate categories

(the similar/dissimilar hypothesis). In concurrence, many accounts propose that a living things deficit reflects a disorder at the level of structural descriptions (e.g. Riddoch & Humphreys, 1987; Riddoch, Humphreys, Coltheart & Funnell, 1988; Sartori & Job, 1988). Recent research has added support and demonstrated that categorical perception is closely tied to inter-object similarity (Newell, Buelthoff & Heinrich, 2002).

Interestingly, however, Rosch et al. (1976) found that the responses of an aeroplane mechanic, were quite different from other subjects, which led to the proposal that it was not merely the object itself, but also the interaction between the perceiver and the world, that specifies the basic level (Rosch, 1978). Lakoff (1987) concurred with Rosch (1978), in proposing that it is the manner in which people perceive, imagine and organise information about particular objects, that constitutes basic level categories.

Whilst agreeing that objects are typically identified at the basic level, and that additional perceptual processing is required for subordinate level classification, Jolicoeur et al. (1984) challenged the "basic first" hypothesis. The authors demonstrated a subordinate level advantage over either basic or superordinate level stimuli when atypical exemplars of subordinate categories were named. For example, a penguin or an ostrich may be classified as a penguin or an ostrich more quickly than as a bird. It was suggested that birds constituted a category with high shape variability (Biederman et al., 1999). Furthermore, as properties of birds typically include flying and singing, and as penguins and ostriches do neither, they represent distinctive or atypical exemplars of the bird

category (Tanaka & Taylor, 1991). As such, penguins and ostriches have their own entry points into semantic memory defined at the subordinate level (Jolicoeur et al., 1984). Similar results, using different stimuli, were also obtained by Murphy & Brownell (1985). The authors' (1985) differentiation hypothesis provided a more parsimonious account of the findings, in proposing that the accessibility of a category is mediated by distinctiveness and specificity, that is, the more differentiated the category, the more readily it can be accessed.

For most individuals, however, basic level is the most inclusive level of abstraction, but it has also been shown that certain individuals describe basic level at a more specific level of abstraction. Hence, domain-specific knowledge, as well as typicality, contribute to category differentiation. It is proposed that expertise is likely to shift the entry points of many objects to subordinate levels, and therefore, increase the accessibility of the subordinate level (Rosch et al., 1976; Tanaka & Taylor, 1991). For example, the basic level for a fisherman would be trout, bass and salmon, which would be considered the subordinate level for non-fishermen. This work prompted numerous studies examining the differences between experts and novices (e.g. Biederman & Shiffrar, 1988; Chase & Simon, 1973; Chi, Feltovich & Glaser, 1981; Murphy & Wright, 1984). Such exceptions, of typicality and expertise, to the basic level first hypothesis indicate that categorisation appears to be continually reshaped and altered by learning and experience (Tanaka & Taylor, 1991).

Consistent with object recognition theories for basic level categories, the recent debate on subordinate level identification, has coalesced around the

theoretical perspectives of metric templates (e.g. Bülthoff & Edelman, 1992; Edelman, 1995; Edelman & Bülthoff, 1992; Edelman & Intrator, 2000; Humphreys & Khan, 1992), and geon structural descriptions or invariant parts (e.g. Beiderman et al., 1999; Biederman, 1987; Biederman & Gerhardstein, 1993; Gerhardstein & Biederman, 1991; Peissig et al., 2002).

Categorisation and object recognition: The effects of categorisation on the object recognition process has been the focus of a number of studies. Bülthoff and Edelman (1992) and Edelman and Bülthoff (1992), employed three-dimensional tube-like objects and bent paper clips respectively, and argued that novel views were recognised by way of either interpolation or extrapolation processes (e.g. Ullman, 1989; Ullman & Basri, 1991). It was demonstrated, that even when stimuli were presented with rich surface, stereo, and motion information, there was a noticeable effect of orientation. The data led to the proposal that object recognition was strongly viewpoint-dependent, and that three-dimensional subordinate level objects were represented as a collection of specific views, each view corresponding to a snapshot of an object from a particular aspect (Edelman & Bülthoff, 1992).

Humphreys and Khan (1992) also investigated view generalisation and used novel objects with a heterogeneous set of parts. The authors considered these parts to be comparable to Biederman's (1987) geons, and Marr and Nishihara's (1978) generalised cones, being symmetrical about the axis and possessing a main axis of elongation. Participants were trained with one view and then tested with novel depth-rotated views. Findings suggested limited

generalisation to novel views, and confirmed the prediction that view-specific representations were formed during the training period, a conclusion confirmed by Jolicoeur and Humphrey (1998).

However, Jolicoeur et al. (1984), and more recently, Kiefer (1996), demonstrated that short exposure can disrupt subordinate, but not basic or superordinate, categorisation decisions. Jolicoeur et al. (1984) proposed that when the basic level name is superordinate to the required level (e.g. one names the object as dog, but is asked about spaniels), it is necessary to collect additional information to determine the subtype. In this case, one may have to look towards the ears of the dog, for example, to check the colour, aspect ratio or the degree of curvature, more carefully . Short exposure, it is argued, does not allow the latter processing.

Jolicoeur and Humphrey (1998), Bülthoff and Edelman (1992), Edelman and Bülthoff (1992), Humphreys and Khan (1992) and Kiefer (1996) then propose that research on the recognition of unfamiliar views of novel three-dimensional objects consistently demonstrates a viewpoint-dependent account of object recognition. The authors concede, however, that the dependency of the results using structurally similar objects, may be questionable (Jolicoeur & Humphrey, 1998).

Using stimuli rotated in the picture plane, Dickerson and Humphreys (1999), also proposed that the strongest effects of misorientation occurred at the subordinate level. This research, therefore, supported previous research in that basic level objects were, on average, more quickly identified than subordinate

level objects. The authors claimed that within-category similarity mediated the

recognition of misoriented objects, which they proposed involves two processes:

1) orientation-dependent mental rotation; and 2) the extraction of orientation-

independent features/parts, derived from non-accidental image properties (cf.

Biederman, 1987). Whilst proposing two routes to object constancy, the authors

suggested that orientation-independent information was employed only in

superordinate level identification, but that mental rotation was required for both

base and subordinate level categorisation. It was further proposed that

orientation-independent information involved multiple component parts of objects

(e.g. cylinders, spheres, bricks), but that the spatial relations between these parts

were not necessarily computed for recognition.

In a similar vein, Vannucci and Viggiano (2000) demonstrated that

viewpoint-dependent mental rotation was involved in the recognition of plane-

rotated stimuli. The authors, however, proposed a viewpoint-dependent

mechanism for animal identification, and a viewpoint-independent mechanism for

vegetable identification. It was considered that some stimuli are orientation-

independent (e.g. vegetables and tools), in that they are frequently viewed at

many different orientations, and, therefore, may be identified via viewpoint-

independent distinctive features. Whilst other stimuli that may be considered

preferentially oriented with respect to internal and external references (e.g.

animals and furniture). That is, they are orientation-dependent, in that they are

not regularly viewed from many different angles, and hence are represented in

long term memory in one particular view, and necessitate some form of
normalisation process for recognition.

Vannucci and Viggiano's (2000), as well as Dickerson and Humphrey's
(1999) findings, then, support the hypothesis that object recognition processes
should be considered as a continuum spanning viewpoint-dependent and
viewpoint-independent mechanisms of identification, which may be related to
both familiarity with the most frequently experienced views, and physical
characteristics.

In concurrence, with viewpoint-dependent proponents, Biederman (1987),
Biederman and Gerhardstein (1993), and Gerhardstein and Biederman (1991) also
proposed that in order to determine subordinate class, a basic level classification
is first performed. On the other hand, Biederman and colleagues (e.g. 1987, 1991,
1993) proposed that after basic level classification, there ensues a search for
viewpoint-independent distinguishing geon differences in order to classify
stimuli.

Biederman et al. (1999) proposed a hierarchical strategy for distinguishing
amongst subordinate level entities, whereby a viewpoint-dependent mechanism is
employed only in the most difficult classifications tasks. At the top of the
hierarchy, is the identification of GSDs of subordinate pairs, which differ greatly
in structural relations and geons, together with large metric differences, such as a
grand piano and an upright piano. In this case, it is argued that recognition is fast,
accurate and viewpoint-independent. Such subordinate stimuli, although rare, are

more readily discriminated than some highly similar basic-level classes, such as a fox and coyote (Biederman et al., 1999).

Secondly, an object may be initially classified as a car (basic level) and subsequently, a particular area of the image is isolated for analysis, for example, a logo (logos are designed to differ in non-accidental properties). In this instance, distinctive GSDs are present at a small scale in a complex object. Here classification, once again, is made based on viewpoint-independent differences of that particular region (Biederman et al., 1999).

Finally, and at the bottom of the hierarchical tree, in the absence of non-accidental property differences, classification would require the discrimination of small differences in aspect ratio or curvature of an area. For example, when distinguishing between a 3" or 4" nail, or between bent paper clips. Biederman et al. (1999) proposed that in this instance alone, would classification require a template specifying precise metric values. Biederman et al. (1999) have argued that stimuli, such as bent paper clips, employed by many proponents of view-based accounts, do not activate normal recognition strategies, in that they lack symmetry, and are not distinguishable by their parts or spatial relations

Viewpoint-independent theorists, therefore, have proposed that subordinate level classification involves a number of visual processes, but argue that in the vast majority of cases, subordinate level classification is based on distinctive GSDs readily communicated in terms of parts, their relations and their viewpoint-invariant properties (e.g. Hummel, 2001; Hummel & Stankiewicz 1998). It is further contested that the presence of such descriptions minimises

recognition latencies and in certain cases may result in no appreciable rotation costs at all (Biederman et al., 1999). As such, advocates of viewpoint-independent accounts of object recognition maintain that geon structural descriptions provide a framework for training people to distinguish between even very familiar objects by defining clear perceptual boundaries, in the same manner as they do for basic level classification. It is however, accepted that viewpoint-dependent mechanisms may be employed for identification is a certain situations.

In agreement with the cognitive literature, current object categorisation theory has proposed that basic level categorisation, and subsequent subordinate level categorisation, may rely on distinct cognitive processes (Tanaka, Luu, Weisbrod & Kiefer, 1999). It is contended that subordinate level categorisation is linked to perceptual processes involving both features (e.g. small size and brown, for a sparrow), and parts (e.g. long beak, for a woodpecker), and this requires finer perceptual analysis than basic level stimuli (e.g. feathers and wings for birds). Thus, it is proposed that subordinate level stimuli require increased visual analysis (Tanaka et al., 1999).

Supporting this assertion, Gauthier, Anderson, Tarr, Skudlarski and Gore (1997) and Tanaka et al. (1999) specify that the additional visual processing, required to verify subordinate over basic level stimuli, is associated with activation of the fusiform and inferior temporal gyri (FIT). Consistent with this, Martin, Wiggs, Ungerleider and Haxby (1996) and Schachter, Reiman, Uecker, Polster, Yun and Cooper (1995), also proposed a specific "subordinate" area in the brain, namely the temporal poles.

Similarly, Kosslyn, Alpert and Thompson (1995) provided PET evidence to demonstrate that different processes were employed at different levels of analysis. Specifically, Kosslyn and colleagues (1995) proposed that additional perceptual information was required to evaluate subordinate level categories and found activation in the area of the brain that implements the performance of top-down processes.

Neuropsychology of categorisation: Neuropsychological studies have provided evidence of category dissociations between living (e.g. Laiacona, Capitani & Barbarotto, 1997; Moss, Tyler & Jennings, 1997; Sartori & Job, 1988; Sheridan & Humphreys, 1993; Warrington & Shallice, 1984), and inanimate objects (e.g. Farah et al., 1996; Caramazza & Shelton, 1998; Hillis & Caramazza, 1991; Sacchett & Humphreys, 1992; Warrington & McCarthy, 1987).

Warrington and Shallice (1984) proposed independent modules for input modalities, and argued that the identification of living things (e.g. fruit, vegetables, animals) involved the retrieval of fine-grained sensory information. For example, distinguishing between a raspberry and a strawberry necessitates detailed information on colour, size, shape and texture (Humphreys & Forde, 2001). In contrast, Warrington and Shallice (1984) suggested that recognition of non-living things was determined by their functional significance (e.g. furniture, tools, vehicles).

Warrington and McCarthy's (1987) suggestion on the sensory/functional dichotomy was that visual information would not be stored in visual modules, but in visual "channels". The authors proposed that different modalities of experience

(visual, auditory, tactile kinesthetic, etc.) contribute in retrieval of the meaning of objects. Different sensory or motor information would differ in the degree of importance for different objects. Furthermore, as initially proposed by Warrington and Shallice (1984), the authors suggested that perceptual/sensory information was required for many living things, whereas functional information, including motor actions, may be critically important for non-living things. By this account, fine-grained category-specific deficits may be reflected by different patterns of "weighting" across "channels".

Research has added support for the sensory/functional "weighting" hypothesis (Laws, 1998; Laws, Humber, Ramsey & McCarthy, 1995). Most recently the functional imaging studies of Gerlach, Law and Paulson (2002) have provided evidence for the "weighting" concept, but suggest that categorisation relies on knowledge regarding whether an object is manipulable or non-manipulable, as opposed to natural or manmade.

Warrington and McCarthy (1987) further proposed that "channels" may store visual information in a number of sub-channels (e.g. colour, size and shape). For example, shape information may be more important when distinguishing between a daffodil and a tulip, whereas colour information would be important for distinguishing between a raspberry and a blackberry. Patients may, therefore, show impairment within subsets of both living and non-living categories and indeed such selective deficits have been observed for fruit and vegetables (e.g. Farah & Wallace, 1992; Forde, Francis, Riddoch, Rumiati & Humphreys, 1997; Hart, Berndt & Caramazza, 1985; Vannucci & Viggiano, 2000), animals (e.g.

Caramazza & Shelton, 1998; Hart & Gordon, 1992; Vannucci & Viggiano, 2000), tools (e.g. Warrington & McCarthy, 1987), furniture and indoor objects (e.g. Yamadori & Albert, 1973), and body parts (e.g. Dennis, 1976.).

Sartori, Job, Miozzo, Zago and Marchiori (1993) have used Marr's (1982) model of visual object recognition to account for category-specific deficits for living things, whereby structural description of objects are represented in a hierarchical form. At the top of the hierarchy are general category exemplars, which lead to increasingly detailed descriptions, down to distinguishing between subordinate level objects. The authors proposed that the living items deficits in patients, reflected accessing the most detailed levels of these structural hierarchies, proposing that living things have "deeper" representations compared to non-living things. Such a theory is consistent with that of Humphreys et al.'s (1988) "finer-grained" processing at the level of structural descriptions, which results as a consequence the structural similarity stimuli.

Based on the living/non-living or sensory/functional dichotomy, Humphreys and Forde (2001) have proposed the Hierarchical Interactive Theory (HIT), which purports to accommodate different patterns of deficits in contrasting patients. The HIT is a three-tier model of memory representation for object naming which proposes an interactive approach, whereby different forms of knowledge can be used for different classes of objects.

Although the living/non-living dichotomy has been extremely influential, and formed the basis of much empirical research in category-specific deficits, it has been argued, that in many cases, the patterns of impaired and preserved

performance demonstrated by patients, undermines such a simple division (Cree

& McRae, 2001; Davidoff, 2001; Lambon-Ralph & Gerrard, 2001; Leek &

Pothos, 2001; Pillon & Samson, 2001). Moreover, the idea of high structural

similarity for living things and low structural similarity for non-living things has

also been questioned (Laws, 2001; Laws & Neve, 1999; Leek & Pothos, 2001;

Mahon & Caramazza, 2001; Turnbull & Laws, 2000). It has been argued that

living things may be easier to recognise, after disruption to stored structural

knowledge, than are man-made objects (Turnbull & Laws, 2000). The authors

contend that descriptions for non-living things may require more structural

information for recognition, and that such categories may, in fact, be harder to

identify.

Together with the above criticisms, it has been further proposed that

individual differences and flexibility in categorisation tasks relating to typicality,

expertise, knowledge and experience, must also be taken into account when

specifying a model of object categorisation (Leek & Pothos, 2001; Tanaka 2001).

To summarise, it has been argued that both viewpoint-independent perceptual

characteristics, e.g. geon structural descriptions (e.g. Biederman, 1987; Biederman &

Gerhardstein, 1993; Hummel & Biederman, 1992; Peissig et al., 2002), and

viewpoint-dependent metric properties (e.g. Edelman & Bülthoff, 1992; Humphreys

& Khan, 1992; Keifer, 1996), or indeed both (e.g. Biederman et al., 1999; Dickerson

& Humphreys, 1999; Vannucci & Viggiano, 2000), are involved in the

representations mediating categorisation. The debate continues regarding internal

representations and processes, but of importance in this research, both viewpoint-

dependent and viewpoint-independent theorists claim that basic level recognition is performed prior to subordinate level recognition, and that some form of additional processing is required, possibly in FIT (Gauthier et al., 1997; Tanaka et al., 1999).

This chapter presents two experiments investigating the effects of concurrent performance of the central executive secondary task on both base and subordinate level stimuli from optimal and non-optimal viewpoints. In Experiment 7, the non-optimal view condition, for both subordinate and base levels of categorisation, involves stimuli with foreshortened principal axes. In Experiment 8, the non-optimal view condition, for both subordinate and base level stimuli, involves stimuli with a critical feature occluded (as outlined in the BORB, see Chapter 2).

Experiment 7: Depth plane misorientation and level of categorisation

In the seminal work of Rosch et al. (1976) it was argued that basic level categories represented the initial and speediest label assigned to an object, and this category level was more readily verified than subordinate level stimuli. It was proposed that recognition latency was due to subordinate category members having similar perceptual structures (Humphreys et al., 1988, 1995; Jolicoeur et al., 1984; Sheridan & Humphreys, 1993). It follows then that distinguishing between objects within the same category may increase response latencies.

It is predicted that: (a) Concurrent performance of the central executive secondary task will selectively disrupt basic level stimuli for non-optimal views,

in this case, rotated in depth, and (b) this effect will be greater for subordinate level stimuli.

Method

Participants

Twenty three volunteers (11 female) were recruited from Bangor University student pool. Each received a course credit for participation. The age of participants ranged from 18 – 24 years ($M = 19.8$ years). The data of seven participants was discarded, five exceeding the error criteria for the primary task as outlined in Chapter 2, and two exceeding the error criteria for the secondary task.

Stimuli and Apparatus

Primary task

Apparatus for the primary object recognition task were identical to those used in previous experiments. The 20 basic level stimuli belonged to one of four categories, those being animal, vehicle, furniture or household equipment (see Appendix D). The majority of the base stimuli were taken from the BORB inventory, as previously. However, it was necessary to produce a further eight objects and these were adapted from the Snodgrass and Vanderwart (1980) corpus of drawings, to be of the same specifications as the BORB stimuli (see Figure

5.1). The 20 subordinate level stimuli also belonged to one of four categories, those being cat, boat, chair and clock (see Appendix D), and each was consistent with the four categories in the base level condition, being animal, vehicle, furniture and household equipment. These stimuli were adapted from Dickerson and Humphreys (1999) (see Figure 5.2). The words presented in the base conditions were as previously employed, whereas subordinate words (e.g. tiger, sailboat, grandfather clock, etc.) were presented in the subordinate conditions.
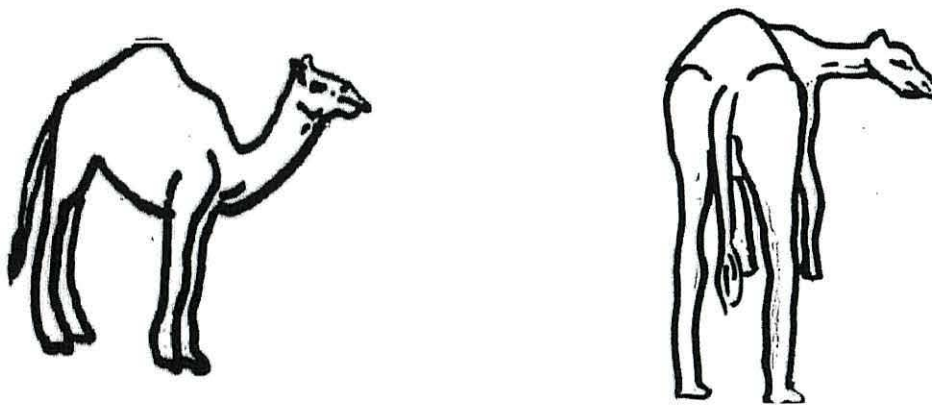
Figure 5.1: Example of a camel from an optimal and non-optimal (foreshortened principal axis) view. A base level stimulus in the animal category.

Figure 5.2: Example of a rocking chair from an optimal and a non-optimal (foreshortened principal axis) view. A subordinate level stimulus in the chair (furniture) category.

Secondary Task

As described in Chapter 2

Design/Procedure

Six blocks of experimental trials were presented to all participants.

Conditions and trials for the primary task followed the same format as outlined in

Chapter 2. For two blocks, participants performed the object recognition task

alone in base and subordinate conditions (no task condition). During the

remaining experimental blocks, however, participants were requested to randomly

generate digits between 1 and 20, in accordance with the criteria described in

Chapter 2, concurrently with the primary task. In the optimal and non-optimal

conditions, participants were presented with both base and subordinate level stimuli. In the non-optimal condition, all stimuli had a foreshortened principal axis, as in previous experiments.

Results

Primary task

Mean percentage errors and range for optimal and non-optimal views in all condition were calculated for analysis. Once again, overall errors for non-optimal views exceeded those for optimal views, and this was a consistent finding in all conditions. Mean error rates were also higher when participants were concurrently performing the secondary task. Errors in the subordinate level condition exceed those in the base level condition in all instances (see Table 5.1).

Table 5.1: Mean percentage error, range and standard deviation for optimal and non-optimal views, with and without a central executive secondary task in both subordinate and base conditions

	Mean (%)	Range (%)	Standard Deviation (%)
Overall errors	6.7	3.7 – 14.1	5.8
Overall errors Non-optimal	8.6	0 – 25.0	6.3
Overall errors Optimal	4.7	0 – 20.0	4.6
Overall errors: No secondary task – subordinate level	3.7	0 – 15.0	3.8
Overall errors: No secondary task – base level	3.5	0 – 35.0	3.3
Overall errors: Secondary task – subordinate level	11.0	0 – 25.0	5.2
Overall errors: Secondary task – base level	8.4	0 – 20.0	6.8
No Secondary Task: Optimal – subordinate level	2.9	0 – 10.0	3.1
No Secondary Task: Optimal – base level	2.3	0 – 10.0	3.1
No Secondary Task: Non-optimal – subordinate level	5.3	0 – 15.0	3.8
No Secondary Task: Non-optimal – base level	4.6	0 – 10.0	3.4
Secondary Task: Optimal – subordinate level	8.4	0 – 12.5	3.7
Secondary Task: Optimal – base level	5.7	0 – 20.0	5.4
Secondary Task: Non-optimal – subordinate level	13.5	2.5 – 25.0	5.3
Secondary Task: Non-optimal – base level	11.0	2.5 – 17.5	7.2

A 2 x 2 x 2 repeated measures ANOVA performed on the reaction time data showed a significant effect of view, $F(1,15) = 105.06$, $p<0.001$, in that non-optimal views were consistently recognised slower. There was also a main effect of task, $F(1,15) = 88.74$, $p<0.001$, indicating that the concurrent performance of primary and secondary tasks increased response latencies, compared to performance on the primary task alone. There was no effect of category. Data were, therefore, collapsed across category and a 2 x 4 ANOVA showed a significant effect of view $F(1,15) = 15.06$, $p<0.001$, and task $F(3,45) = 48.31$, $p<0.001$, together with a significant interaction between view and task, $F(3,45) = 9.76$, $p<0.001$. There were interactions between no task and secondary task in both base and subordinate conditions for non-optimal view recognition. Thus participants took relatively longer to recognise non-optimal views, compared to optimal views, whilst performing the secondary task, both for base and subordinate stimuli (see Figure 5.3). Statistical analysis in the no secondary task condition showed that there was a significant difference between optimal and non-optimal view recognition for basic level stimuli, $t(15) = 8.31$, $p<0.001$, and for subordinate level stimuli, $t(15) = 8.65$, $p<0.001$.

Analysis of errors showed a significant effect of both view, $F(1,15) = 38.22$, $p<0.05$, and task, $F(3,45) = 12.60$, $p<0.05$. There was no significant interaction between the factors. Participants made more errors in non-optimal views than in optimal views in all conditions (see Figure 5.3).
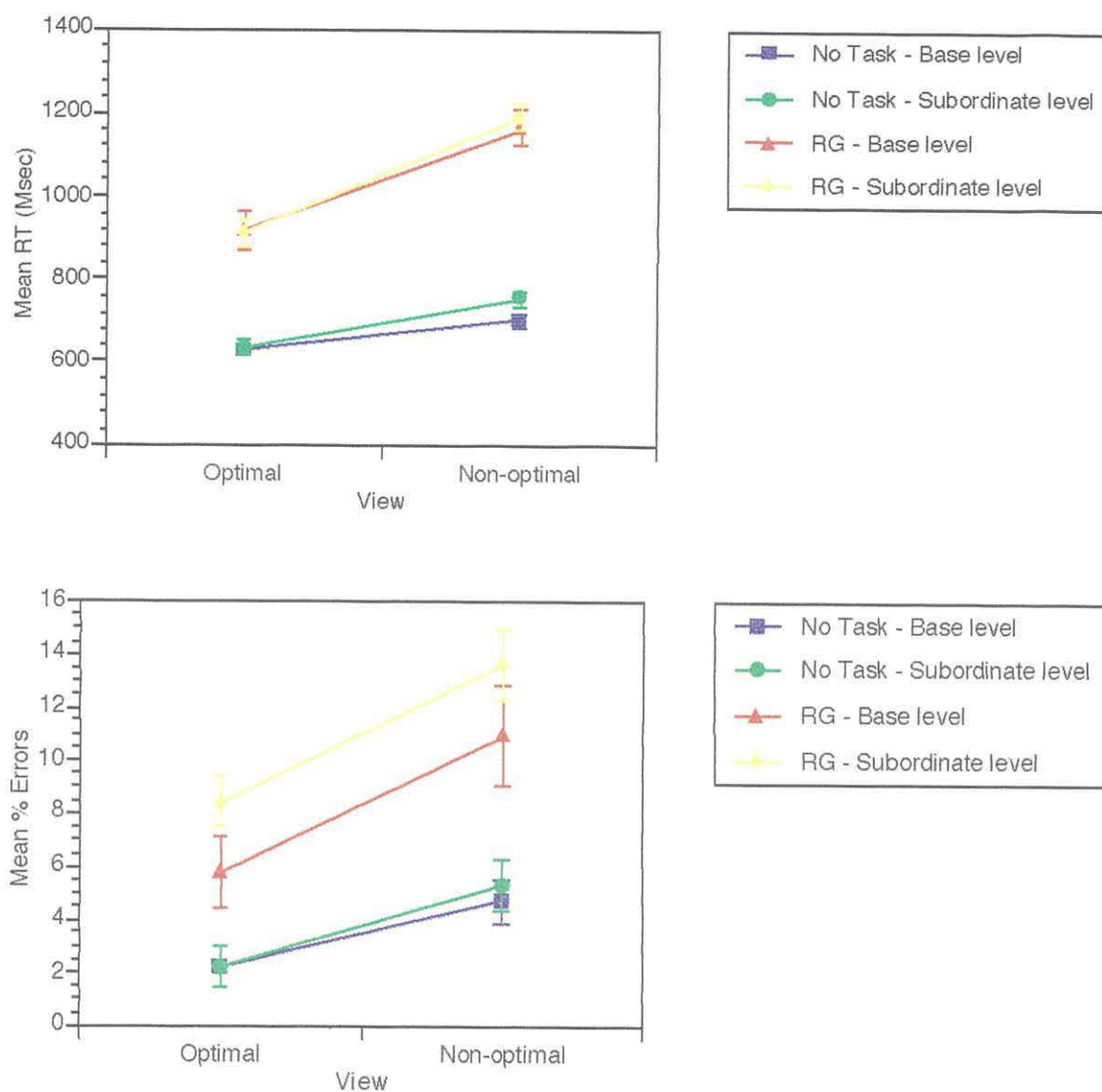
Figure 5.3: Mean reaction time and percentage errors for optimal and non-optimal view (foreshortened principal axis), for base and subordinate level stimuli, using random generation (1 – 20) as a central executive secondary task; Error Bars = ± 1 standard error *(SE)*.

Secondary Task

Mean overall errors in random digit generation ranged from 0% - 26% (M = 11.0%). Mean errors in the base condition were 5.1% (range, 0% - 14%), and in the subordinate condition ranged from 0% - 16% (M = 5.8%).

Comment

The data are consistent with the findings of Experiment 5, and previous experiments, whereby executive resources appear to be preferentially involved in the recognition of objects with foreshortened principal axes. Furthermore, the findings confirm the hypotheses that concurrent performance of the central executive secondary task selectively disrupts base level stimuli, and that this effect is greater for subordinate level stimuli.

Experiment 8: Minimal features and level of categorisation

Experiment 8 addresses a similar question to that of Experiment 7, with the exception that the non-optimal view, in this instance is minimal features, as opposed to foreshortened principal axis. This being the case, and based on the findings of Experiment 6, the prediction is that concurrent performance of a central executive secondary task should <u>not</u> selectively disrupt stimuli from a non-optimal view, at either base or subordinate level of categorisation. The non-

optimal view, in this case, being minimal features stimuli from BORB (Riddoch & Humphreys, 1993).

Method

Participants

Twenty one volunteers (12 female) were recruited from Bangor University student pool. Each received a course credit for participation. The age of participants ranged from 18 – 39 years ($M = 21.3$ years). The data of five participants was discarded, three exceeding the error criteria for the primary task as outlined in Chapter 2, and two exceeding the error criteria for the secondary task.

Stimuli and Apparatus

Primary task

Stimuli and apparatus for the primary object recognition task were identical to those used in experiment 7, with the exception that all non-optimal views were objects with a salient feature occluded (minimal features condition), as described in Chapter 2, and in accordance with the BORB inventory.

Secondary Task

As described in Chapter 2.

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

blocks 1 to 6 in Experiment 7. Conditions and trials for the primary task followed

the same format as outlined in Chapter 2. For two blocks, participants performed

the object recognition task alone in both base and subordinate conditions (no task

condition). During the remaining experimental blocks, however, participants

were requested to randomly generate digits between 1 and 20, in accordance with

the criteria described in Chapter 2, concurrently with the primary task. In the

optimal and non-optimal view conditions, participants were presented with both

base and subordinate level stimuli (see Figures 5.4 and 5.5). In the non-optimal

view condition, all stimuli were minimal feature objects.
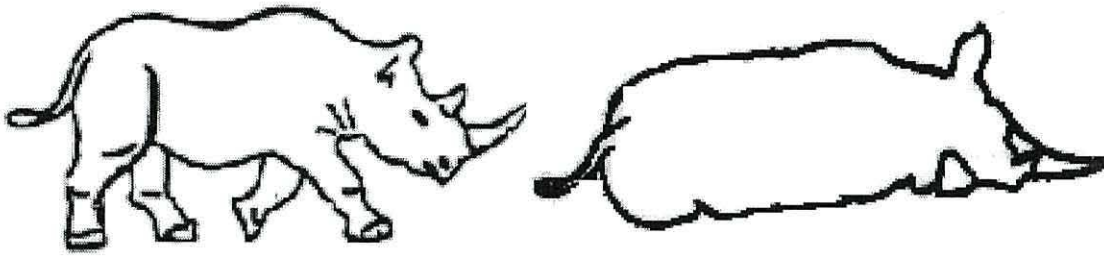
Figure 5.4: Example of a rhino from an optimal and non-optimal view (minimal features). A base level stimulus in the animal category.
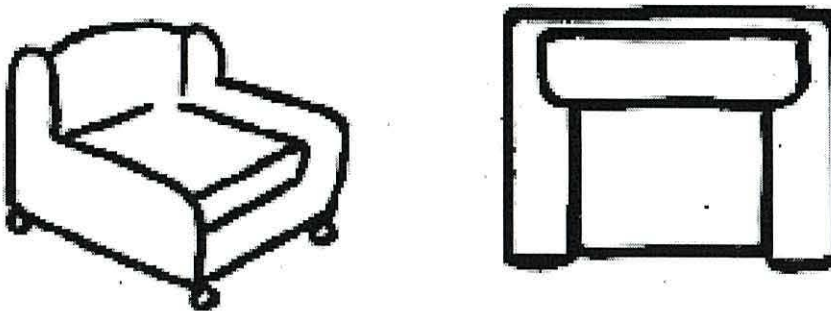
Figure 5.5: Example of an armchair from an optimal and a non-optimal view (minimal features). A subordinate level stimulus in the chair (furniture) category.

Results

Mean percentage errors and range for optimal and non-optimal views in all conditions were calculated for analysis (see Table 5.2). Once again, overall errors for non-optimal views exceeded those for optimal views, and this was a consistent finding in all conditions. Mean error rates were also higher when

participants were concurrently performing the secondary task. Errors in the

subordinate level condition exceed those in the base level condition in all

instances.

Table 4.4: Mean percentage error, range and standard deviation for optimal and non-optimal views, with and without a central executive secondary task

	Mean (%)	Range (%)	Standard Deviation (%)
Overall errors	12.5	6.6 – 19.1	7.7
Overall errors Non-optimal	15.0	0 – 42.5	9.6
Overall errors Optimal	8.0	0 – 25.0	6.0
Overall errors: No secondary task – subordinate level	9.3	0 – 35.0	3.4
Overall errors: No secondary task – base level	7.9	0 – 25.0	6.2
Overall errors: Secondary task – subordinate level	16.5	5 – 42.5	9.1
Overall errors: Secondary task – base level	12.1	0 – 35.0	8.7
No Secondary Task: Optimal – subordinate level	6.5	0 – 20.0	5.6
No Secondary Task: Optimal – base level	5.0	0 – 10.0	4.0
No Secondary Task: Non-optimal – subordinate level	12.1	0 – 35.0	7.9
No Secondary Task: Non-optimal – base level	10.9	0 – 25.0	8.4
Secondary Task: Optimal – subordinate level	12.3	5 – 25.0	5.6
Secondary Task: Optimal – base level	8.2	0 – 22.5	6.2
Secondary Task: Non-optimal – subordinate level	20.7	10 – 42.5	10.0
Secondary Task: Non-optimal – base level	16.0	2.5 – 35.0	9.5

A 2 x 2 x 2 repeated measures ANOVA performed on the reaction time data showed a significant effect of view, $F(1,15) = 91.26$, $p<0.001$, task, $F(1,15) = 136.66$, $p<0.001$, and of category, $F(1,15) = 520.49$, $p<0.001$, indicating that optimal view recognition was performed more efficiently than non-optimal view recognition, primary task alone was performed more efficiently than concurrent performance of primary and secondary tasks, and subordinate level stimuli took significantly longer to recognise than base level stimuli. There was also a significant interaction between task and category, $F(1,15) = 8.89$, $p<0.05$, but there were no interactions between the remaining factors. It was found that response latencies increased when performing the primary and secondary tasks concurrently for both the base and subordinate level stimuli, compared to when participants were performing the primary task alone. However, non-optimal recognition was not selectively disrupted in either base or subordinate conditions with performance of random generation (see Figure 5.6). Statistical analysis in the no secondary task condition showed that there was a significant difference between optimal and non-optimal view recognition for basic level stimuli, $t(15) = 8.01$, $p<0.001$, and for subordinate level stimuli, $t(15) = 8.51$, $p<0.001$.

Analysis of errors showed a significant effect of view, $F(1,15) = 10.96$, $p<0.05$, task, $F(1,15) = 7.96$, $p>0.05$, and category, $F(3,45) = 96.16$, $p<0.05$, but there was no significant interaction between the factors. Participants, did, however, make more errors in non-optimal views than in optimal views, in all conditions (see Figure 5.6).
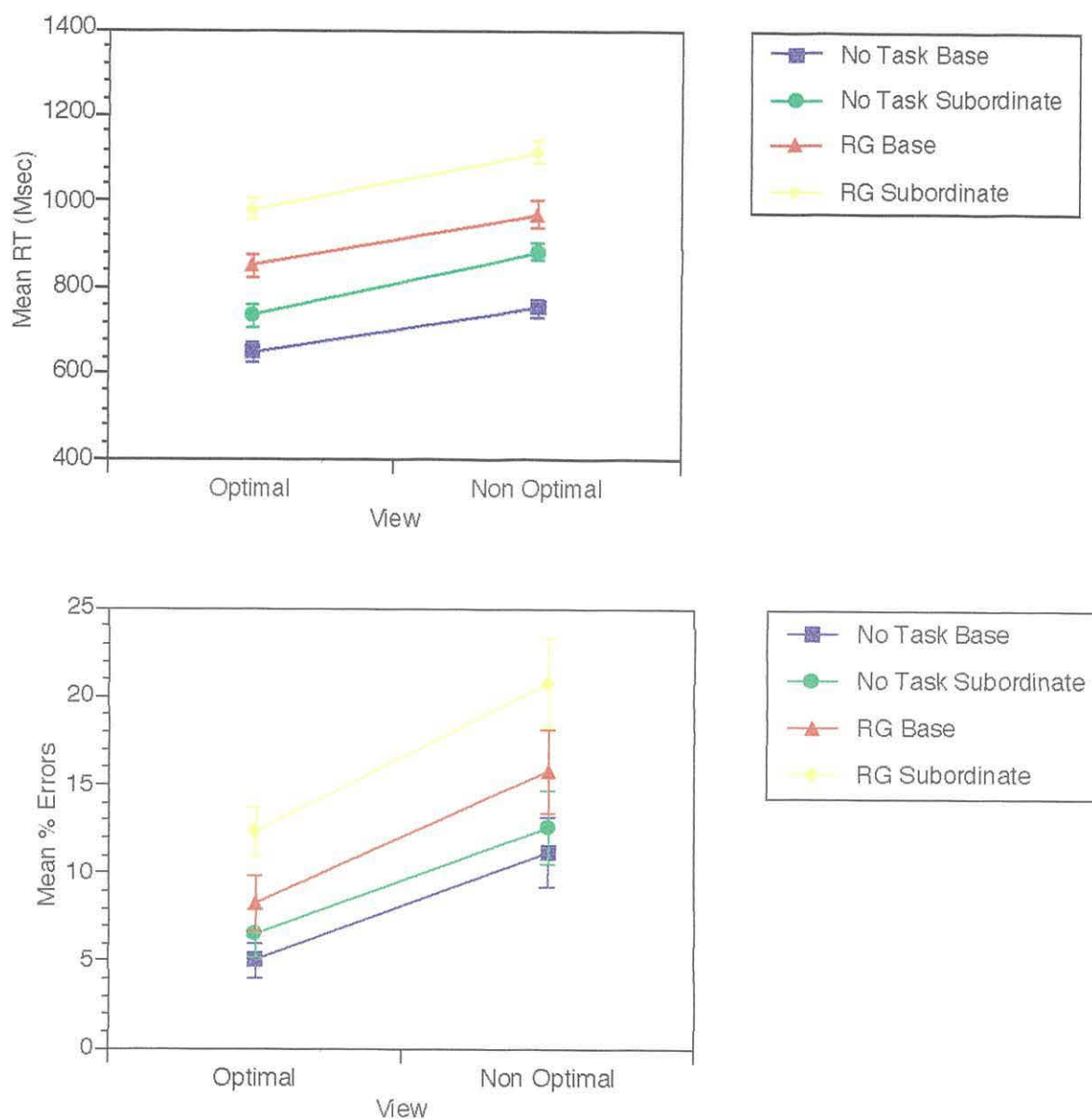
Figure 5.6: Mean reaction time and percentage errors for optimal and non-optimal view (minimal features), for base and subordinate level stimuli, using random generation (1 – 20) as a central executive secondary task; Error Bars = ± 1 standard error *(SE)*.

Secondary Task

Mean overall errors in random digit generation ranged from 0% - 22% (M = 11.7%). Mean errors in the base condition were 5.6% (range, 0% - 10%), and in the subordinate condition ranged from 0% - 12% (M = 6.9%).

Comment

As predicted, the findings of Experiment 8 demonstrated that minimal features stimuli were <u>not</u> selectively disrupted with concurrent performance of a central executive secondary task, namely random generation. This is confirmed by the lack of an interaction in the data analysis. Furthermore, this finding is a replication of Experiment 6, and it appears that minimal features recognition does not involve executive resources.

General Discussion: Experiments 7 & 8

As with the experiments in Chapter 4, both of the experiments in Chapter 5 show a consistent increase in response latencies and errors from optimal to non-optimal views, indicating that non-optimal view recognition may require some form of additional processing (Farah, 1990; Turnbull et al., 1997a; Turnbull & McCarthy, 1996).

Experiments 7 and 8 consolidate the findings of Experiments 5 and 6, and appear to demonstrate that only stimuli with a foreshortened principal axis involves the central executive. Furthermore, the data indicate that subordinate level stimuli are less readily verified than base level stimuli, and may require more specific descriptions (e.g. Humphreys et al., 1988, 1995; Jolicoeur et al., 1984; Sheridan & Humphreys, 1993).

Despite the consistent finding that executive resources appear to be involved in the recognition of depth rotated stimuli (Baragwanath & Turnbull, 2002), it is feasible to propose that some specific components of central executive function may be more directly involved in the perception of objects with a foreshortened principal axis. As discussed in Chapter 1, it has been widely proposed that the central executive may not be a unitary entity (e.g. Baddeley & Logie, 1999; Schneider, 1999). The opportunity, therefore, arises to custom-design secondary tasks which target specific aspects of executive function to test this hypothesis directly. A new paradigm was developed to investigate this question and is outlined in Chapter 6.

CHAPTER 6: EXPERIMENTS 9 – 12: THE

CONTRIBUTION OF SPECIFIC SUBCOMPONENTS

IN NON-OPTIMAL VIEW RECOGNITION

The findings of previous experiments lead us to question why one reputed central executive task, random generation, effects non-optimal view recognition, and another, serial subtraction, does not. However, it has been demonstrated that executive tasks do not consistently inter-correlate to a high degree (see Chapter 2), and recent research has led to the proposal that the central executive may be represented as a number of subfunctions. The fractionation of the central executive is of crucial importance in the area of working memory research, and has become the subject of intensive investigation (e.g. Baddeley & Logie, 1999; Cowan, 1999; D'Esposito et al., 2000; Lovett et al., 1999; Menon et al., 2002; Owen et al., 2000; Robbins, 2000; Rowe & Passingham, 2001; Sakai & Passingham, 2002; Schneider, 1999). If this account is correct, the degree of performance decrement in dual tasks depends on the extent to which the primary and secondary tasks involve the same subcomponents of the non-unitary central executive (Hegarty, Shah & Miyake, 2000).

As discussed in Chapter 2, it is proposed that random generation, considered to be the prototypical central executive task, involves the

suppression/inhibition of prepotent responses (e.g. Towse & McLachlin, 1998;

Van der Linden et al., 1998; Wiegersma, 1982), together with the active

retrieval/search for candidate responses (Baddeley, 1986).

Furthermore, as demonstrated in Experiments 7 and 8, recognition is

mediated by the "comparability" of views of competing stimuli from which they

must be discriminated, as well as the "quality of fit" of the view which depicts the

object. For example, an aerial view of a house would be less efficiently

recognised than a street level view, as it is similar to the aerial view of a barn, for

example, and moreover, such a view conceals the three dimensional structure of

the house (Lawson, 1999).

It is proposed then that the recognition of an object with a foreshortened

principal axis also involves the search for distinctive geons or invariant features,

and the inhibition of alternative possible objects (see Hummel, 2001; Hummel &

Biederman, 1992; Hummel & Stankiewicz, 1996, 1998; Stankiewicz & Hummel,

2002, in Chapter 1).

On the basis that executive processes are involved in the recognition of

non-optimal views, Experiments 9 -12 systematically investigate the involvement

of two postulated executive functions, those of search and inhibition. In Chapter

6, secondary tasks are custom-designed to tap these two specific functions, and

examine the relationship between them.

The secondary tasks in the initial three experiments of Chapter 6 all have

the same auditory input (fruit/vegetables) and the same verbal output (colours). It

was necessary in Experiment 12, however, to adapt the auditory stimuli in order

to accommodate three different set size search conditions. In this experiment, the

auditory input was names of cities, and the verbal output was names of

hemispheres, continents and countries.

Experiment 9: Search, Inhibition and Non-optimal Views

The aim of Experiments 9 – 12 was to investigate the contribution of

search and inhibition to object constancy. It is hypothesised that one, or both, of

the search and inhibition tasks will selectively disrupt non-optimal, but not

optimal, view recognition.

Method

Participants

Twenty participants (11 female) were recruited from the Bangor

University student pool. Participants' mean age was 19.9 years (range 18 to 23

years). All matched the inclusion criteria outlined in Chapter 2. Participants were

requested to rate the secondary tasks using a Likert scale, with 5 being hard and 1

being easy, at the conclusion of the experiment. The data of four participants

were subsequently discarded as their mean reaction times was greater than two

SDs away from the sample mean. No participants exceeded the error exclusion

criteria for the secondary task.

Stimuli and Apparatus

Primary Task

All stimuli and apparatus for the primary object recognition task were

identical to those used in previous experiments.

Secondary Task

Auditory stimuli were pre-recorded by the experimenter, secondary task

equipment is outlined in Chapter 2. Auditory stimuli consisted of 25 familiar

words, all of which were fruit or vegetables (see Appendix E). The verbal output

of participants to the auditory stimuli was one of five colours, those being red,

green, orange, yellow or brown (see Appendix E). Each word was presented at

three second intervals, and a randomised list of 125 verbal stimuli was produced

to enable participants continuous responses throughout the relevant experimental

blocks. All verbal responses were recorded on tape, as described in Chapter 2.

All secondary task responses were analysed, and error criteria included:

(a) missing a response; (b) responding incorrectly, and (c) responding with a

colour outside of the instructed set. Across all relevant experiments in this

chapter, no participants produced a colour outside of the instructed set.[1]

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

blocks 1 to 6 in Experiment 1. Conditions and trials for the primary task followed

the same format as those in Experiment 1. For two blocks, participants performed

the object recognition task alone (no task condition). During two of the six

experimental blocks, however, participants were requested to respond with the

appropriate colour, to the name of the fruit/vegetable heard over the headphones,

e.g. "pea" – "green", "cherry" – "red" etc. (search condition), whilst

simultaneously performing the object recognition task. For a further two blocks,

participants were required to respond with the word "black" to all fruit/vegetables

heard, apart from when they heard "apricot", in which case they were to respond

with the word "purple", e.g. "cherry" - "black", "pea" – "black", "apricot" –

"purple" (inhibition condition).

Results

Mean overall errors were 8.5% (range 3.3% - 12.8%). Mean errors for the

no secondary task condition were 5.2% (range 0% - 7.5%), for the search

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[1] In the four experiments in Chapter 5, missing a response constituted 45.6%, and responding incorrectly, 54.4% of all errors.

condition were 11.6% (range 2.5% - 25%), and for the inhibition condition were

8.8% (range 2.5% - 22.5%). Mean overall errors for the non-optimal view were

10.2% (range 0% - 25%), with search condition errors ranging from 0% - 25% (M

= 12.8%), and inhibition errors ranging from 2.5% - 20% (M = 10.8%), which

exceeded those for optimal views which ranged from 0% - 22.5% (M = 6.8%),

with search condition errors ranging from 2.5% - 25% (M = 10.3%), and

inhibition errors ranging from 0% - 22.5% (M = 6.9%) (see Figure 6.1).

Analysis of the reaction time data showed a significant effect of view,

$F(1,15) = 18.94$, $p<0.01$, and also task condition, $F(2,30) = 25.52$, $p<0.001$.

Participants, were significantly slower at recognising non-optimal views,

compared to optimal views, and were also significantly slower when performing

the primary and secondary tasks concurrently. However, there was no significant

interaction between the two conditions. Indicating that non-optimal view

recognition was not selectively influenced by the central executive secondary task

(see Figure 6.1). Statistical analysis in the no secondary task condition showed

that there was a significant difference between optimal and non-optimal view

recognition, $t(15) = 7.42$, $p<0.001$.

Analysis of errors showed an effect of both view, $F(1,15) = 19.14$,

$p< 0.01$, and task $F(2,30) = 10.64$, $p<0.001$. Indicating that participants made

significantly more errors in the non-optimal, compared to optimal view

recognition in the primary task and also made more errors whilst concurrently

performing the primary and secondary tasks. There was no interaction between

factors (see Figure 6.1).
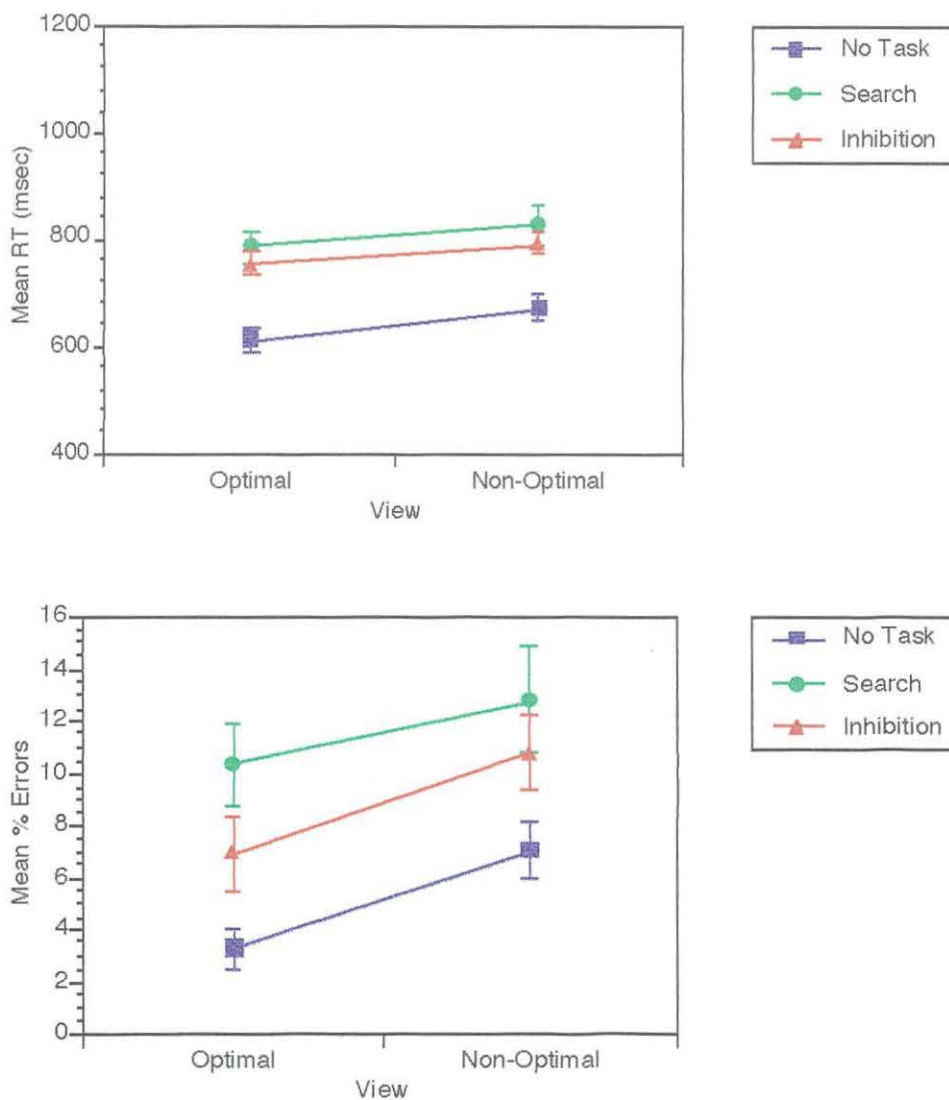
Figure 6.1: Mean reaction time and percentage errors for optimal and non-optimal views when using search and inhibition conditions as a secondary central executive tasks; Error Bars = ± 1 standard error *(SE)*.

Secondary Task

Mean overall errors ranged from 0% - 11% ($M = 1.7\%$). Mean errors in the search condition were 2.1% (range 0% - 11%), and in the inhibition condition were 1.4% (range 0% - 5%).

Comment

The results suggest that subjects found the search condition more difficult than the inhibition condition, demonstrated in both reaction time latencies and error rates, although post hoc analysis showed no statistical significance between the conditions. This was confirmed by participant feedback, in that twelve of the total participants found this particular task appreciably harder than the inhibition task. On the other hand, neither condition appears to have any preferential effect on non-optimal views. We are, therefore, unable to conclude that either the search or the inhibition component is selectively involved in non-optimal view recognition.

However, it may be argued that neither condition in this experiment was comparable to the inhibition and search components involved in random generation performance, and secondary task error rates appear to substantiate this. In these studies, even when randomly generating between 1 and 10 (Experiment 3), it is necessary to inhibit a minimum of three responses, those being the number

just generated, and those directly above and below it. In this instance, the ratio is

at least 3:10 inhibition component (inhibiting three numbers from a possible ten

choices), compared to 1:7 search component (searching for one number from a

possible seven choices). This ratio is reversed in the present study, where the

inhibition ratio is 1:25 (the stimulus "apricot" alone from the list of 25 stimuli)

and the search ratio 1:5 (searching for one colour category from a choice of five).

On the basis of the above, Experiment 10 replicates the search condition in

Experiment 9, but increases the frequency of inhibition by expanding the number

of stimuli to be inhibited from one to five (Baddeley, 1986; Towse & McLachlin,

1998). Furthermore, in Experiment 10, the inhibition condition was modified to

maintain the verbal output of both secondary tasks, in that participants did not

respond with colours outside of the five colour set.

Experiment 10: Inhibition, Search and Non-optimal Views

The new paradigm developed in Experiment 9 was adapted for the present

study to increase the frequency of inhibition and maintain the verbal output of

both secondary tasks. The aim of the study was to investigate the effect of an

increased inhibition component in non-optimal view recognition.

Method

Participants

Nineteen participants (15 female) were recruited from the Bangor
University student pool. Participants' mean age was 21.1 years (range 18 to 31
years), and all fitted the inclusion criteria outlined in Chapter 2. At the conclusion
of the experiment, participants were requested to rate the auditory tasks using a
Likert scale, with 5 being hard and 1 being easy. The data of three participants
were subsequently discarded. In the primary task two participants produced mean
reaction times greater than two SDs away from the sample mean, and in the
secondary task, one participant produced more than 30% errors.

Stimuli and Apparatus

Primary Task

All stimuli and apparatus for the primary object recognition task were
identical to those used in previous experiments.

Secondary Task

All stimuli and apparatus for the secondary tasks were identical to those
used in Experiment 9 (see Appendix E).

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

blocks 1 to 6 in Experiment 1. Conditions and trials for the primary task followed

the same format as those in Experiment 1. For two blocks, participants performed

the object recognition task alone (no task condition). During two of the six

experimental blocks, however, participants were requested to respond with the

appropriate colour, to the name of the fruit/vegetable heard over the headphones,

e.g. "pea" – "green", "cherry" – "red" etc. (search condition), whilst

simultaneously performing the object recognition task. For a further two blocks,

participants were required to respond with the word "green" to all

fruit/vegetables heard, apart from when they heard any fruit/vegetable that was

orange in colour, those being, satsuma, mandarin, apricot, clementine and carrot,

in which case they were to respond with the word "red", e.g. "banana" - "green",

"pea" – "green", "satsuma" – "red"(inhibition condition).

Results

Mean overall errors were 8.7% (range 3.3% - 17.5%). Mean errors for the

no secondary task condition were 6.3% (range 0% - 20%), for the search

condition were 9.1% (range 0% - 27.5%), and for the inhibition condition were

8.9% (range 0% - 25%). Mean overall errors for the non-optimal view were

9.2% (range 0% - 27.5%), with search condition errors ranging from 0% - 27.5%

($M = 9.5\%$), and inhibition errors ranging from 0% - 25 % ($M = 10.9\%$). Mean

errors for non-optimal views exceeded those for optimal views, which were 7.7%

(range 0% - 22.5%), with search condition errors ranging from 0% - 17.5% ($M =$

8.6%), and inhibition errors ranging from 0% - 2.25 % ($M = 9.0$).

Analysis of the reaction time data showed a significant effect of view,

$F(1,15) = 22.29$, p<0.01, and also task condition, $F(2,30) = 16.76$, p<0.001. It

would appear that participants, were significantly slower at recognising non-

optimal views, compared to optimal views, and were also significantly slower

when performing the primary and secondary tasks concurrently. However, there

was no significant interaction between the two conditions, $F(2,30) = 0.68$, p>0.05,

neither condition selectively disrupted non-optimal view recognition (see Figure

6.2). Statistical analysis in the no secondary task condition showed that there was

a significant difference between optimal and non-optimal view recognition, t(15)

= 8.01, p<0.001.

Analysis of the error data showed a significant effect of view and task,

$F(1,15) = 3.55$, p<0.05 and $F(2,30) = 3.65$, p< 0.05, respectively. Participants

made significantly more errors in the non-optimal, compared to optimal view

recognition in the primary task, and also made more errors whilst concurrently

performing the primary and secondary tasks. There was no interaction between

factors (see Figure 6.2).
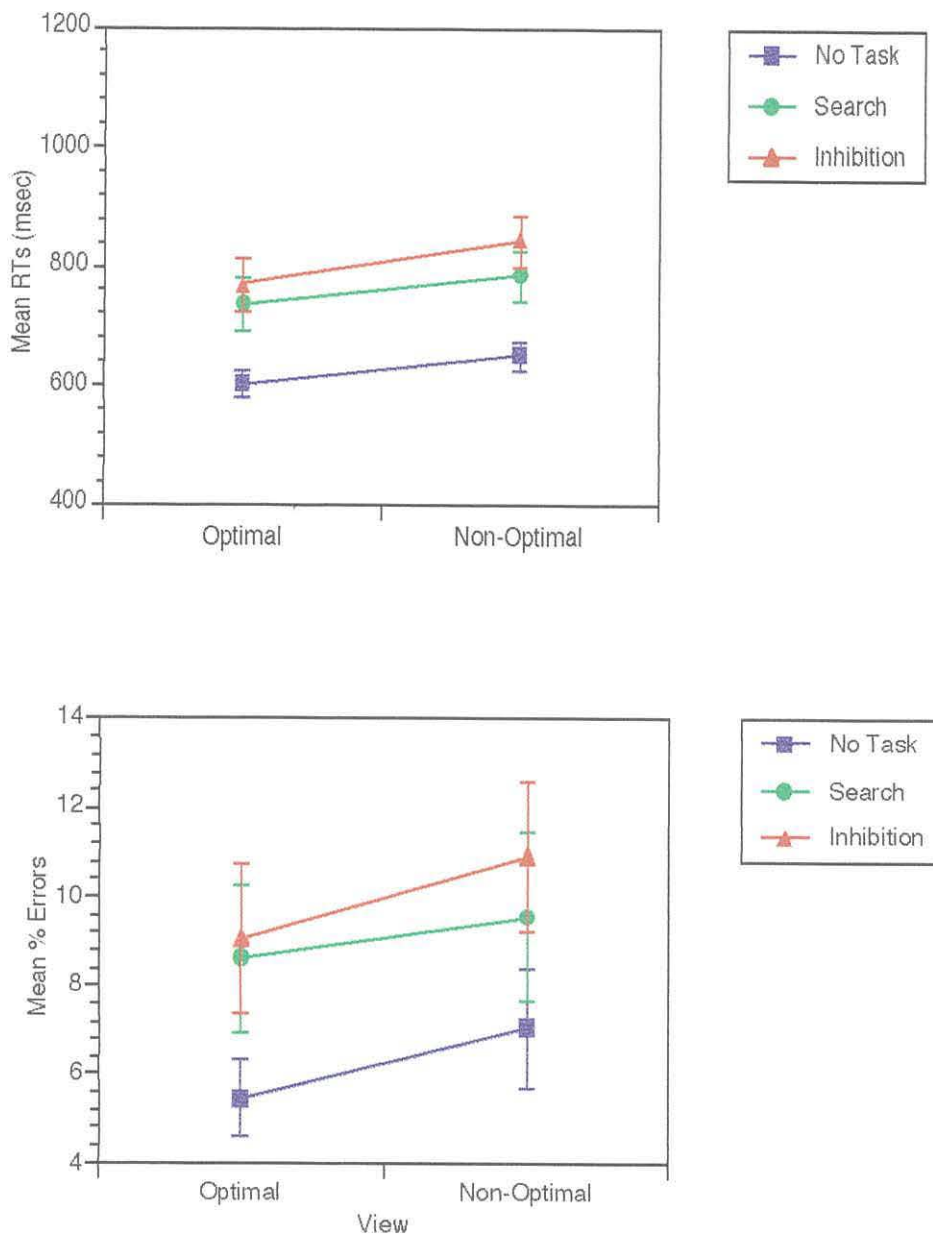
Figure 6.2: Mean reaction time and percentage errors for optimal and non-optimal views when using search and inhibition conditions as a secondary central executive tasks; Error Bars = ± 1 standard error *(SE)*.

Secondary Task

Mean overall errors ranged from 0% - 9% ($M = 2.4\%$). Mean errors in the search condition were 2.0% (range 0% - 4%), and in the inhibition condition were 2.3% (range 0% - 9%).

Comment

The results of this study reversed the search and inhibition findings of Experiment 9. In that participants in this experiment took longer and made more errors in the inhibition condition, compared to the search condition. This was confirmed by participant feedback, where ten of the sixteen participants reported that they found the inhibition task more difficult than the search task. Once again however, as with the previous experiment, neither condition appears to have had any preferential effect on non-optimal views, and we are unable to conclude that either the search or the inhibition component is selectively involved in non-optimal view recognition. Nevertheless, although there was no interaction, there seems to be a small selective decrement for non-optimal views with an increase in frequency of inhibited responses.

It is also of note that the search tasks in both Experiments 9 and 10 produce very similar reaction times and errors, consolidating this particular

finding. Furthermore, data demonstrate that it has proved possible to successfully manipulate the inhibition condition.

It is plausible to argue that the inhibition content in both Experiments 9 and 10 remains difficult to compare directly with the frequency of inhibition involved in random generation. Although there was more inhibition of responses involved in Experiment 10, the ratio was still 1:5 (inhibiting five of 25 verbal stimuli), as opposed to 1:25 in Experiment 9. It has been argued that random generation (Experiment 3) involves the inhibition of a minimum of three in ten responses (3:10), which surpasses the inhibition content in either of the previous two studies. With this in mind, Experiment 11 explores the question of frequency of inhibited responses.

Experiment 11: Frequency of Inhibition and Non-optimal Views

Based on the idea that neither Experiment 9 nor Experiment 10 involved sufficient inhibited responses, together with the slight trend for preferential disruption of non-optimal views under the inhibition condition in Experiment 10, Experiment 11 manipulated the frequency of inhibition in three conditions. The previous two experiments were also adapted to ensure that in all conditions, the correct colour category was retrieved, prior to it being inhibited.

On the basis of the previous two findings, the hypothesis is that only the most frequent inhibition condition would preferentially disrupt non-optimal views.

Method

Participants

Twenty two participants (16 female) were recruited from the Bangor University student pool. Participants' mean age was 22.2 years (range 18 to 39 years). Participants were requested to rate the secondary tasks using a Likert scale, with 5 being hard and 1 being easy, at the conclusion of the experiment. The data of six participants were subsequently discarded, one having produced mean reaction times greater than two SDs away from the sample mean, one participant had more than 30% errors in the primary task, and three participants exceeded 30% in the secondary task.

Stimuli and Apparatus

Primary Task

All stimuli and apparatus for the primary object recognition task were identical to those used in previous experiments.

Secondary Task

All stimuli and apparatus for the secondary task were identical to those used in Experiments 9 and 10.

Design/Procedure

Six blocks of experimental trials were presented to all participants, being blocks 1 to 6 in Experiment 1. Conditions and trials for the primary task followed the same format as those in Experiment 1. In all blocks of experimental trials, participants performed both the object recognition task and a secondary inhibition tasks concurrently. For two experimental blocks, participants were required to respond with an <u>inappropriate</u> colour (i.e. either red, green, yellow, brown or orange) to the name of all the fruit/vegetables heard over the headphones, e.g. "pea" – "red", "cherry" – "green" etc. (the 1:1 inhibition condition). During another two of the six experimental blocks, participants were requested to respond with the <u>appropriate</u> colour to the name of all the fruit/vegetables heard over the headphones, apart from when they heard any fruit/vegetable that was orange in colour, being, satsuma, mandarin, apricot, clementine, and carrot, in which case they were to respond with any other colour from the four remaining colour categories, e.g. "cherry" - "red", "pea" – "green", "satsuma" – either "brown", "yellow", "green" or "red" (the 1:5 inhibition condition). For a further two of the

six experimental blocks, participants were requested to respond with the

appropriate colour to the name of all the fruit/vegetables heard over the

headphones, apart from when they heard the fruits strawberry and raspberry, in

which case they were to respond with any colour, apart from red, from the four

remaining colour categories, e.g. "cherry" - "red", "pea" – "green", "strawberry"

– either "orange", "yellow", "green" or "brown" (the 1:12.5 inhibition condition).

In all secondary task conditions, participants were requested to respond as

randomly as possible to the auditory trials which required an inappropriate colour

response, and to avoid the repetition of one particular colour.

Results

Mean overall errors were 11.1% (range 5% - 17.9%). Mean errors for the

1:1 inhibition condition were 13.6% (range 0% - 30%), for the 1:5 inhibition

condition were 10.6% (range 5% - 30%), and for the 1:12.5 inhibition condition

were 8.9% (range 0% - 22.5%). Mean overall errors for the optimal view were

9.8% (range 0% - 30%), with the 1:1 condition ranging from 5% - 30% ($M =$

12.7%), the 1:5 condition ranging from 2.5% - 30% ($M = 9.2\%$), and the 1:12.5

condition ranging from 0% - 22.5% ($M = 7.6\%$). Optimal view errors were

exceeded by those for the non-optimal views with a mean of 12.2% (range 0% -

30%), with the 1:1 condition ranging from 0% - 30% ($M = 14.5\%$), the 1:5

condition ranging from 5% - 20% ($M = 11.9\%$), and the 1:12.5 condition ranging

from 0% - 22.5% ($M = 10.3\%$) (see Figure 6.3).

Analysis of the reaction time data showed a significant effect of view, $F(1,15) = 190.07$, $p<0.001$, and also task condition, $F(2,30) = 102.60$, $p<0.001$, together with a highly significant interaction between the two conditions, $F(2,30) = 70.32$, $p>0.001$. Participants, were significantly slower at recognising non-optimal views, compared to optimal views, and were also significantly slower when performing the primary and secondary tasks concurrently. Non-optimal view in this case, was selectively disrupted by the 1:1 inhibition secondary task (see Figure 6.3).

Analysis of the error data showed a significant effect of view and task, $F(1,15) = 4.41$, $p<0.05$, and $F(2,30) = 4.64$, $p<0.05$, respectively. Participants made significantly more errors in the non-optimal, compared to optimal view recognition in the primary task, and also made more errors whilst concurrently performing the primary and secondary tasks. There was no interaction between factors (see Figure 6.3).
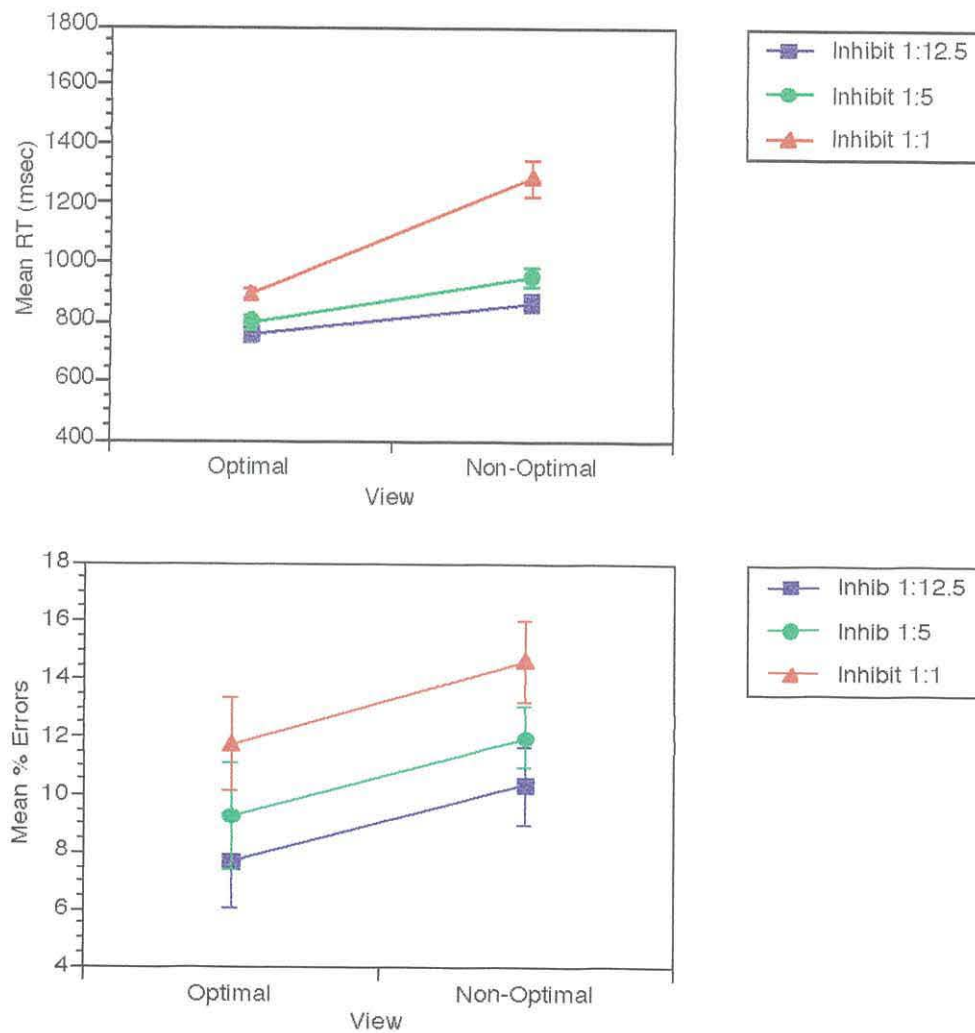
Figure 6.3: Mean reaction time and percentage errors for optimal and non-optimal views when using three inhibition conditions as secondary central executive tasks; Error Bars = $\pm$ 1 standard error *(SE)*.

Secondary Task

Mean overall errors ranged from 0% - 12% ($M = 3.1\%$). In the 1:12.5 condition, mean errors were 2.1% (range 0% - 4%), in the 1:5 condition, mean

errors ranged from 0% - 5% ($M = 2.5\%$), and in the 1:1 condition mean error

percentage was 4.8% (range 2% - 12%). The majority of errors produced

occurred in the 1:1 condition, clearly participants found this the most demanding

task. Data from the 1:12.5 and 1:5 conditions were notably similar to those

produced in Experiments 9 and 10 respectively.

Comment

Analysis of both the reaction time and error data show the consistent

finding of significantly increased response latencies and error rates for non-

optimal, compared to optimal, view recognition in all inhibition conditions. Non-

optimal view recognition, however, was selectively disrupted when performing

the 1:1 inhibition task, but this was not the case in the 1:5 and 1:12.5 inhibition

conditions. It was predicted that inhibition, as a subcomponent of the central

executive system, would produce a decrement in recognition performance

selectively for non-optimal view stimuli under the condition where participants

were required to inhibit all responses (i.e. 1:1 inhbition condition). This was

confirmed by the significant interaction between task and view in Experiment 11.

Participants' feedback forms also indicated that the 1:1 condition was the most

demanding. It is proposed that these findings may go some way to explaining the

null results in Experiments 9 and 10, in that the inhibition components in these

two experiments, being 1:25 and 1:5 respectively, were insufficient to

preferentially disrupt non-optimal views. It is important to note, as with the

secondary task errors, that reaction times in Experiment 11, in the 1:12.5 and the

1:5 conditions, can be readily compared to the inhibition data of Experiment 9 and

10 respectively.

Data suggest that the consistent inhibition, involved in the 1:1 condition,

and as with random generation, has a selective effect on stimuli rotated in depth.

However, one cannot dismiss that a search component was also present in all

conditions in Experiment 11, in that in order to inhibit a colour, one has to search

for the correct colour first. Initially, then, it would seem feasible to suggest from

these findings, that both inhibition and search are involved in the resolution of

foreshortened principal axes.

In Experiments 9 and 10, the search component, remained stable, in that

participants were searching for one colour from five. Experiment 12 was custom-

designed to investigate the effect of frequency of search in non-optimal view

recognition.

Experiment 12: Frequency of Search and Non-optimal Views

The search components in Experiments 9 and 10 both involved a search

between five colours and it is of note that the results in the primary and secondary

tasks in these experiments were comparable in terms of reaction times and errors

in the search conditions. Experiment 12 modified the secondary task stimuli in an

attempt to manipulate search set size by controlling the number of candidate responses available to participants. In Experiment 12 there are three search conditions, those being search between two, four and twelve possible responses. To achieve this, cities, as opposed to fruit and vegetables, were employed in order to satisfy the three search conditions.

On the basis of the findings of the preceding three experiments, the hypothesis is that only the search condition with the largest set size (1:12) will preferentially disrupt non-optimal view recognition.

Method

Participants

Twenty participants (12 female) were recruited from the Bangor University student pool. Participants' mean age was 20.9 years (range 18 to 37 years). Participants were requested to rate the secondary tasks using a Likert scale, with 5 being hard and 1 being easy, at the conclusion of the experiment. The data of four participants were subsequently discarded, two having produced mean reaction times greater than two SDs away from the sample mean, and two participants exceeded 30% in the secondary task.

Stimuli and Apparatus

Primary Task

All stimuli and apparatus for the primary object recognition task were identical to those used in previous experiments.

Secondary Task

All apparatus for the secondary task were identical to those used in the previous experiments in Chapter 6. The auditory stimuli, which was pre-recorded by the experimenter, consisted of 24 words, all of which were cities (see Appendix F). The verbal output of participants to the auditory stimuli was either a hemisphere (North or South), a continent (Africa, Americas, Asia or Australasia), or a country (Australia, New Zealand, New Guinea, South Africa, Egypt, Israel, America, Canada, Mexico, China, India, or Japan), each corresponding to one of three search conditions (1:2, 1:4 and 1:12 respectively) (see Appendix F). As in the three previous experiments in this chapter, each word was presented at three second intervals, and a randomised list of 120 verbal stimuli was produced to enable participants continuous responses throughout the relevant experimental blocks.

Analysis of the secondary task was as outlined in Experiment 9.

Design/Procedure

Six blocks of experimental trials were presented to all participants, being

blocks 1 to 6 in Experiment 1. Conditions and trials for the primary task followed

the same format as those in Experiment 1. In all blocks of experimental trials,

participants performed the object recognition task whilst concurrently performing

a secondary search task. For two experimental blocks, participants were required

to respond with the appropriate hemisphere, to the name of the city heard over the

headphones, e.g. "New York" – "North", "Sydney" – "South" etc. (the 1:2 search

condition). During another two of the six experimental blocks, participants were

requested to respond with the appropriate continent, to the name of the city heard

over the headphones, e.g. "New York" - "Americas", "Sydney" – "Australasia"

etc. (the 1:4 search condition). For a further two of the six experimental blocks,

participants were requested to respond with the appropriate

country, to the name of the city heard over the headphones, e.g. "New York" -

"America", "Sydney" – "Australia" etc. (the 1:12 search condition). All

participants confirmed their understanding of the procedure, and repeated blocks

of practice trials until they performed at 100% accuracy in all task conditions.

Results

Mean overall errors were 9.3% (range 4.5% - 16.2%). Mean errors for the

1:2 search condition were 8.0% (range 0% - 17.5%), for the 1:4 search condition

were 10.0% (range 0% - 25%), and for the 1:12 search condition were 9.0%

(range 0% - 25%). Mean overall errors for the optimal view were 6.9% (range

0% - 22.5%), with the 1:2 condition ranging from 0% - 17.5% ($M = 6.4\%$), the

1:4 condition ranging from 0% - 22.5% ($M = 7.1\%$), and the 1:12 condition

ranging from 0% - 15% ($M = 7.3\%$). Optimal view errors were exceeded by those

for the non-optimal views with a mean of 11.0% (range 0% - 25%), with the 1:2

condition ranging from 0% - 17.5% ($M = 9.6\%$), the 1:4 condition ranging from

5% - 25% ($M = 12.8\%$), and the 1:12 condition ranging from 0% - 25% (M

$= 10.7\%$) (see Figure 6.4B).

Analysis of the reaction time data showed a significant effect of view,

$F(1,15) = 336.63$, $p<0.001$, and also task condition, $F(2,30) = 3.58$, $p<0.05$,

together with a highly significant interaction between the two conditions, $F(2,30)$

$= 45.38$, $p>0.001$. Participants, were significantly slower at recognising non-

optimal views, compared to optimal views, and were also significantly slower

when performing the primary and secondary tasks concurrently, compared to

performing the primary task alone. Depth rotated stimuli in the 1:12 search

condition was selectively disrupted by the secondary task (see Figure 6.4A).

Analysis of the error data showed a significant effect of view, $F(1,15) =$

33.83, $p<0.001$. The data demonstrate that participants made significantly more

errors in the non-optimal, compared to optimal view recognition in the primary

task, and also made more errors whilst concurrently performing the primary and

secondary tasks. There was no effect of task and no interaction between factors

(see Figure 6.4B).
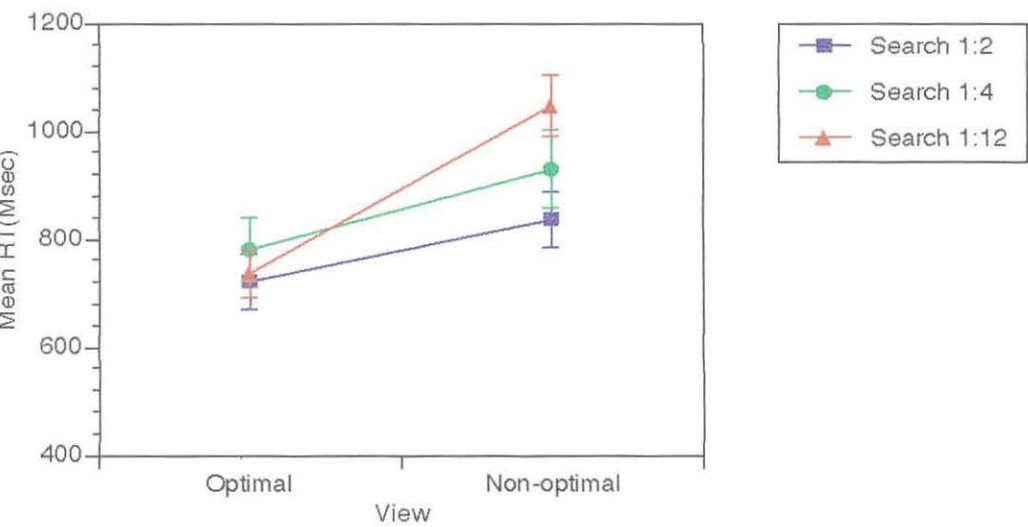
Figure 6.4A: Mean reaction time for optimal and non-optimal views when using three search conditions as secondary central executive tasks; Error Bars = ± 1 standard error *(SE)*.
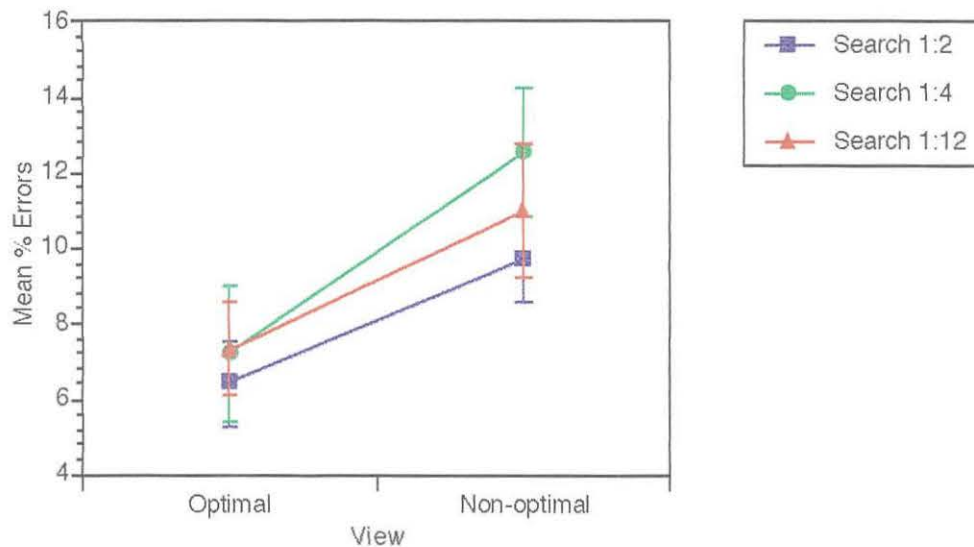
Figure 6.4B: Mean percentage errors for optimal and non-optimal views when using three search conditions as secondary central executive tasks; Error Bars = ± 1 standard error (SE).

Secondary Task

Mean overall errors ranged from 0% - 7% ($M = 2.1\%$). In the 1:12 condition, mean errors were 2.8% (range 0% - 7%), in the 1:4 condition, mean errors ranged from 0% - 5% ($M = 2.5\%$), and in the 1:2 condition mean error percentage was 1.1% (range 0% - 3%). Secondary task error data from the 1:4 search condition were once again similar to those produced in Experiments 9 and 10.

Comment

As with the data in Experiment 11, response times and error rates increased for non-optimal, compared to optimal, view recognition, across all search conditions. The question of interest in Experiment 12 was whether an increase in response set size in search conditions would selectively disrupt non-optimal view recognition. The prediction was borne out by the interaction between the 1:12 search condition.

Interestingly, participants' feedback forms indicated that the 1:4 search condition was the most demanding, although this was not borne out in terms of reaction times in the primary task or errors in the secondary task. Indeed these were comparable to the search condition in both Experiments 9 and 10. Analysis of the reaction time and error data, in both primary and secondary tasks for the 1:4 search condition, compared to those in Experiments 9 and 10 (1:5) demonstrated no significant difference.

As suggested for inhibition in Experiment 11, it may be proposed that the search components in Experiments 9 and 10, being 1:5, were insufficient to preferentially disrupt non-optimal views. Findings of Experiment 12 suggest that the increased set size for search (1:12), as with inhibition and random generation, has a selective effect on the recognition of stimuli rotated with a foreshortened principal axis.

It could be argued that these findings, however, as with those of Experiment 11, are inconclusive. It may be suggested that apart from search, there was also an inhibition component involved in all search conditions, in that searching for one response also involves inhibiting alternative candidate responses. This was, of course, also the case in Experiment 11, where the inhibition of one colour necessarily involved a search for that colour. However, clearly there is preferential disruption of non-optimal view recognition in the 1:12 search condition alone. Consequently, it is proposed that both subcomponents of executive function investigated in this experiment, namely search and inhibition are involved in non-optimal view recognition.

Experiments 9 - 12: General Discussion

The aim of the four experiments in Chapter 6 was to custom-design tasks which tap specific subcomponents of executive function involved in object constancy. Experiments 9 and 10 attempted to manipulate both search and inhibition, and this proved successful, although the data from these studies suggest that neither of these subcomponents of executive function appear to be selectively involved in the recognition of depth rotated stimuli. The findings, however, led to the proposal that neither the search nor the inhibition components in these experiments were comparable to those in random generation.

To address this issue directly, Experiments 11 and 12 increased the frequency/set sizes in both conditions individually. The results suggested that only in the most extreme conditions was non-optimal view recognition disrupted. One conclusion, therefore, is that both subcomponents may contribute to the recognition of foreshortened principal axes, but that this is heavily modulated by the frequency of each.

The present results are, therefore, consonant with the view that executive functions play a role in the recognition of depth rotated stimuli. Findings also demonstrate the potential utility of the dual task paradigm in the future investigation of those processes involved object constancy.

CHAPTER 7: DISCUSSION

The primary objective of this study was to examine the role of executive resources in non-optimal view recognition. A number of issues emerge from the data presented in Chapters 3, 4, 5 and 6 with regard to the question of the viewpoint-dependency and viewpoint-independency of the internal representations mediating object recognition, and the neural substrates of this clearly complex achievement by the human visual system. In some cases, the results replicate published findings, and in some instances, there are reports of novel findings.

There were four basic findings of the study, which were: 1) Non-optimal view recognition was slower and less accurate than optimal view recognition; 2) The non-optimal view recognition of picture plane rotated, and minimal features, stimuli was <u>not</u> selectively disrupted by a central executive secondary task; 3) Random generation, but not serial subtraction as a secondary executive task, selectively disrupted the recognition of stimuli with a foreshortened principal axis, and this was independent of category level; and 4) The search and inhibition subcomponents of central executive functioning, individually disrupted, depth rotated stimuli, but this was heavily modulated by the frequency of each component. These are discussed below.

Optimal and non-optimal view recognition

A notably robust finding in the present study, was a significant main effect of view in all experiments (1 – 12). This non-optimal view effect was reflected in both reaction times and error rates, suggesting that the internal representations for optimal views are more efficiently and accurately accessed than those for non-optimal views, and this replicates numerous results reported in the literature (e.g. Christou & Bülthoff, 2000; Edelman & Intrator, 2000; Humphrey & Jolicoeur, 1993; Jolicoeur, 1985, 1988, 1990; Jolicoeur & Humphrey, 1998; Lawson & Humphreys, 1998; Lawson, 1999; Lawson et al., 2000; Marr, 1982; Marr & Nishihara, 1978; Riesenhuber & Poggio, 1999, Srinivas, 1993, 1995; Zourtzi & Shiffrar, 1997).

Results also indicate that experience improves recognition, but does not eliminate the effect of a non-optimal viewing perspective. Again, this replicates a number of findings reported in the literature (e.g. Corballis et al., 1978, 1985; De Caro, 1998; Eley, 1982; Jolicoeur 1985, 1988, 1990; Jolicoeur & Humphrey, 1998; Jolicoeur & Milliken, 1989; Lawson, 1999; Lawson & Jolicoeur, 2003; Lawson et al., 2000; Murray, 1995; Murray et al., 1993; Tarr & Pinker, 1989; Young et al., 1980). It appears in this case, that practice does not make perfect.

Interestingly, optimal view recognition, despite the changes in non-optimal views, consistently outperformed non-optimal view recognition.

Specifically, the non-optimal view effect remained across changes in the depth plane, in the picture plane, and with the occlusion of minimal features. Results strongly suggest that the internal representations employed in these particular forms of non-optimal view recognition are viewpoint-dependent in nature, and involve some form of additional processing, above and beyond that required for optimal view recognition. These findings, therefore, appear to be consistent with neuropsychological literature, which proposes that the viewpoint-independent ventral system may require an "optional" resource, based in the dorsal stream, which would contribute to object identification when orientation-specific information was critical (McCarthy & Warrington, 1990; Turnbull et al., 1997a).

In Experiment 5, it was notable that there was a significant effect of view across both depth and picture plane recognition. Some research, however, has suggested that depth plane misorientation is compensated for prior to picture plane misorientation (e.g. Humphreys & Biederman, 1992). This was clearly not the case in the present study, where depth plane stimuli increased response latencies, compared to picture plane stimuli. Also, other research has suggested that depth and picture plane misorientations are compensated for using the same cognitive resource (e.g. Humphreys & Jolicoeur, 1988, 1993; Shepard, 1984). Again this is not supported by the findings of the present study. On the contrary, Experiment 5 data, in the absence of a secondary task, support, to some extent, the research of Lawson

et al. (2000) in suggesting that depth and picture plane recognition are dissociable processes.

Of interest, some recent research (Lawson & Jolicoeur, 2003) has proposed that certain picture plane misorientations may be "advantaged" (i.e. 90^0, 180^0, 270^0 and $\pm 30^0$ from the upright). As such, this research suggests that only 60^0, 120^0, 240^0 and 300^0 rotations in the picture plane are "disadvantaged". The findings of Experiment 5 appear to be consistent with this view, in that the stimuli employed were rotated to 120^0 and 240^0 in the picture plane.

The findings of Experiment 6 are consistent with numerous studies, which propose that salient features are important, and may be employed to achieve object recognition (e.g. Biederman & Gerhardstein, 1993; Corballis et al., 1978, 1985; Hummel, 2000; Jolicoeur, 1985, 1990; Jolicoeur & Humphrey, 1998; Lawson & Jolicoeur, 1998; Rolls & Deco. 2002; Stringer & Rolls, 2002; Tanaka, 2003; Tsunoda et al., 2001; Warrington & James, 1986; Yamane et al., 2001). On the other hand, data are inconsistent with other aspects of the literature (e.g. Dickerson & Humphreys, 1999; Humphrey & Jolicoeur, 1993; Lawson, 1999; Lawson & Humphreys, 1999; Lawson & Jolicoeur, 1998), who have suggested that features are only employed by the human visual system for recognition when axis-based information in unavailable. In Experiments 6 and 8, the principal axis of elongation was maintained in the minimal features condition, and in these experiments

response latencies did increase, suggesting that to some extent participants may have been searching for distinctive features in the recognition process, despite the availability of an intact principal axis of elongation.

The findings of Experiments 6 and 8 also replicated those of Experiment 5, in that depth rotated stimuli were recognised less efficiently and less accurately than minimal features stimuli. The pattern of increased reaction times for minimal features and picture plane misoriented stimuli found in Experiments 5, 6 and 8, therefore, appear to suggest two functionally distinct routes for object recognition, one being reliant of viewpoint-invariant feature extraction, and the other on axis-based information and results support the findings of Humphreys and Riddoch (1987), Jolicoeur (1990), Lawson & Jolicoeur (1998) and Riddoch and Humphreys (1984). This suggestion is further supported by the data from Experiments 1 – 4 and 11 – 12, in that all these experiments employed stimuli with a foreshortened principal axis.

Additionally, in the present series of studies, the non-optimal view effect was demonstrated for subordinate (Experiments 7 & 8), as well as basic (Experiments 1 – 6 & 9 – 12), level stimuli. In both categorisation experiments, and consistent with much research (e.g. Biederman, 1987; Biederman et al., 1999; Biederman & Gerhardstein, 1993; Dickerson & Humphreys, 1999; Gregg, 1975; Humphreys et al., 1988; Hutcheon, 1970; Jolicoeur et al., 1984; Murphy & Brownell, 1983; Murphy & Smith, 1978; Rosch et al., 1976; Segui & Fraise, 1968; Smith et al., 1978), subordinate

level stimuli, produced slower reaction times and more errors than basic level stimuli. The findings concur with the hypotheses of the above research, in suggesting that subordinate level recognition occurs after basic level recognition. The increase in response latencies, together with the high structural similarity within categories (Newell, 2002) for subordinate level stimuli in Experiments 7 and 8, supports the proposal that such recognition may require more detailed perceptual analysis (e.g. Humphreys et al., 1988; Jolicoeur et al., 1984).

In Experiments 7 and 8, 25% of the stimuli were animals, and 75% were inanimate objects. Interestingly, on inspection of the data, no significant difference was found between reactions times for living and non-living categories. The findings of these experiments, therefore, appear to concur with recent suggestions (e.g. Laws, 2001; Leek & Pothos, 2001; Mahon & Caramazza, 2001; Turnbull & Laws, 2001), that both living and non-living categories may be considered of high structural similarity.

In summary, the findings of the present study are consistent with the hypothesis that an additional resource is employed in non-optimal recognition, which may aid in establishing the relative depth of a foreshortened principal axis, in identifying an occluded critical features, or in the recognition of picture plane misoriented stimuli (McCarthy & Warrington, 1990; Turnbull et al., 1997). Furthermore, in support of the latest viewpoint-independent (e.g. Hummel, 2000), and viewpoint-dependent (e.g. Edelman & Intrator, 2000)

hybrid models of object recognition, the data appear to suggest that both viewer-centred and object-centred representations may be involved in object recognition, under different circumstances.

The efficiency of optimal, over non-optimal, view recognition, found in this series of experiments, has replicated many of the findings reported in the object constancy literature. However, the primary focus of this study was the effect of a central executive secondary task on non-optimal view recognition, and this issue has not (to the author's knowledge) previously been investigated, using conventional cognitive psychological methods. In the following section, non-optimal view recognition is discussed, in relation to the effect of a central executive secondary task on such recognition.

The central executive and non-optimal view stimuli

The significant effect of task in <u>all</u> experiments involving a secondary task (Experiments 2 – 12) demonstrated a consistent decremental effect for concurrent performance of the primary object recognition and secondary central executive tasks, compared to performance on the object recognition task alone - replicating previous literature (e.g. Baddeley et al., 1991; Baddeley et al., 1986; Duff, 2000; Logie et al., 1990; Navon & Gopher, 1979), in proposing a cost when two tasks are concurrently performed. This was the case for serial subtraction (Experiment 2), random generation (Experiments 3

– 8) and interestingly, for the search and inhibition conditions, employed in the newly developed paradigm (Experiments 9 – 12).

Experiment 2 employed serial subtraction as the central executive secondary task, and it was found that non-optimal views were not selectively disrupted by this particular task. As suggested in Chapter 3, there was no control over the rate of response at which serial subtraction was performed, possibly resulting in a trade-off between the primary and secondary tasks - and consequently, non-concurrent performance of the tasks. The conclusions drawn in this instance, therefore, require further clarification.

Some recent literature on mental arithmetic (Menon et al., 2002) has proposed that executive resources are recruited only in the processing of incorrect equations (e.g. $2 + 2 = 5$). The authors have suggested that the processing of incorrect responses necessarily involves <u>inhibition</u> of conflicting information, and selection/<u>search</u> for an appropriate response. On these grounds, it is viable to suggest that serial subtraction may not be a suitable task in the recognition of non-optimal views. Studies involving incorrect arithmetic equations, as a central executive secondary task, may constitute a potential area for future investigations.

Random generation, however, was successfully employed as a central executive task in Experiments 3, 4, 5, 6, 7 and 8, although picture plane misorientations (Experiment 5), and stimuli with an occluded critical feature

(Experiments 6 & 8) were not selectively disrupted by this secondary task. These findings are discussed below.

The central executive and the recognition of picture plane rotated and minimal features stimuli

Experiment 5 data suggest that whilst depth plane recognition appears to rely on executive resources, picture plane recognition does not. There are a number of possible explanations for this finding. For instance, as proposed in the literature (e.g. Lawson, 1999), the holistic properties of stimuli remain constant when stimuli are rotated in the picture plane, whereas rotation in depth plane results in much more visually catastrophic changes in shape. It may then be suggested that such recognition does not constitute as much of a visual "problem" (Farah, 1990), as the recognition of depth plane stimuli.

Moreover, in consideration of the data from Experiments 9 – 12, where non-optimal view recognition was modulated by frequency (set size) of the search and inhibition subcomponents of executive function, it may be suggested that picture plane recognition does not involve, at least to a sufficient degree, an inhibition (or a search) component. Although not directly comparable, this explanation is supported, to some degree, by recent neurophysiological evidence (Riesenhuber & Poggio, 2002), which proposes

that picture plane recognition requires training on a single view, whilst depth plane recognition requires training on multiple views.

The findings of Experiment 5 may be considered compatible with the hypothesis that participants employ a viewpoint-dependent, mental rotation process in the recognition of picture plane rotated stimuli (e.g. Jolicoeur, 1985, 1990; Lawson, 1999; Murray, 1997; Tarr & Pinker, 1989), in which the parietal lobe plays a part (e.g. Farah et al., 1988; Harris et al., 2002; Lawson et al., 2000). This hypothesis is supported by the an abundance of neuroimaging studies (e.g. Alivisatos & Petrides, 1997; Booth et al., 2001; Carlesimno et al., 2001; Passini et al., 2000; Just et al., 2001; Sugio et al., 1999).

In agreement with Lawson & Jolicoeur (2003), the data from this study suggest that the processes involved in picture plane recognition have yet to be satisfactorily specified, and this important issue would be best addressed by further experimentation (see Future studies below).

The findings of Experiments 6 and 8 also suggest that executive resources do not contribute to the recognition of stimuli with a critical feature occluded, but are involved in depth rotated recognition. It was suggested above that axis- and feature-based recognition may involve independent processes. Experiment 6 and 8 add further support for this suggestion. The literature has proposed that the search for distinctive features of objects is considered to operate by viewpoint-independent means (e.g. Hummel & Biederman, 1992; Humphreys & Riddoch, 1984; Kosslyn, 1990, 1994), and

that this processing takes place in temporal brain areas (e.g. Harris et al., 2000, 2001). The findings of Experiments 6 and 8, are consistent with this hypothesis. Indeed, this proposal may posit a potential explanation for the increased reaction times for minimal features stimuli, and also for the lack of an interaction in these studies.

In summary, as suggested earlier, both picture plane rotated and minimal features stimuli appear to require additional processing. However, based on the results of Experiments 5, 6 and 8, these do not appear to be executive in nature. One explanation for this is that the stimuli in the primary tasks do not enlist search and inhibition, to the same extent, as is required in depth plane recognition. An alternative interpretation of the data, is that the additional processing required for such stimuli occurs in areas other than those involved in executive function. This suggestion is supported by the neurobiological literature, in that viewpoint-independent salient features are purported to activate temporal areas, and that picture plane recognition involves a mental rotation process, which elicits activation in the parietal lobes.

The central executive and depth rotated stimuli

Experiments 3, 4, 5, 6 and 7 suggest that random generation selectively disrupts the recognition of objects with a foreshortened principal

axis. Comparison may be drawn between these findings and working memory studies, in that random generation disrupts executive resources (e.g. Diennes et al., 1991; Gilhooly et al., 1993; Logie et al., 1994; Robbins et al., 1991).

The notably consistent interactions between random generation and depth rotated recognition demonstrated in these five experiments, provide a strong case in suggesting that central executive resources may be involved in the recognition of stimuli with a foreshortened principal axis (Baragwanath & Turnbull, 2002).

Further support for the hypothesis above, was evidenced in the data from Experiment 7, which suggest that the central executive is involved in the recognition of subordinate level stimuli, as well as basic level stimuli, rotated in depth. In this respect, the data from Experiments 7 and 8, generally concur with the findings of Tanaka et al. (1999) and Gauthier et al. (1997), in arguing that the verification of subordinate, over basic level stimuli, may be associated with activation of inferior temporal gyri. Direct support for this anatomical proposal was not, of course, possible.

As discussed in the previous section, it appears that non-optimal view recognition is mediated by viewpoint-dependent internal representations. Data from Experiments 3, 4, 5, 6, and 7 expand on this finding, in suggesting that regions outside of the classic ventral visual object recognition system appear to play a part in non-optimal view recognition. Specifically, that executive resources, purported to have their substrate in the frontal lobe,

appear to be involved in the recognition of stimuli with a foreshortened principal axis.

Clearly, these findings suggest that recognition of depth rotated stimuli constitutes a troublesome problem for the visual system (Farah 1990). It is suggested that this finding may be regarded as akin to the unusual views deficit seen in neurological patients, in that random generation appears to act as a 'functional' lesion, selectively disrupting the recognition of depth rotated stimuli. In this way, the results confirm suggestions from the neurological lesion literature (e.g. Farah, 1990, Turnbull and colleagues, 1996, 1997, 2002), as well as the functional imaging literature (e.g. Kosslyn, 1990, 1994), that the frontal lobes may be selectively involved in the recognition of objects from non-optimal views.

The results of the present study indicate that optimal and non-optimal view recognition require independent resources and the data, therefore, are also supportive, to a certain extent, of the hypothesis (e.g. Caterini et al., 2002; Turnbull et al., 1995, 1996, 1997, 2002) that object identity and object orientation are processed independently, in the ventral and dorsal streams, respectively.

The involvement of search and inhibition in the recognition of depth rotated and minimal features stimuli

The dual task technique, designed for the final four experiments in this study, allowed investigation into the specific contribution of the search and inhibition components of executive function, in non-optimal view recognition. Experiments 9 and 10 showed that it was possible to manipulate these subcomponents of central executive function, however, the manipulation of neither search nor inhibition appear sufficient, relative to the search and inhibition components involved in random generation, to selectively disrupt the recognition of depth rotated stimuli.

However, it was demonstrated that an increase in set size for both components (Experiments 11 and 12) resulted in interactions between non-optimal view recognition and secondary task. Interestingly, this is comparable to the manipulation of random digit generation in Experiment 4, which in this case resulted in a more powerful statistical significance level. The conclusions drawn from the data were that both search and inhibition may play a role in recognition of stimuli with a foreshortened principal axis. In this respect, the recent model of Hummel and Stankiewicz (1998) outlines a workable definition for non-optimal view recognition, which conforms to the suggestion of search and inhibition in executive function.

In conclusion, all of the experiments in this study found an advantage for optimal view recognition, compared to non-optimal view recognition, in

terms of accuracy and speed. Depth rotated stimuli were consistently

selectively disrupted by random generation, independent of the category level

of stimuli. This was not, however, the case for picture plane rotated and

minimal feature stimuli. The frequency of both search and inhibition (as

subcomponents of central executive functioning), was a critical factor in the

involvement of executive resources in the recognition of depth rotated stimuli.

Limitations of the present study and future research

Word/picture verification was employed in this research, as opposed to

picture/picture verification, in order to avoid participants simply matching

visual characteristics of stimuli and ensure the accessing of stored knowledge.

However, a limitation of this match/mismatch verification, is that it provides

the name of the object. It could be argued that tasks without contextual cues

(such as the name of the object) may more closely approximate the functional

requirements of the human visual object recognition system, and are,

consequently, more ecologically valid.

Tasks reliant on information derived from the input stimulus alone, for

example, naming tasks, may also prove informative regarding the nature of

the internal representations and processes mediating object recognition.

However, in the dual task methodology used in this series of studies, this

would have proved impossible, as the secondary task required an auditory

input and a verbal output, and the primary task a visual input and a manual response. Nonetheless, additional support from naming tasks would strengthen the conclusions drawn from this study, and, therefore, constitute interesting further research. Such research, would necessitate a reversal in the input and output modalities for primary and secondary tasks. The primary object recognition task requiring a verbal response, and the secondary central executive task, a manual response, hence this would involve extending and refining the novel dual task paradigm employed in the present series of studies.

Furthermore, as pointed out in Chapter 2, there are some limitations associated with dual task methodology. The use of an entirely different method would, therefore, add supportive evidence to the conclusions drawn from the findings of this study. In this respect, Transcranial Magnetic Stimulation (TMS), a technique used in the investigation of cognitive processes, could be employed in non-optimal recognition with neurologically normal individuals. This technique fares relatively well in terms of spatial and temporal resolution and allows transient interference with the physiological activity of distinct cortical regions. The prediction would be that TMS over the dorsolateral prefrontal areas[1] would disrupt recognition of non-optimal, but not optimal, views. TMS studies have already begun to

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[1] It is considered that this area of the frontal lobe is an extension of the dorsal system that may be involved in orientation analysis (Goodale & Milner 1992; Jeannerod, 1981, 1994; Milner & Goodale, 1993, 1995; Ungerleider & Mishkin, 1982).

study the frontal lobes in relation to working memory (e.g. Brandt, Ploner, Meyer et al., 1998), and it has been demonstrated that TMS disrupts executive function and increases non-randomness in digit generation (e.g. Jahanshahi & Dirnberger, 1999).

To date there seems to be insufficient cross-talk between neuropsychological research and research on neurologically intact individuals. It can also be difficult to make direct inferences from studies based on fMRI and PET studies, with regard to brain regions involved in specific cognitive functions, due to the correlational nature of neuroimaging methods. However, examination of particular deficits resulting from focal brain injury allows causal inferences regarding structure and functional relationships (Walsh & Kulikowski, 1998). Neuropsychological studies would, therefore, provide additional supportive evidence for the findings of this study. The present results form the basis for strong predictions in future research, in that any source of disruption to central executive functions should effect the recognition of stimuli with a foreshortened principal axis. The most obvious example of this, would be the study of patients with focal lesions of the frontal lobe. Such investigations would naturally compliment neuroimaging studies, and the cognitive data presented in the present series of experiments.

The data presented above suggest that additional processing is involved in picture plane, and minimal feature, recognition, and some suggestions have been made as to what form of supplementary processing

these may involve. However, further investigation employing such primary task stimuli is necessary, and use of dual task technique, developed in this series of studies, might be appropriate, especially, if secondary tasks could be custom-designed to disrupt selective components of the cognitive apparatus. For example, selectively targeting the 'rotation' aspect of spatial cognitive ability.

Moreover, there are numerous forms of non-optimal views of stimuli, for example, overlapping drawings, silhouettes, fragmented stimuli and stimuli presented under unusual lighting conditions, which have not been examined in the present study. It would be of interest to examine whether the central executive, or indeed other visuospatial resources, play a role in the manipulation and reorganisation of such stimuli. Furthermore, in this connection, it is proposed that the employment of photographs or perhaps real objects, in the primary object recognition task, would be more ecologically valid, and add support for the data from this series of experiments.

Conclusions

The findings of this series of experiments suggest that the achievement of object constancy by the human visual system constitutes a complex visual problem, which involves viewpoint-dependent mechanisms, outside of the ventral visual stream. The achievement of object recognition across depth rotation appears to be dissociable from that of picture plane rotation, and from

recognition of stimuli with an occluded critical feature, but not independent of category level. Specifically, evidence from a number of different experiments converge on the same overall conclusion – there appears to be a role for executive resources in the recognition of stimuli with a foreshortened principal axis.

Viewpoint-dependent and viewpoint-independent models continue to evolve in response to empirical data and the current findings place important constraints on theoretical accounts of object recognition, with regard to the nature of the internal representations and processes involved in the achievement of object recognition over depth misorientation, picture plane misorientation, and minimal feature stimuli, such that clear predictions cannot be derived from them in respect of these issues.

Moreover, the findings of the present study may also have some impact on current working memory research on the fractionation of executive resources. The search for the elusive central executive of working memory may, in time, lead to the conclusion that there is no specialised system, and the present data may add, in some small way, to shifting research questions from which parts of working memory are involved in which area of the frontal lobe, to which frontal lobe functions are required by which type of tasks.

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Appendices

Appendix A – BORB (Riddoch & Humphreys, 1993) stimuli used for experimental trials.

Object	Different Condition
Car	Bus
Bus	Car
Jug	Cup
Cup	Jug
Spoon	Fork
Fork	Spoon
Nailbrush	Paintbrush
Paintbrush	Nailbrush
Elephant	Rhino
Rhino	Elephant
Watch	Glasses
Glasses	Watch
Razor	Corkscrew
Corkscrew	Razor
Pig	Horse
Horse	Pig
Shoe	Digger
Digger	Shoe
Scissors	Peg
Peg	Scissors

Appendix B – BORB (Riddoch & Humphreys, 1993) stimuli used in practice trials.

Object	Different Condition
Saw	Comb
Comb	Saw
Screw	Screwdriver
Screwdriver	Screw
Cottonreel	Pepperpot
Pepperpot	Cottonreel

Appendix C – BORB (Riddoch & Humphreys, 1993) stimuli at picture-plane rotations of 120^0 or 240^0 used in Experiment 5.

120^0	240^0
Watch	Glasses
Spoon	Fork
Scissors	Razor
Peg	Corkscrew
Nailbrush	Paintbrush
Elephant	Rhino
Digger	Bus
Jug	Cup
Horse	Pig
Shoe	Car

Appendix D – Basic and subordinate level stimuli used in Experiments 7 and 8 (including practice stimuli).

Basic level Stimuli		
		Different Condition
Animals	Horse	Elephant
	Rhino	Camel
	Elephant	Horse
	Pig	Rhino
	Camel	Pig
Vehicles	Bus	Train
	Digger	Bus
	Car	Digger
	Train	Bicycle
	Bicycle	Car
Furniture	Table	Sofa
	Dresser	Bed
	Desk	Table
	Sofa	Dresser
	Bed	Desk
Household Items	Fork	Knife
	Jug	Cup
	Cup	Jug
	Spoon	Fork
	Knife	Spoon

Basic level practice stimuli as Appendix B.

Subordinate level Stimuli		
		Different condition
Cats (Animals)	Tiger	Leopard
	Lion	Tiger
	Lynx	House Cat
	Leopard	Lion
	House Cat	Lynx
Boats (Vehicles)	Ocean Liner	Container
	Container	Ocean Liner
	Sailboat	Canoe
	Rowboat	Sailboat
	Canoe	Rowboat
Chairs (Furniture)	Grandfather	Cuckoo
	Cuckoo	Grandfather
	Wall	Radio Alarm
	Carriage	Wall
	Radio Alarm	Carriage
Clocks (Household Items)	Kitchen	Armchair
	Rocking	Swivel
	Directors	Rocking
	Swivel	Directors
	Armchair	Kitchen

Subordinate level Stimuli for practice trials		
		Different condition
Glasses	Beer	Tumbler
	Tumbler	Beer
	Brandy	Wine
	Wine	Champagne
	Champagne	Brandy

Appendix E –Auditory stimuli used for secondary tasks in Experiments 9 -11.

Colour Category	Fruit and Vegetables
Red	Cherry
	Raspberry
	Strawberry
	Tomato
	Radish
Green	Pea
	Sprout
	Cucumber
	Lettuce
	Cabbage
Orange	Satsuma
	Clementine
	Apricot
	Carrot
	Mandarin
Yellow	Banana
	Lemon
	Sweetcorn
	Pineapple
	Grapefruit
Brown	Raisin
	Prune
	Sultana
	Date
	Potato

Appendix F –Auditory stimuli used for secondary task in
Experiment 12.

Hemisphere	Continent	Country	City
North	Americas	America	New York
			Los Angeles
		Canada	Toronto
			Montreal
		Mexico	Acapulco
			Mexicali
	Asia	China	Peking
			Shanghai
		India	Bombay
			Deli
		Japan	Tokyo
			Hiroshima
South	Africa	Egypt	Cairo
			Luxor
		Israel	Jerusalem
			Eilat
		South Africa	Capetown
			Johannesburg
	Australasia	Australia	Sydney
			Melbourne
		New Zealand	Wellington
			Auckland
		New Guinea	Papua
			Port Moresby