Durham University

Durham E-Theses

Colour and Naming in Healthy and Aphasic People

EVELYN MARTINA SUSI MOHR

How to cite:

MOHR, EVELYN MARTINA SUSI (2010) Colour and Naming in Healthy and Aphasic People. Doctoral thesis, Durham University.

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a https://etheses.durham.ac.uk/id/eprint/394/ is made to the metadata record in Durham E-Theses
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the full Durham E-Theses policy for further details.

Academic Support Office, The Palatine Centre, Durham University, Stockton Road, Durham, DH1 3LE
e-mail: e-theses.admin@durham.ac.uk Tel: +44 0191 334 6107
https://etheses.durham.ac.uk

Colour and Naming in Healthy and Aphasic People

Evelyn Martina Susi Mohr

Thesis submitted for the Degree of Doctor of Philosophy

University of Durham, Department of Psychology

2010

Abstract

The purpose of this study was to create a paradigm suitable for people with aphasia and healthy subjects to evaluate the influence of colour on naming pictures of objects. We designed a completely new stimulus set based on images of 140 common real objects that were inspired by the Snodgrass & Vanderwart picture set (1980). We were especially interested whether there is a difference in performance between the aphasic patients and the group of healthy controls.

Adding chromatic information to pictures of objects shows only a small effect in verification and categorisation tasks. However, when observers are required to name objects, colour speeds performance and enhances accuracy (Rossion & Pourtois, 2004). The present study contrasts two different claims as to why colour may benefit object naming. The first is that colour simply aids the segmentation of the object from its background (Wichmann et al., 2002). The second is that colour may help to elicit a wider range of associations with the object, thereby enhancing lexical access (Bisiach, 1966). To distinguish between these processes an equal number of pictures containing high and low colour diagnostic objects were presented against either fractal noise or uniform backgrounds in a naming task to aphasic subjects with anomia and to healthy controls. Performance for chromatic stimuli was compared with that for monochrome stimuli equated in luminance.

Results show that colour facilitates naming significantly in both subject groups and there was no significant difference between objects with high or low colour diagnostic values. We also found that object segmentation and the lexical access seem to occur in parallel processes, rather than in an additive way.

Declaration

I hereby declare that this thesis has been composed by myself and that the research reported herein has been conducted by myself.

March, 2010

Evelyn, Martina, Susi Mohr

Statement of Copyright

The copyright of this thesis rests with the author. No quotation from it should be published without prior written consent and information derived from it should be acknowledged.

Acknowledgements

Many thanks to my two supervisors, Robert Kentridge and Charles Heywood, who encouraged my creativity and supported me during the research process. Also many thanks to Bob Metcalfe for writing the computer programme for the audition software package.

Thanks also to everyone in the rehabilitation clinics in Germany who helped provide exciting and perfectly organized research environment. Special thanks to Prof. Dr. Joachim Liepert, and Georg Greitemann, Kliniken Schmieder, Allensbach and Dr. Andreas Winnecken, Aphasiestation, MediClin, Soltau, for the fantastic support and organisation during the testing of their patients.

Many thanks also go to many people in the Psychology Department at Durham for their useful advice and support. Finally, a big thank you to everyone who participated in the experiments.

Table of content

Chapter 1: General Introduction **15**

1.1: Background **15**

1.2: Aim of the thesis **18**

1.3: What are the benefits of colour vision? **19**

1.3.1: Evolution of colour vision 19

1.4: Colour effects on object segmentation **21**

1.4.1: Colour effects in visual attention and their influence on object segmentation. 21

1.4.2: The computation of object segmentation and object recognition in the brain.. 23

1.4.3: The time course of figure-ground segmentation and object categorization 24

1.4.4: Colour and luminance cues in the segmentation process of objects 26

1.4.5: Categorization of objects in scenes 28

1.4.6: Is colour processed later than shape? 29

1.4.7: Colour and shape interactions during object categorization 30

1.4.8: Summary 31

1.5: Colour effects in object recognition **32**

1.5.1: Edge based theories of object recognition 32

1.5.2: Colour as an intrinsic object property 37

1.5.3: Colour effects related to object category and colour diagnosticity 40

1.5.3.1: Theories about category effects in living and non-living objects 41

1.5.3.2: Methodological issues in the category debate 43

1.5.3.3: Definition of colour diagnosticity 45

1.5.3.4: Category effects and colour diagnosticity 46

1.5.4: Summary of colour effects on object segmentation and object recognition 49

1.6: The effects of colour on object naming **51**

1.6.1: Naming stages 51

1.6.2: Linguistic models of object naming 53

1.6.3: A common semantic network for picture and words 57

1.6.4: Colour in the semantic selection process 60

1.6.5: Factors affecting picture naming 66

1.6.6: Summary of colour effects on naming 70

1.7: The effects of colour on priming 70

1.7.1: Multiple forms of memory 71

1.7.2: General definition of priming 71

1.7.3: Visual Priming 72

1.7.4: Cognitive models for visual object recognition priming 75

1.7.5: Mechanisms of priming in object naming 79

1.7.6: Priming effects in naming pictures of single objects 80

1.7.7: Colour priming effects in verification tasks with scenes 82

1.7.8: Summary 84

1.8: Thesis outline 85

Chapter 2: The stimulus set 86

2.1: Introduction 86

2.2: Background 86

2.3: Description of the new stimulus set 87

2.3.1: Stimuli for experiment 1 and 2 88

2.3.2: Stimuli for experiment 3 92

Chapter 3: Experiment 1 - Colour effects on object naming and priming 95

3.1: Introduction 95

3.2: Method 101

3.2.1: General method 101

3.2.2: Participants 101

3.2.3: Stimuli 106

3.2.4: Apparatus 108

3.2.5: Procedure 108

3.3: Results experiment 1 111

3.3.1: Design 111

3.3.2: Immediate naming task 111

3.3.2.1: Analysis 111

3.3.2.2: Results 114

3.3.3: Repeated naming task – priming 133

3.3.3.1: Analysis 133

3.3.3.2: Results 134

3.4: Discussion experiment 1 138

3.4.1: Colour effects on immediate naming 140

3.4.2: Colour effects on repeated naming 151

3.4.3: Conclusion 157

Chapter 4: Experiment 2 - Colour effects on priming during repeated object naming using different delays 161

4.1: Introduction 161

4.2: Method 163

4.2.1: Participants 163

4.2.2: Stimuli 164

4.2.3: Procedure 165

4.3: Results 165

4.3.1: Design 165

4.3.2: Immediate naming task 165

4.3.2.1: Analysis 165

4.3.2.2: Results 166

4.3.3: Repeated naming task – priming 174

4.3.3.1: Analysis 174

4.3.3.2: Results 175

4.4: Discussion 180

4.5: Conclusion 185

Chapter 5: Experiment 3 - Colour effects on rapid object detection 188

5.1: Introduction 188

5.2: Method 192

5.2.1: Participants 193

5.2.2: Stimuli 193

5.2.3: Procedure 195

5.3: Results 196

5.3.1: Design 196

5.3.2: Analysis 196

5.4: Discussion 207

5.5: Conclusion 215

Chapter 6: General Discussion 218

6.1: Colour effects according to object category or colour diagnosticity of the object 220

6.2: Naming and detecting living versus non-living things 221

6.3: Colour effects on repeated object naming (priming) 221

6.4: Conclusion 224

References 225

Appendices 253

Appendix 1: Colour plate with six picture examples of the stimuli for experiment 1 and 2 253

Appendix 2: Colour plate with eight picture examples of the stimuli for experiment 3 254

Appendix 3: Object list for experiment 1 and 2 255

Appendix 4: Object list for experiment 3 260

Appendix 5: Subject details aphasic participants experiment 1 261

Appendix 6: Subject details German participants experiment 1 262

Appendix 7: Subject details British participants experiment 1 and 2 263

Appendix 8: Subject details British participants experiment 3 265

List of tables

Table 1. Review of studies that investigated effects of colour on object recognition in adult people. p. 50

Table 2. Review of studies that investigated effects on object naming in adult people. p. 64

Table 3. Experiment 3. Mean reaction times per subject for the rapid object detection task. p.205

Table 4. Experiment 3. Mean reaction times per object for the rapid object detection task. p.206

List of figures

Figure 1. Example of an illustration of a briefcase in four different image conditions. Images taken from Sanocki et al., 1998. p. 35

Figure 2. Example of an illustration that objects that look very similar can be represented and recognized as different objects, whereas objects that look very different can be recognized as the same basic-level objects. Illustration taken from Bar (2004). p: 36

Figure 3. A photographic example of a telephone and the processed line drawing of the same object. Image taken from Biederman & Ju (1988). p. 36

Figure 4. Example of different identification rates of *contours* of picture samples from the Snodgrass & Vanderwart picture set (1980). Image taken from De Winter & Wagemans (2004). p. 36

Figure 5. Illustration of the distractor conditions for a target object, tomato as used in the experiments by Joseph (1997). p. 38

Figure 6. Examples of multicomponent versus simple shaped natural and man made objects. Illustration taken from Moore & Price, (1999). p. 43

Figure 7. Illustration of local maxima from studies of visual recognition subdivided by stimulus class into objects, faces and printed words placed in standard space and projected onto sagittal, coronal and axial views. Images taken from Farah & Aguirre (1999). p. 44

Figure 8. An illustration of areas of the brain that activate during naming visual pictures. Image taken from Price (2000) with data from Moore & Price, (1999). p. 52

Figure 9. Example of schematic representation of the brain structures involved in the name retrieval of an object presented visually as proposed by Damasio et al. (2004). p. 52

Figure 10. A schematic representation of a *serial* model of visual object naming as proposed by Hillis & Caramazza (1995). p. 54

Figure 11. A schematic representation of the discrete forward account of object naming as proposed by Dell & O'Seaghda (1991, 1992) adapted by Rapp & Goldrick (2000). p. 54

Figure 12. The interactive activation and competition model of object naming as proposed by Humphreys et al. (1995). p. 56

Figure 13. The restricted interaction account of object naming as proposed by Rapp & Goldrick (2000). p. 56

Figure 14. A model of object naming from Davidoff & de Bleser (1993), adapted by Davidoff (2001), taken from Humphreys & Forde (2001). p. 62

Figure 15. Model of the classification of memory. Image taken from Squire (1992). p. 71

Figure 16. Implications of models for neural tuning following repetition (priming). Image taken from Grill-Spector, Henson & Martin (2006). p. 77

Figure 17 a. Experiment 1. Mean naming reaction times for the control group in the immediate naming task subject based. p.117

Figure 17 b. Experiment 1. Mean naming reaction times for the control group in the immediate naming task item based. p.117

Figure 18 a. Experiment 1. Mean naming reaction times for the aphasic group in the immediate naming task subject based. p.119

Figure 18 b. Experiment 1. Mean naming reaction times for the aphasic group in the immediate naming task item based. p.119

Figure 19. Experiment 1. Mean naming reaction times for the aphasic group and the control group in the immediate naming task. p.121

Figure 20 a. Experiment 1. Mean naming reaction times for the aphasic group plus the control group for the comparison of the overall picture colour. p.122

Figure 20 b. Mean naming reaction times for the aphasic group plus the control group for the comparison of the two background conditions: plain (cocp and gogp) versus noise (cocn and gogn). p.122

Figure 21 a. Mean naming reaction times for living versus non-living things for the control group. p.123

Figure 21 b. Mean naming reaction times for living versus non-living things for the group of aphasics. p.123

Figure 22 a. Mean naming reaction times for the control group and the three main categories fruits & vegetables, animals, and manmade objects presented in a graph with columns. p.124

Figure 22 b. Mean naming reaction times for the group of aphasics and the three main categories fruits & vegetables, animals, and manmade objects presented in a graph with columns. p.124

Figure 23. Mean naming reaction times for the control group and the three main categories fruits & vegetables, animals, and manmade objects presented in a graph with lines. p.124

Figure 24. Mean naming reaction times for the aphasic subject group and the three main categories fruits & vegetables, animals, and manmade objects presented in a graph with lines. p.125

Figures 25 a-f show the mean naming reaction times for each subject group and the three main categories fruits & vegetables animals, and man made objects separately per picture design. p.125

Figure 26 a. Mean naming reaction times for the category of manmade objects divided into high and low colour diagnostic objects and per picture design for the control group. p.128

Figure 26 b. Mean naming reaction times for the category of manmade objects divided into high and low colour diagnostic objects and per picture design for the group of aphasics. p.128

Figures 27 a-d show the mean naming reaction times for each subject group subject based and object based, for the immediate naming at day 1 (RT 1), and for the repeated naming at day 12 (RT 2). p.135

Figure 28. Mean naming reaction times for both subject groups subject based, for the immediate naming at day 1 (RT 1), and for the repeated naming at day 12 (RT 2). p.136

Figure 29. Mean naming reaction times for both subject groups object based, for the immediate naming at day 1 (RT 1), and for the repeated naming at day 12 (RT 2). p.136

Figure 30. Experiment 2. Mean naming reaction times for the 3 subject groups in the immediate naming task. p.168

Figure 31 a. Experiment 1. Mean naming reaction times for the 60 participants in the immediate naming task subject based. p.168

Figure 31 b. Experiment 1. Mean naming reaction times for the 60 participants in the immediate naming task item based. p.169

Figure 32 a. Experiment 2. Mean naming reaction times for the 60 participants in the immediate naming task according to age. p.170

Figure 32 b. Experiment 2. Mean naming reaction times for the 60 participants in the immediate naming task according to gender. p.170

Figure 33. Experiment 2. Mean naming reaction times for the 60 participants in the immediate naming task for the 3 categories animals, fruits & vegetables, and manmade objects per picture design presented in a graph with lines. p.171

Figures 34 a - c. Experiment 2. Mean naming reaction times for the 60 participants in the immediate naming task for the 3 categories animals, manmade and objects fruits & vegetables per picture design presented in a graph with columns. p.171

Figure 35. Experiment 2. Mean naming reaction times for the 3 groups (1-month group, 3-months group, and 6-months group) in the repeated naming task per picture design. p.175

Figure 36. Experiment 2. Mean naming reaction times for the 3 groups (1-month group, 3-months group, and 6-months group) in the repeated naming task as a group comparison. p.176

Figures 37 a-f. Experiment 2. Mean naming reaction times per picture design in the repeated naming task of Experiment 2 subject based and object based for the 3 groups (1-months group, 3-months group, and 6-months group). p.176

Figure 38 a. Experiment 2. Mean naming reaction times in the repeated naming task for the 5 different subject groups that took part in experiment 1 and 2. p.179

Figure 38 b. Experiment 2. Mean naming reaction times in the repeated naming task for the 5 different subject groups that took part in experiment 1 and 2 as group analysis per picture condition. p.179

Figure 39. Experiment 3. Mean reaction times for the rapid object detection task subject based. p.197

Figure 40. Experiment 3. Mean reaction times for the rapid object detection task object based. p.198

Figures 41 a-f. Experiment 3. Mean reaction times for the rapid object detection task, subject and object based per background condition, object colour, and background colour. p.199

Figure 42. Experiment 3. Mean reaction times for the rapid object detection task for living and non-living items. p.201

Figure 43. Experiment 3. Mean reaction times for the rapid object detection task for living and non-living items per picture design. p.203

Chapter 1: General introduction

1.1: Background

What is colour vision for? Our vivid perception of colours in the environment leads to the assumption that colour must be important for processing natural scenes and, specifically, recognizing objects therein. Seeing in colour offers several advantages; there is considerably more information in a chromatic than in an achromatic world. However, there is still much of a debate as to whether the availability of colour information in the visual image benefits the identification, memorization or naming of objects

The idea for this thesis arose during the clinical work of the author as a speech and language therapist when examining and treating patients with aphasia. Aphasia is a language impairment caused by brain damage that crosses all input (verbal speech comprehension, reading comprehension) and output modalities (speaking, writing), and can be divided into various syndromes. A symptom common to nearly all of the different syndromes of aphasia is *anomia*, a difficulty or inability to retrieve the names for concepts (objects) that previously were available to the speaker. Anomia is usually present whatever the input modality: visual, tactile, auditory, gustatory, or olfactory (Goodglass et al., 1968). This research will focus on the *visual* input modality, i.e. the failure to retrieve the name when the object is presented *visually* (naming pictures), and in the absence of any impairments of visual object recognition. Although anomic patients may be unable to produce the name for the desired object, they can still *identify* the object by pointing when provided with the spoken or written name. This indicates that even when object names are inaccessible for verbal production, they are still not generally lost in memory.

Assessing the severity of the word-finding deficit in anomia usually involves confrontation naming using pictures of objects. Retrieving the name of an object from a picture involves perceptual analyses of the visual input and the mapping from an object's semantic concept to its name. A sufficient identification of an object is a prerequisite for successful name retrieval (Riddoch & Humphreys, 2001) and the better a picture matches the semantic concept of the object stored in memory, the easier it is to retrieve that object's name (Levelt et al., 1991). Whether colour information benefits the *perceptual* analyses and what role colour plays during the *identification* process of single objects is still unsettled (e.g. Davidoff & Ostergaard 1988; Price & Humphreys 1989; Delorme et al., 2000; Edwards et al., 2003). However, there is more agreement that colour does play a role when the semantic task demands increase as for the lexical selection process when *naming* single objects. A number of studies across different populations have found more or fewer advantages for colour on naming accuracy, naming latencies, or on both (e.g. Bisiach, 1966; Wurm et al., 1993; Humphrey et al., 1994; Barrow et al., 2000; Vernon & Lloyd-Jones, 2003; Rossion & Pourtois, 2004). However, there is disagreement among studies about the conditions under which colour plays a role in visual perception and lexical selection to boost the naming process. For example, some studies suggest that the advantages of colour are only found for objects belonging to natural categories (e.g. Chainay & Rosenthal 1996) or when the images are degraded (e.g. Laws & Hunter, 2006), or when the colour is diagnostic for the object (e.g. Humphrey et al., 1994).

Therapeutic treatment of anomia commonly uses repeated picture naming with the aim of strengthening (priming) the neural pathway leading from the perceptual analyses of the object to its spoken name (Cornelissen et al., 2003; Wingfield et al. 2006). Research with healthy subjects (e.g. Mitchell & Brown, 1988; Cave, 1997; Vernon & Lloyd-Jones, 2003) and aphasic patients (Mills et al., 1979) has shown that item repetition across naming trials often

results in significantly faster naming latencies, which confirms that repetition must facilitate object-naming processes at certain levels of processing. Such facilitation of performance or so-called priming effects have been observed after just a single trial and without telling subjects explicitly to memorize the pictures they have to name. The majority of studies examining priming during picture naming have used achromatic stimuli. Only two studies have directly contrasted *realistically* coloured pictures with achromatic ones. Vernon & Lloyd-Jones (2003) used only natural objects and found faster naming for coloured pictures during encoding and recall. In contrast, Nicholson & Humprey (2001), using mainly fabricated (manmade) objects, found little difference in priming times between the chromatic and achromatic picture conditions when pictures were presented in an upright position, but large advantages for colour when the same images were rotated. These results indicate that there is, as yet, no clear picture to be drawn about the role of colour during priming of object naming. There is however some evidence that colour can facilitate *recognition memory* in *scenes* (Gegenfurtner & Rieger, 2000; Wichmann et al., 2002). It was speculated that these effects might result from *sensory factors* such that colour improves image segmentation (Wichmann et al., 2002). In addition, *cognitive factors* may play a role such that colour may facilitate memory retention by providing additional information about the object, thereby shortening the duration of the process of parallel matching of object attributes to the stored representations (Nicholson & Humphrey, 2003; Vernon & Lloyd-Jones, 2003). There are still many open questions about how visual characteristics of a display might influence how much information is *encoded* and *retained* prior to the onset of an utterance when naming and renaming visually presented objects.

Research has shown that even mildly impaired aphasic patients differ considerably in their naming accuracy and naming latencies (Goodglass et al., 1968; Mills et al., 1979; Wingfield et al., 2006) when compared with non-aphasic speakers of the same age. Aphasic patients also

differ in their semantic distractibility when identifying pictures compared with normal subject groups (LaPointe et al., 2006). Hence, it seems that aphasic subjects with anomia are more vulnerable when transmitting visual information "between the sensory analyzer and the verbal sphere" (Bisiach, 1966). In fact, some older studies suggest that the performance of aphasic patients is influenced by the *visual* form in which objects are presented, and that pictures with more redundant information (such as colour) reduce the failure of their name retrieval (Luria, 1947; 1962; Bisiach, 1966; Benton et al., 1972). Thus, it seems that aphasic subjects with anomia could be an ideal subject group to explore the influence of colour at the vision-language interface of confrontation naming. Could they benefit from additional colour cues when tested and trained with picture material? In addition, it is of interest to revisit how colour influences non-aphasic (healthy) participants and whether there are differences between these two subject groups.

1.2: Aim of the thesis

The research reported in this thesis aims to shed light on the processes involved at the vision-language interface by particularly evaluating the effects of *colour* on object recognition and priming during (repeated) confrontation naming in healthy participants and aphasic patients with anomia. The experiments have been designed to specifically examine how colour contributes to image segmentation and object identification in the process of naming common single objects, and how colour affects priming measures when those objects have to be renamed after a delay. In addition, one of the experiments is specifically designed to contrast aphasic subjects and healthy participants to evaluate whether these two groups differ in their responses to colour. However, this research is not designed to compare *individual* subjects or objects in respect to colour, as this would be far beyond the scope of this thesis. Instead, this research aims to explore whether there is a *general pattern* for the response to colour that is

valid for more than one population and language and therefore incorporates a cross-linguistic design that compares group performances of English with German speaking healthy participants.

1.3: What are the benefits of colour vision?

The human visual system is capable of processing objects within a fraction of a second, whether detecting the presence of an object, defining the class of an object, or uniquely identifying and naming an object. Neurophysiological research provides evidence that a significant amount of visual processing is committed to the analysis of colour information. Indeed, for human observers, Chaparro et al. (1993) found that coloured stimuli are detected 5-9 fold better than the best luminance spot. They conclude that "colour is what the eye sees best". Why has the human brain developed specialized mechanisms for processing colour and what ecological advantage does this give in everyday vision?

1.3.1: Evolution of colour vision

Colour vision, in the sense of wavelength specific behaviour, is apparent in various invertebrates, bacteria, and even plants. However, 'cognitive' colour vision, where the visual scene is endowed with the property commonly referred to as 'colour', suggests something more than the ability to automatically direct behaviour to certain spectral lights. It entails a visual system that uses colour to learn about and classify regularities in the environment (Skorupski & Chittka, 2008). Colour vision in humans evolved in order to see objects, give them meaning, and to name the objects.

What are the underlying mechanisms of colour vision? The retina in humans and Old World primates contains two different types of photoreceptors, namely rods and cones. Rods respond

under conditions of low illumination, such as in nocturnal vision, while cones are sensitive to higher levels of illumination, as in diurnal vision, and mediate colour vision. There are three cone classes which have different spectral sensitivities, responding preferentially to short-, middle and long-wavelength light, respectively. A visual system that simply sums the activity of its receptors will signal only luminance. However, by comparing the activity of the three cone classes, their relative activity can signal different spectral distributions i.e. colour. This is the basis of trichromatic vision. Colour vision allows us readily to tell apart two spectrally different stimuli that appear equally bright, e.g. to distinguish the ripe from the unripe fruit. It also allows us to distinguish objects in fluctuating light conditions, e.g. detecting the fruit amongst foliage falling in sunlight or shadow, and to successfully discriminate a real edge from a simple shadow boundary (Gordon & Abramov, 1998). Hence colour is particular useful for the segmentation of objects from their backgrounds and allows better detection of objects in a visual scene (Heywood et al., 2001). In short, colour adds a further dimension to the visual system where spectral reflectance is independent of luminance (Bowmaker & Hunt, 2006; Bowmaker, 2008).

Colour vision is not only particularly helpful for segregating and organizing visual input into three- dimensional objects and scenes (Tanaka et al., 2001), differentiating edible fruits and leaves amongst a background of others and selecting plants from a complex scene (e.g. Summer & Mollon, 2000). Its ecological advantage extends to the recognition of co-specifics (Edwards et al., 2003; Changizi, 2006; Fernandez & Morris, 2007), the detection of subtle changes in the colouration of faces to signal mood, like anger or embarrassment, signalling ill-health (Bruce & Young, 1998, p. 73; Yip & Sinha, 2002), sexual signalling (Fernandez & Morris, 2007) and may even sustain gender classification (Tarr et al., 2001).

1.4: Colour effects on object segmentation and categorization.

Early processes of segmenting objects in the visual scene rely on colour and luminance differences. However, there is also support for the view that luminance cues alone are sufficient to derive the shape of an object and that surface attributes such as colour are filled in later and are not necessary for object detection. Moreover, colour also plays a role in visual attention which supports the segmentation process. In addition, segmentation, object categorization and identification are unlikely to be distinct processes but instead are mutually dependent but differing in their time-course.

1.4.1: Colour effects in visual attention and their influence on object segmentation

What influence does colour have on visual attention? The visual system has limited capacity to process simultaneously multiple objects from the entire visual field. It is therefore necessary to filter relevant from irrelevant information in a scene and to bring the most important features into the centre of the visual field. Attention can either narrow the focus down to a small area with high resolution, or spread it over a wider area with the loss of detail. This process can be directed either automatically and stimulus driven by bottom-up mechanisms, such as stimulus *salience* (e.g. a red strawberry is salient among green leaves), or by *selective attention* as a result of top-down mechanisms driven by an observer's goals.

Attentional processing may occur in two *serial* stages according to influential theories by Treisman (1988, 1990) and Koch & Ullman (1985). In a first *preattentive* stage, colour, form, luminance, and position features are recorded independently by feature detectors to produce a 'master map of locations', which is a prerequisite for segmentation. This map contains the boundaries of all the features and registers *where* they are located there, but not *what* features

are located. The preattentive stage is then followed by a stage of *focused attention* where these features are combined to achieve object recognition. Features with the greatest difference in signal, i.e. salience, will preferentially attract focal attention and produce the largest amount of bottom-up activation. This means that attentional selection is determined by position in space.

Colour attributes can drive attention automatically by their signals of position when they are *salient* enough. In addition, colour can capture attention when the use of the colour singleton is *task relevant* and happen to be the critical item for subsequent encounters (Van der Heijden et al., 1996; Goolsby & Suzuki, 2001). Furthermore, colour can even summon attention when the use of the colour singleton is irrelevant for the task. For instance, Cole et al. (2009) used a 'change blindness' test design where subjects had to discover the location of a changing element, embedded in a display of other simultaneously presented transient non-singleton stimuli, to evaluate the extent to which colour singletons are resistant to change blindness. "Change blindness" occurs when observers overlook unexpected objects in a scene while performing a difficult visual search task. Results show that colour singletons are more resistant to change blindness compared with other singleton stimuli. In addition, items located immediately adjacent to the colour singletons benefit from the enhanced focus of processing relative to items outside the attentional field. Comparing one scene with a subsequent one requires not only attention but also involves mechanisms of visual short-term memory. Cole et al. suggest that the primacy of attention elicited by a colour singleton may result in an enhanced representation in visual short-term memory, which in turn makes it more robust to change blindness.

To summarize, the above findings support the idea that colour may play a role in attention by supporting object segmentation and by signalling the appearance of a *new* stimulus. Colour

vision evolved because it facilitates the segregation and organization of visual input into three-dimensional objects and scenes (Tanaka et al., 2001). It is of importance for survival to have a system that automatically alerts the observer about unexpected events to enable a rapid behavioural response to potentially threatening events. Colour seems to be a useful tool in such an automatic alerting and survival system.

1.4.2: The computation of object segmentation and object recognition in the brain

What visual processes underlie the segmentation and recognition of objects? Research indicates that the processing of object segmentation and object recognition occurs in an interactive way. This process involves several brain areas that are linked together and driven by feedback connections. Vision entails neural processing in a complex network of some thirty or more cortical visual areas (Van Essen et al., 1992) that are conjoined in three different ways: by *feed forward connections* from lower to higher areas, where most of these feed forward connection have reciprocal *feedback connections* that also run from higher to lower areas, and in *lateral connections* within areas of equivalent processing complexity (Ullman, 1995, 1996; Segalowitz, 2007; Kveraga et al., 2007; Rolls, 2008). Neurons in different areas respond preferentially to different *combinations* of scene properties (i.e. colour and motion, shape and depth) and processing can occur in serial or parallel stages.

In a cluttered scene, how does the brain establish which parts of objects belong together? The visual system must decide which of the perceived features belong together to form a figure and which of them form a background against which the figure appears. This interactive process involves the *segmentation* of an image into coarse regions that can be rough candidates for objects, and the *binding* of perceptual attributes to form an object representation (Ullman, 2006). This computation is achieved by feedback loops during early visual processing stages where the perceptual information of the sensory input is transferred

from the visual cortex to the prefrontal areas of the brain and back again. During those processing loops, analogical mapping of early visual features interacts with associative representations of objects stored in memory to form predictions about the object's identity (Kveraga et al., 2007). It is assumed that the basic notion of figure-ground differentiation is based on experience and driven by stored knowledge of the world, in that top-down information can influence and modulate lower visual processing stages (Borenstein & Ullman, 2002; Friston, 2005; Ullman, 2006).

In summary, the brain is not just a passive recipient of sensory information but "continuously employs memory from the past to interpret sensory information and predict the immediately relevant future" (Kveraga et al., 2007). The computation of object segmentation is driven by experience and requires knowledge about associative representations of objects previously stored in memory.

1.4.3: The time course of figure-ground segmentation and object categorization

Objects in real life situations are rarely seen in isolation. They are often partly occluded and embedded in cluttered environments. Empirical evidence suggests that *segmentation* and *categorization* of scenes and objects are strongly linked together in that object categorization influences segmentation (Peterson & Gibson, 1993, 1994; Peterson & Kim 2001; Peterson & Lampignano, 2003), or that both are based on the same processing mechanisms (Borenstein & Ullman, 2002; Grill-Spector & Kanwisher, 2005). The underlying model for the latter view states that incoming images are compared with template-like fragments, stored in memory from previous experience of the world, where each subregion of the template is computed as either figure or ground. The information in this fragment-based representation then entails both the information about the object category *and* the figure-ground segmentation of the image.

Indeed, both data from magnetoencephalography (MEG), event-related potentials (ERP) in people (Liu et al., 2002; Halgren et al., 2003) and behavioural results support the notion that object *detection*, *segmentation*, and *basic level categorization* occur at the same time and may use the same perceptual information (Grill-Spector & Kanwisher, 2005; Bowers & Jones, 2007; Mack et al., 2008). If either process fails, so does the other, as subjects in the study of Grill-Spector & Kanwisher (2005) were unable to categorize an object that they failed to detect and detection performance was no better than chance whenever they failed to categorize an object.

In contrast, studies measuring ERPs during object categorization and recognition (Curran et al., 2002) and data from functional magnetic resonance imaging (Grill-Spector et al., 2004; Grill-Spector & Kanwisher 2003) show that *identification* of a given category engages the same cortical regions as detection, but evokes later ERPs and needs an average of 65 milliseconds more time for processing when measured with fMRI. It seems that object detection and identification are computed by similar cortical regions but that they differ on a temporal basis, as additional processing is needed to perform an identification task compared with simple object detection.

An object *detection* task requires subjects to decide whether a scene contains a certain object or not. *Basic level* visual *categorization* is the ability to establish that an object belongs to a general (superordinate) class such as a bird or a flower. The term '*object identification'* is used in some studies for *within-category classification*, where subjects need to discriminate exemplars of a particular subordinate level category (e.g. sunflower) from other members of the category (e.g. flowers). However, other studies use the term for the recognition of a particular unique object, for example a specific house or chair even when the object is depicted in different conditions such as its viewpoint. Grill-Spector et al. (2004) and Grill-

Spector & Kanwisher (2005) have shown that object detection and categorisation can occur without prior identification, but that identification depends on successful object detection, segmentation, and categorization.

In summary, the above-mentioned research strongly indicates that object segmentation, detection, classification, and identification are computed by similar cortical regions but that they differ on a temporal basis.

1.4.4: Colour and luminance cues in the segmentation process of objects

Colour can give additional cues to segment scenes into 'intrinsic images' because it contributes with the two additional dimensions of the red-green and the yellow-blue axes (Goffaux et al., 2005) and therefore provides additional access to the experience of the thousands of shades we are able to tell apart (Stoerig, 1998). In an early theory, Switkes et al. (1988) suggest that the visual system may even suppress the luminance noise in favour of chromatic borders, because chromatic borders present more reliable information of object boundaries than luminance ones. Indeed, in some instances colour can be the only factor allowing sufficient object discrimination and this is especially true for shadows. Shadows that are solely defined by luminance often do not provide sufficient information to divide shape from shading and are not reliably linked to object contours. This is because the brain has learned that chromatic changes typically occur at *object* and not at *shadow* boundaries. Rivest & Cavanagh, (1996) show that low contrast figures are more easily discriminated when they differ in *colour* from their ground than by *luminance* differences created by shadows. Kingdom et al. (2004) showed that human participants identify simulated shadows and simulated transparencies (Kingdom & Kasrai, 2006) much better when projected on chromatic than on achromatic 'Mondrian-like' backgrounds, when both backgrounds are adjusted to the same luminance distribution. Even though colour and luminance can act

independently in some instances (Livingston & Hubel, 1988; Gegenfurtner & Rieger, 2000), they lack independence when it comes to computing *differences* in luminance between two locations in a natural (chromatic) scene. This was demonstrated in a study by Fine et al., (2003). The authors examined differences in luminance and colour between neighbouring pixels in natural scenes. They show that when two points fall on the *same* surface, differences in luminance and colour are perceived as small, but differences look larger when they fall at *different* surfaces. In their studies, observers were asked to categorize pixels of patches of images as either belonging to the surface of an object or to a background when compared with a reference pixel. Image patches were scaled to subtend 10.2 deg of visual angle and consisted of parts of natural and manmade scenes and the full image was not available to the observer. The authors propose that segregation of scenes can be carried out by cells that are insensitive to the sign of chromatic contrast, but sensitive to *differences* in both luminance *and* colour (see also Kentridge et al., 2004). Their function might be especially useful in the segmentation of partly occluded objects. In line with this view are findings from Rubin (1921), one of the early Gestalt psychologists. He found that colour looks more *substantial* in the figure than in the ground and that these effects can not only be seen in direct perception, but can also be replicated in afterimages. Rubin's observations follow the principle of similarity (as part of the Gestalt principles) that regions with similar brightness, *colours* and depth are more likely to be part of a single common surface (object) than to belong to two different surfaces (see also Gelb & Granit, 1923; Croner & Albright, 1997). In addition, a common border between two regions of an image has the effect of shaping only one of the regions and highlighting it as figure, and having little or no effect on the ground (figure-ground principle).

To summarize, there is evidence that colour information facilitates object segmentation. This facilitation seems to be computed not only by cells that are sensitive to colour but also by

cells that are insensitive to colour but sensitive to differences in both luminance *and* colour to enhance the processing of chromatic borders in scenes. Indeed, the visual system is endowed with a great sensitivity to low-spatial frequency colour variations and is therefore ideally equipped to segment objects on the basis of their *colour* rather than on luminance cues only (Heywood et al., 2001). It might be that *pooling* information from different attributes such as luminance *and* colour is advantageous to discriminate objects in scenes, as scenes naturally contain shadows (Gur & Akri, 1992; Rivest & Cavanagh, 1996; Syrkin & Gur, 1997).

1.4.5: Categorization of objects in scenes

Scene categorization is a fast process that can be extracted from a single fixation (Henderson & Hollingworth, 2003; Fei-Fei et al., 2007). How this process is organized hierarchically and temporally and at what stages attributes like colour, luminance, texture, shape, depth or motion interact to segment the image and to facilitate detection, categorization and identification of the objects in the scene is still a matter of debate. The role of *chromatic* information in scene and object recognition remains especially controversial and has become of increasing interest in recent years. Perception of natural scenes depends on the matching of *pre-existing knowledge* of the world (stored in memory) with the immediate outcome of attentional processing of what is perceived (Silva et al., 2006). Coarse boundary contours of a scene that may consist of low level cues such as luminance, *chromaticity*, movement and depth can form a representational skeleton (also called ‘scene gist’ or ‘scene schema’) that can be sufficient to access categorization without prior recognition of component objects (Schyns & Oliva, 1994; Oliva et al., 2003; Goffaux et al., 2005). These boundary contours can be completed by an automatic, rapid and preattentive process (Grossberg & Mingolla, 1985). Coarse information about a stimulus becomes available before fine detail (Sugase et al, 1999), and feature integration can start before the analyses of the separate features have been completed (Smid et al., 1997).

1.4.6: Is colour processed later than shape?

There is evidence that coarse scales in *luminance* variations are sufficient to bootstrap scene recognition when subjects are asked to recognize achromatic scenes (Parker et al., 1992; Oliva & Torralba, 2001). In line with those findings, Delorme et al. (2000) report that at *very short* stimulus presentation times (20ms for human observers and 32ms for monkeys) coarse *achromatic* magnocellular information is sufficient to allow object categorization for images, which contain animals or food items. Their human participants and the test monkeys responded to new and familiar stimuli with similar latencies and removing the colour cues had little effect on accuracy or reaction times. The authors propose that ultra-rapid categorization relies on feed-forward processing that is mainly transmitted by the near colour-blind magnocellular pathway (M-pathway). Chromatic information processed in the parvocellular pathway (P-pathway) reaches the cortex about 20 msec later than the magnocellular inputs, therefore at 20-30ms presentation time *luminance* cues are better processed than *colour* cues. Colour would only be needed as an additional factor if the first coarse information by the M-pathway has been insufficient to access object categorization, for example, when object shapes tend to be very similar as in subordinate classification tasks (Thorpe et al., 1996; Fabre-Thorpe et al., 1998, see also Price & Humphreys, 1989). However, in their study responses for *food* items were slightly faster (10-15ms) in both subject groups and a minor increase in accuracy was noticed in human participants when the images were shown in colour compared with their achromatic versions (Delorme et al., 2000). Although those effects for colour were small, they do show that colour must have been processed to some extent.

In contrast, no evidence was found for a first wave of achromatic processing when Edwards and colleagues (2003) tried to replicate the results of the Delorme study. They used single cell recordings from IT neurons in an adult monkey while the animal was presented with chromatic and achromatic photographs of human and monkey heads, animals, everyday objects and abstract figures. The majority of the tested neurons (70%) in the inferior temporal lobe (IT) evoked significantly reduced responses with the achromatic images compared with coloured ones. Response onset with the coloured stimuli showed that the most colour-sensitive cells responded earliest. Furthermore, colour information and form information that derived solely from luminance cues arrived *simultaneously* in IT cortex. Differences in the latency of M- and P-cells have been reported in the lateral geniculate nucleus (LGN) where earliest M-responses arrive around 10ms earlier than the P-responses (Maunsell et al., 1999), and about 20ms in V1 (Nowak et al., 1995). However, Edwards et al. argue that such latency differences between the M- and P-cells may have been corrected when the visual information arrives at the IT. There are 10 times more P- than M-neurons and this greater number may provide a sufficient level of excitatory firing to exceed threshold more rapidly in the P- than the M-cells whose single transmissions are nevertheless faster. Further evidence for a fast processing of colour derives from the priming literature (see section 1.7). It has been shown that colour can influence object perception at the earliest stages, possibly as early as in V1 (primary visual cortex). Research shows that colour can elicit visual priming at stimulus presentation times as early as 10ms (Schmidt, 2002; Breitmeyer, Ogmen & Chen, 2004) or 14.3ms (Breitmeyer, Ro & Singhal, 2004), while priming of shape (form) occurs later.

1.4.7: Colour and shape interactions during object categorization

Smid, Jacob & Heinze (1997) measured early event-related brain potentials while subjects performed a picture-matching task. They found that when *colour*, *global* shape and *local* shape are easy to discriminate (e.g. red vs. blue in the colour dimension, parallel lines in the

global shape dimension, and a diagonal between the parallel lines in the local shape dimension), processing of *colour* and *global* shape start at the same time and in parallel. Colour and global shape have equal completion times and interact later for further task-directed processing, while *local* shape processing starts later than colour and global shape. However, in conditions with higher demands of discrimination, the attribute that is less discriminable starts later (colour or global shape), but not the *onset* to the local shape selection. The authors conclude that feature integration can start at a second stage before the first stage of independent and parallel processing of attributes has been terminated.

More evidence for colour-shape interactions at very early processing stages is demonstrated in experiments by Ling & Hurlbert (2004). It takes participants longer to discriminate the *similarity* of simple novel 3D objects made from plaster of Paris when only the variable size is available and significantly shorter when the variable colour is presented. Furthermore, size and colour must have already interacted at coarser scales, as objects with more saturated colours were judged as bigger than objects with less saturated colours, although all objects had exactly the same size. It was concluded that size and colour interaction must have occurred via bottom-up mechanisms at very early stages of object processing when judging object similarity, as the entire test objects were made of non-familiar shapes for which no previous colour knowledge could exist. However, although their subjects had no previous experience with the *colour of the specific objects used in the test*, they may still have accessed their *general* knowledge about *object colour and saturation* as a top down information.

1.4.8: Summary

In summary, it has been shown that coarse scales in *luminance* variations are sufficient to bootstrap scene recognition if scenes do not contain colour. However, there is no evidence that the visual system does not make use of colour once it is available to the eye. Observations

from the priming literature and the findings by Edwards et al., (2003), Smid, Jacob & Heinze, (1997), and Ling & Hurlbert (2004) clearly speak against a *serial* model where shape is *generally* processed first and colour attributes filled in later.

1.5: Colour effects in object recognition

Having segmented the visual scene, how do we recognize objects? Chief theories of object vision are edge-based accounts, for example those championed by Biederman and Marr, but these are perhaps inadequate because they fail to take into account that colour is an intrinsic property of an object. But it may be the case that the contribution that colour makes depends on the *category* of the object, for example to of the recognition of living but not non-living items. However, there are many methodological issues, which might question this assumption. In particular there is a debate as to whether colour really only aids the recognition of living things because in these instances the colour is frequently *diagnostic* of the object, i.e. the object is invested in its natural and characteristic colour.

1.5.1: Edge based theories of object recognition

Early influential theories of object recognition by Marr (1982) and Biederman (1987) have postulated that objects can be classified by their main three- dimensional parts, which are constructed with a fixed set of basic geometric forms. Descriptions on the basis of a few simple volumetric primitives are sufficient to form a primary *achromatic* mental representation of any given object. Surface information such as colour is not needed in early stages, except when shape information is degraded, occluded or absent. Colour may even have an inhibitory effect on early object recognition by increasing the difficulty of edge extraction (Biederman, 1987; Biederman & Ju, 1988). In fact, some early studies using black and white outline drawings as two-dimensional images of common objects show that the

achromatic line drawings are verified as quickly as coloured images of the same objects (Biederman & Ju, 1988, Exp. 4 and 5; Brodie et al., 1991, Exp. 4; Chainay & Rosenthal, 1996), and colour made no difference when coloured and grey-scaled photographs of objects were compared (Ostergaard & Davidoff, 1985, Exp. 2 and 3). Object verification requires participants to decide whether two successively presented stimuli (two pictures or a word then a picture) refer to the same object. It was proposed that object segmentation is mainly based on the luminance image at a low-level stage of visual processing in a simple bottom-up manner and that other surface detail is filled in later, but only if necessary and if sufficient time for processing is available.

The above-mentioned studies were later criticised for not using appropriate stimuli or test designs to determine colour effects. For example, Biederman & Ju used a set of 29 target objects where only five of them had a typical natural colour (apple, banana, mushroom, rolling pin, flowerpot) and were most of the other objects where either achromatic (e.g. old-fashioned telephone) or metallic (e.g. fork, stapler, kettle, hairdryer, lock). The same was true for the stimulus set used by Brodie et al. (1991). Their choice of stimuli may have been responsible for their observation of only a weak and unreliable colour effect. Ostergaard & Davidoff (1985) used only a very small number of target items (three in exp. 2 and four in exp. 3) which may have worked against finding any colour effects. Chainay & Rosenthal (1996) failed to find an advantage for colour when testing verification with five subjects with Alzheimer’s disease. The authors did not provide any information about whether these patients were examined for their visual abilities prior to the test. All of them failed to *name* a substantial proportion of the pictures (< 40% correct); it is possible that other cognitive or visual impairments may have biased the results.

There are several weak points in the approaches and methodologies of edge-based accounts of object vision. In general, the computation of edges needs to be carried out for objects in *natural* settings and not merely from line drawings or objects that are presented against a clear white background which rarely, occurs in natural scenes. See an example in figure 1 by Sanocki et al., 1998). Simplification of object details in some cases ignores crucial aspects and may result in problems in distinguishing objects within categories such as different models of telephones (Sanocki, 1995; Sanocki et al., 1998), see also figures 2-4 (Bar, 2004; Biederman & Ju, 1988; De Winter & Wagemanns, 2004) or species of birds such as chicken, goose and ducks (De Winter & Wagemanns, 2004; Gerlach et al., 2006). Simple volumetric primitives are also insufficient to represent for example the different appearances of a flying, swimming or waddling duck. Furthermore, a line drawing is not a product of low-level and local, signal based visual processing, instead, an artist has produced it as a high-level rendering of an object where some edges have been highlighted and details omitted. In this way, a line drawing does not depict anything that is real; it represents a *symbolic* representation of an object and often stands for an object class (e.g. a generalization of a car) rather than for an individual object (e.g. a Honda or a Ford). Line drawings of faces generated by computer contour detection reduced recognition significantly when compared with grey-scaled photographs (Leder, 1996; see also Davies, Shepperd & Ellis, 1978). The authors stated that fine grain processing of facial configuration (e.g. distance between the eyes, eyebrows, and nose) is crucial for the recognition of individual faces and such line drawings do not provide sufficient information to allow fine grain processing of facial configuration. Unambiguous extraction of simple edge-based and achromatic images has been shown to be difficult and they have therefore rarely been used in computer vision recognition systems (Ullman, 2004). Moreover, work in artificial recognition systems clearly shows that colour facilitates extraction of image details such as material types and surface wetness; moreover, it

aids extraction of shape and enhances stereo correspondence (Funt & Cardei, 2000; Carson et al., 2002).

Taken together, edge-based theories of object recognition reveal several weak points in their methodologies and fail to explain the computation of objects in *natural* settings. However, those theories are still widely used in literature despite the fact that there is mounting evidence that colour plays a major part in object segmentation and that colour interacts with shape at the earliest visual processing stages, which would be more in line with 'surface-plus-edge-based' accounts (Tanaka et al., 2001).

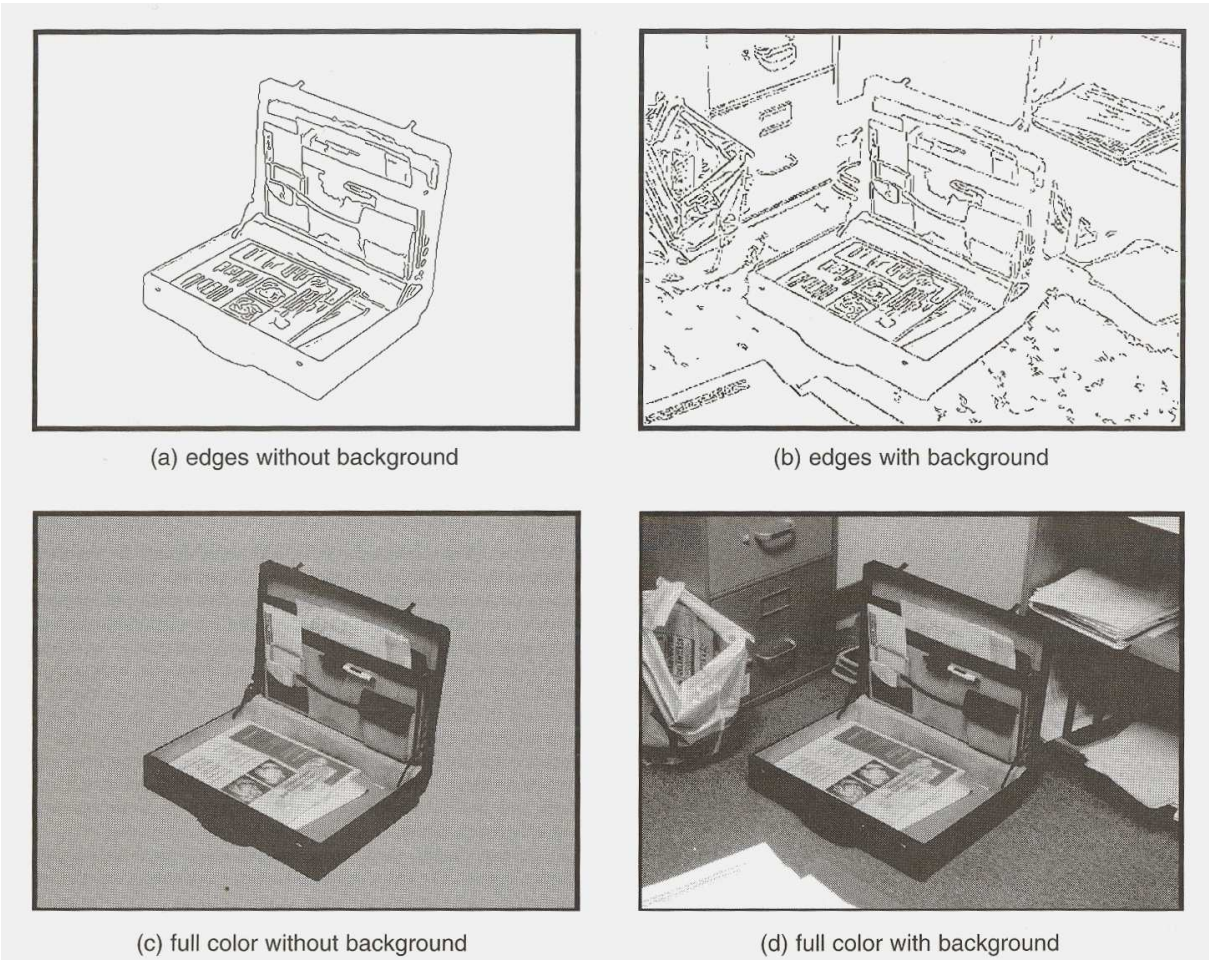


Figure 1 shows an illustration of a briefcase in four different image conditions, (a) and (b) are produced with a computerized edge extractor, (c) shows the briefcase after it was cut out from its background and pasted into an uniform background, (d) shows the original photograph. Images taken from Sanocki et al., 1998.

Figure 2 gives an example that objects that look very similar can be represented and recognized as different objects, whereas objects that look very different can be recognized as the same basic-level objects. Illustration taken from Bar (2004).

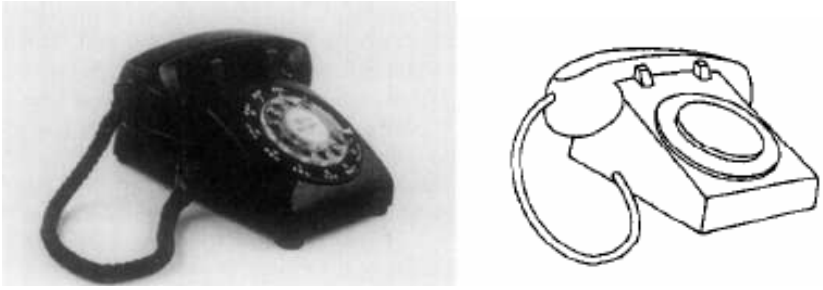
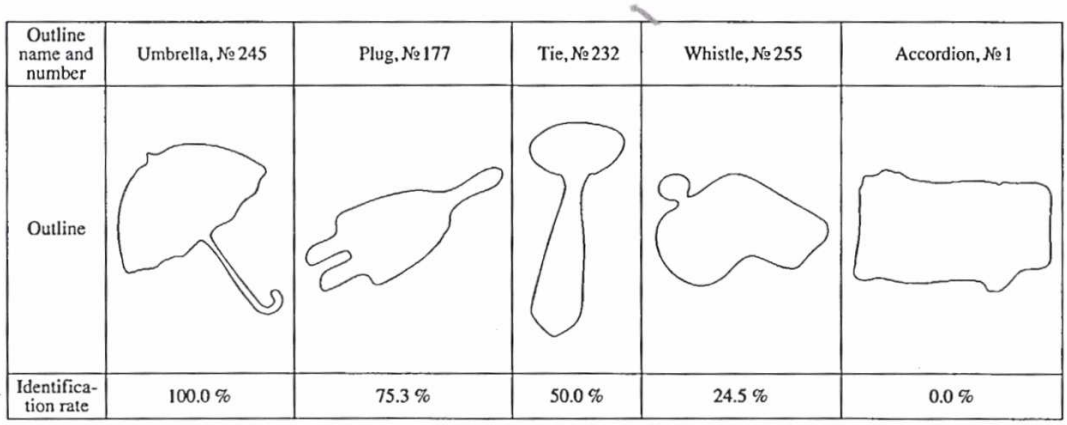


Figure 3 shows a photographic example of a telephone and the processed line drawing of the same object. Image taken from Biederman & Ju (1988).



Outline name and number	Umbrella, № 245	Plug, № 177	Tie, № 232	Whistle, № 255	Accordion, № 1
Outline					
Identification rate	100.0 %	75.3 %	50.0 %	24.5 %	0.0 %

Figure 2. Examples of contour versions with variable identification.

Figure 4 shows different identification rates of *contours* of picture samples from the Snodgrass & Vanderwart picture set (1980). Image taken from De Winter & Wagemans (2004).

1.5.2: Colour as an intrinsic object property

The internal representation of colour is not a simple construct of physical wavelength information, but rather triggered by basic semantic units that are predetermined by *colour experience* (Mausfeld, 1998). Perceptual within-item features of an object such as object colour represent *intrinsic* information. Binding the within-item features of an object is an automatic data-driven process (Treisman, 1992; 2006), which is activated involuntarily whenever an object is attended to even when the features are not relevant for recognition (e.g. Ecker et al., 2007). In other words, we cannot avoid seeing and processing colour when colour is available to our eyes. Several bottom-up and top-down factors can influence the participation of colour at very early processing stages. Research has shown that colour is rarely processed independently and often interacts with other perceptual properties such as form, space and movement during object recognition. In addition, it has been demonstrated that *colour experience* as high-level information has the potential to interact with *perceptual* visual input by either facilitating or interfering with object (Gauthier et al., 2003; Ecker et al., 2007) or scene recognition (Oliva & Schyns, 2000; Goffaux et al., 2005; Castelhano & Henderson, 2008). For instance, Joseph & Proffitt (1996) and Joseph (1997) show that stored colour knowledge (colour experience) about the prototypical colour of an object can be more influential then the presented surface colour. In object verification tasks subjects had to decide whether a briefly (at 25 and 50ms) presented *picture* matches a following *label* (written word). For example, a picture of an apple was followed by either the written word *apple* or a distractor word (*cherry,* or *dog*). When both stimuli share the same prototypical colour such as apples and cherries are red, conceptual knowledge that an apple is red interferes with the knowledge that a cherry is red and slows down reaction times even when the image of the apple is shown as black-and-white line drawing or presented in an incongruent colour (e.g. purple). In contrast, reaction times are faster with the distractor word *dog,* as apple and dog do not share the same prototypical colour (an example is shown in figure 5 on page 38). Results

indicate that *conceptual* processing of colour can be more powerful and independent from *perceptual* processing and that stored colour knowledge is activated automatically in any task that requires semantic description (Joseph, 1997).

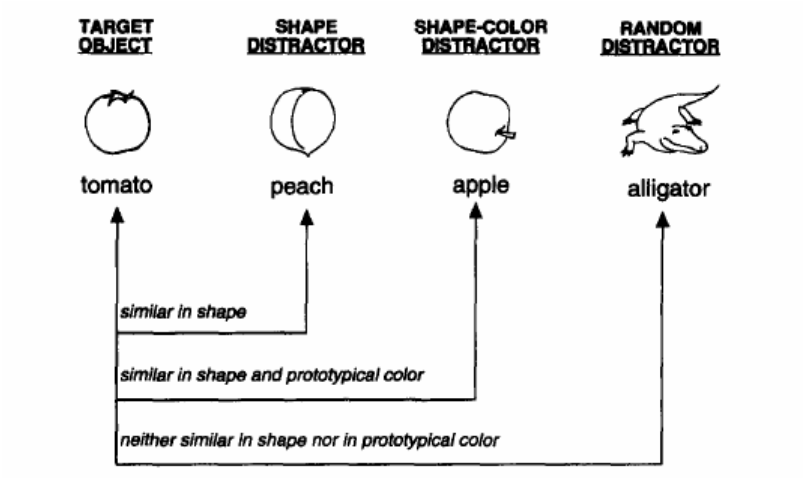


Figure 5. Illustration of the distractor conditions for a target object, tomato. Figure taken from Joseph (1997)

Naor-Raz & Tarr (2003) made similar observations when using different Stroop-designs. Their subjects performed a colour-naming task on a number of colour diagnostic objects, a task that does not require any knowledge about object shape or identity as only the colour has to be perceived and its appropriate label to be retrieved. Naming for example the *colour* of the object banana was faster when the banana was shown in a congruent colour (yellow) than in an incongruent colour (e.g. blue). It appears that the picture of the object automatically activated the visual knowledge about the colour and the shape regardless of the task requirements. The intrinsic colour yellow of the banana interfered with the perceived incongruent colour blue and slowed down the responses. However, naming the congruent colour of an object such as a banana did not prime (facilitate) a word like ‘monkey’ in a following lexical decision task (whether monkey is a word or non-word) although monkey and banana are conceptually related. It was speculated that the observed Stroop-effect during colour naming might have occurred at the level of structural descriptions, which contains the

visual representation of an object, but not at the conceptual level, as naming an object's colour did not affect a conceptually related word. In contrast, an opposite Stroop-effect was observed when objects were specified as *words*. When using words instead of pictures, the congruent colour of the print (e.g. yellow for the word banana) was named more slowly, because the yellow print caused competition between the lexical entries of the *name of the object* ('banana') and the *name of the colour* ('yellow'). No interference was observed with an atypical coloured print (e.g. blue). Furthermore, when subjects *named* the *objects* depicted in each picture (instead of naming only their colour), priming in the same lexical decision task was observed. For instance, naming the picture of a banana or seeing the word 'banana' primed the conceptually related word 'monkey'. The authors attributed these effects to the conceptual and lexical levels of object knowledge. They conclude that colour is an *intrinsic* property of visual representations of objects and that colour-shape associations can arise automatically at different levels of representations, see figure 14 for a model of different processing levels for object colour (model by Davidoff, 2001, in the naming section). Recollection experiments, as used in the priming literature (see section 1.7.4 about colour and priming), provide further evidence that colour is an intrinsic part of an object representation. When subjects have to decide whether they have seen an object before, changing the colour between study and test always increases reaction times and is detrimental for the performance even when the colour information is irrelevant for the task (e.g., Nicholson & Humphrey, 2003; Zimmer & Steiner, 2003; Spence et al., 2006; Ecker at al., 2007). This suggests that colour is bound as an intrinsic sensory feature and stored automatically when the object is first attended to. At retrieval, colour information is supplied involuntarily by the memory system leading to a mismatch of the stored colour at study with the colour perceived at test. Other studies contrasted *congruent* with *incongruent* coloured objects during object recognition to examine at which *level* colour may aid the recognition process. If colour aids segmentation only at a low level processing stage as bottom up activation, no differences

between the correctly and incorrectly coloured pictures should be observed. On the other hand, if colour is an intrinsic object property and if object colour knowledge already interferes as top down activation at early processing stages, performance for incorrectly coloured pictures should be worse. The majority of the studies show that incongruent object colour worsens recognition significantly, no matter whether stimuli are shown as photographs (Price & Humphreys, 1989; Edwards et al., 2003; Nicholson & Humphrey, 2003), as line drawings (Price & Humphreys, 1989; Joseph & Proffitt; Joseph, 1997; Tanaka & Presnell, 1999; Zimmer & Steiner, 2003; Lloyd-Jones, 2005; Lloyd-Jones & Nakabayashi, 2009), but see Davidoff & Ostergaard (1988, exp. 2 and 3), or placed in scenes (Castelhano & Henderson, 2008). These results clearly demonstrate that colour is an intrinsic property of visual representations of objects and that colour-shape associations can arise at early levels of representations.

In summary, the internal representation of colour is predetermined by colour experience. Perceptual within-item features of an object such as object colour is bound as an intrinsic property of the object and stored automatically when the object is first attended to. Furthermore, several experiments have shown that object colour knowledge has the potential to interact with perceptual visual input by either facilitating or interfering with the object.

1.5.3: Colour effects related to object category and colour diagnosticity

The literature provides controversial results as to whether colour aids object recognition only in certain *categories* of objects and whether the colour of an object has to be *diagnostic* of that object for such an advantage to occur. The most obvious object-categorisation is that between living and non-living things, or, at the level of scene, between natural or urban scenes. Categories of living things include objects such as body parts, food items, plants, or animals, whereas non-living things are defined as man made objects, tools or artefacts.

Several studies have measured category-specific effects in healthy subjects and in patients with brain damage by using either identification tasks involving object naming, or object decision tasks including superordinate object classification. Results are equivocal with no clear direction. Some studies find a disadvantage of living over non-living things for naming objects (e.g. Humphreys et al., 1988; Moore & Price, 1999), while other more recent studies observe the reverse effect when variables such as word frequency, visual complexity, and concept familiarity are matched (Laws, 1999, 2000; Laws & Gale, 2002). One study reports slower naming *and* classification for living things (Lloyd -Jones & Humphreys, 1997), whereas others find no differences between living and non-living things in naming tasks (Price & Humphreys, 1989; Gale et al., 2006), but an advantage for living things when objects have to be in classified (Price & Humphreys, 1989; Moore & Price 1999; Gale et al., 2006).

1.5.3.1: Theories about category effects in living and non-living objects

The visual crowdedness hypothesis (Humphreys et al., 1988; Gaffan & Heywood, 1993; Gale et al., 2006) provides one possible explanation for the non-living things advantage in object recognition that is found in some of the studies. It is argued that natural things such as fruit (e.g. apples, oranges, grapefruits etc.) or animals (e.g. horses and zebras) tend to have more *structurally similar* neighbours, and present with more multi-component shapes than man-made objects. Therefore, living things may require more perceptual differentiation including colour surface information for identification to take place. Whereas non-living things are *structurally* more *dissimilar* and could be processed more easily by their shape, which mostly consists of geometrical forms (Humphrey et al., 1994; Gerlach et al., 1999; Price et al., 2003). In addition, non-living things often have more distinct semantic attributes and therefore fewer competing neighbours that need to be dismissed prior to identification. This view is supported by observations in nonhuman primates. Gaffan & Heywood (1993) report that primates show similar category effects to humans when trained to respond to living and non-living things. A

different view proposed by Laws & Neve (1999) and Gerlach (2001) claims that the *similarity* of features *within* basic level object class (one sheep looks very much like any other sheep), as well as *between* categories (e.g. sheep are similar to other animals like goats or dogs) may actually benefit identification of natural objects over artefacts in some cases. Features of natural objects are more correlated and co-occur more frequently with each other (e.g., animals have legs, eyes) than features of artefacts (e.g. furniture: a table differs very much from a wardrobe). Therefore, features of natural objects can support each other with mutual activation, which can be particularly beneficial in basic object decision tasks (Humphreys et al., 1999; Gale et al., 2003; Låg, 2005). In contrast, the *distinctive* features of natural objects tend to be more weakly correlated which makes it more difficult in identifying a specific natural object within its category, for example deciding whether an animal has stripes or dots, feathers or fur. Accordingly, whether structural similarity may be beneficial or detrimental will depend on the task characteristics and the degree of perceptual differentiation needed (Price & Humphreys, 1989). Breakdowns can occur at different levels of the recognition system, with each leading to a form of category-specific deficit (Lloyd-Jones & Humphreys, 1997; Forde & Humphreys 1999; Devlin et al., 2002; Tyler et al., 2004; Gerlach et al., 2006). Furthermore, choice and quantity of category members as well as visual presentation mode (e.g. visual complexity of the stimulus; line drawing or photograph; coloured or black and white) can have an effect on the test results (Moore & Price, 1999; Devlin et al., 2002; see also Laws, 2005 a, b, 2007 for critical reviews). This may explain why people have found different results when testing category effects for living and non-living things. For instance, there would be fewer contour overlap (structural similarity) between a monkey, giraffe, snake, and a grasshopper (all members of the category animals) than between a fridge, oven, washing machine, and a television (all man made things) (Gale et al., 2003). See figure 5 for examples of multicomponent and simple shaped objects of the categories natural objects and man made objects.

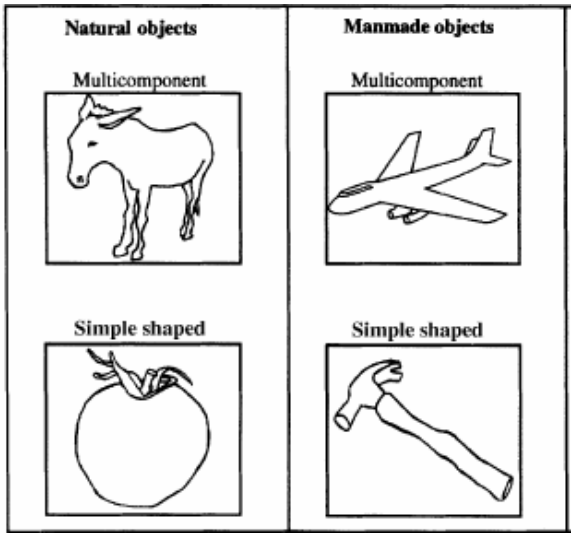


Figure 6 shows examples of multicomponent versus simple shaped natural and man made objects. Illustration taken from Moore & Price, (1999).

1.5.3.2: Methodological issues in the category debate

There is an ongoing debate how objects and their categories are represented in the brain. Do anatomically distinct brain areas, cells and columns process different categories? There is evidence that at least the procession of printed words as well as the recognition of faces is computed by cortical regions that are to some extent optimized for those features (Farah, 2000; Kanwisher, 2000; Ullman, 2004). Findings of distinct locations in the brain for different object classes such as plants, animals, tools, musical instruments, or cars come from brain mapping studies done with healthy humans on different aspects of object recognition. Farah & Aguirre (1999) surveyed a high number of such reports. They found overall 84 different activation maxima that were linked to specific object classes. Those different activation maxima spread all over both halves of the posterior brain (see figure 6). As stimuli and test designs were highly heterogeneous, no clear picture could be drawn from these results.

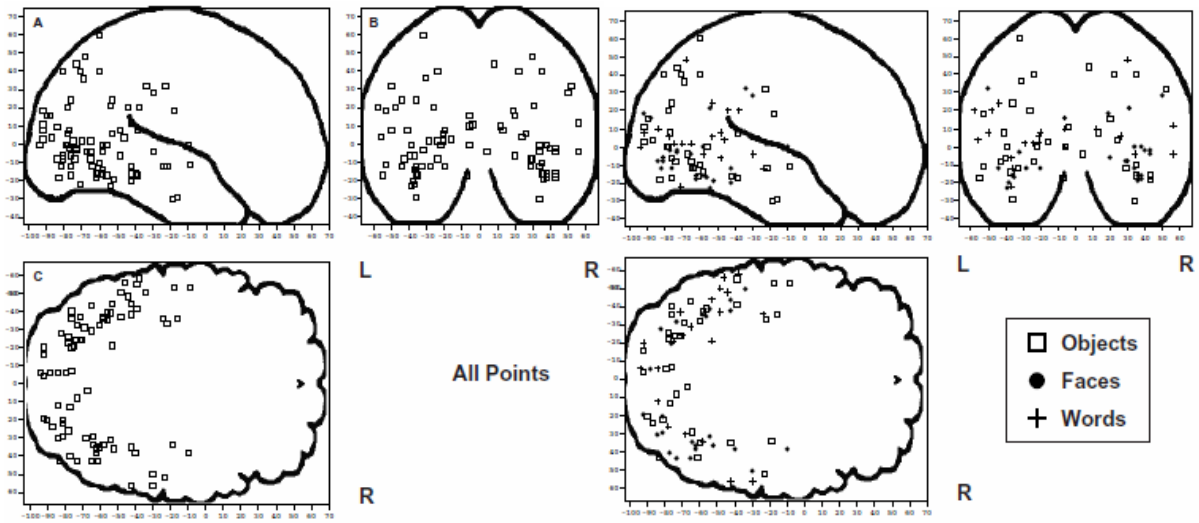


Figure 7. The left side shows an illustration of local maxima from studies of visual recognition placed in standard space and projected onto sagittal (A), coronal (B) and axial (C) views. The right side shows the same views of local maxima subdivided by stimulus class into objects, faces and printed words. Images taken from Farah & Aguirre (1999).

Other data come from patients with visual agnosia, a central neurological disorder in which people cannot recognize objects in the absence of a sensory loss. Reports are chiefly single-case studies of patients and include those that are selectively impaired in recognizing a certain category of objects such as living versus non-living things. There is so far no agreed structure for such studies to make them comparable. Inclusion and exclusion criteria of the agnosic subjects vary, subjects often suffer from additional neurological symptoms, the underlying diseases vary (stroke, haemorrhage, encephalitis, tumour etc.), lesion site and size differs and measurement methods and test designs are heterogeneous. Gainotti (2000) reviewed over 47 of such cases with the conclusion that the reported results lack evidence that there are common sites for object categories that could be generated for *most human brains*.

Another critical point is that the majority of studies on category effects have used stimuli from the Snodgrass & Vanderwart pictures set (1980). This set contains pictures of simple line drawings depicting objects that provide little or no surface or depth information. Some researchers have produced and included a coloured version of the set. However, the result of the colouring of these line drawings is often quite basic. Some images show an

overgeneralization or caricature of the natural object colour and images often lack colour detail (for instance, the alligator in the coloured set by Rossion & Pourtois, (2004) is coloured in an unnatural bright green instead in brownish green and does not show the typical skin marks of a real alligator). Therefore, these stimuli do not reflect anything that is real and may not reveal the full picture of differences between object categories. Using more natural stimuli and settings may help to present a clearer picture about category effects in visual object recognition.

1.5.3.3: Definition of colour diagnosticity

Probably one of the biggest debates is whether colour only helps when colour is diagnostic to the object. *Colour diagnosticity* relies on memory and is determined by two factors: first, the colour must be 'symptomatic' of the object (Hansen et al., 2006) and second, not many other objects in the allowable domain should have the same colour (Wurm et al., 1993). For instance, red should have a strong effect of colour in the recognition of a fire engine, whereas red is less useful when it comes to identifying automobiles in general (Tanaka et al., 2001). Alternatively, yellow can be the colour of more than one fruit (e.g. bananas, honeydew melons, lemons, and grapefruits) and yellow should be associated with their shapes. For example, Tanaka & Presnell (1999) report that objects with high colour diagnosticity like a lemon show a stronger effect of colour in object recognition than objects with low colour diagnosticity like a screwdriver. The same concept is found to be valid for the recognition of scenes; scenes with rich colour-diagnostic content like coast, forest, or desert are more readily recognized when seen in their natural colour than non-colour-diagnostic scenes such as a shopping area (Oliva & Schyns, 2000; Steeves et al., 2004; Goffaux et al., 2005). However, there is a problem with such fixed classifications of objects (and scenes) into high and low colour diagnosticity, because colour diagnosticity may vary among tasks, modes of presentation (e.g. scenes in different weather conditions), or may differ from region to region

(e.g. asparagus is typically white in Germany, but green in Spain), and depends very much on the experiences of the individual (Tanaka, 2001; Thompson-Schill; 2003, Haushofer & Kanwisher, 2007). For instance, it might be particularly difficult to find agreement in colour diagnosticity ratings for *food items* when different age groups and subjects from different local areas are tested. This is because the appearance and distribution of food products have changed over recent decades. There is now much more choice available and products can appear in more colour variations (e.g. tomatoes can be red, yellow, green, or reddish-black). In addition, the food industry has created new species of fruits and vegetables and manipulated old species in size, colour or shape. Some of these new products can look more similar to each other than older ones (e.g. some new sorts of peaches, nectarines, and apricots have nearly the same size and colour). There is currently no generally agreed procedure as how to rate an objects' colour diagnosticity; scores for similar objects may vary between different studies, and even subjects from homogeneous groups may rate the dominant colour of an object differently (Lloyd-Jones & Nakabayashi, 2009, p 317). For instance, subjects rated objects like a fish, nail, fork, or a camera as high colour diagnostic in the experiments by Biederman & Ju (1988, p. 46) but those objects were classified as low colour diagnostic in other studies (e.g., Tanaka & Presnell, 1999, p 1142). Hence, people may mean different things when referring to colour diagnosticity in their papers.

1.5.3.4: Category effects and colour diagnosticity

More studies have used *natural* objects from the category of living things than objects from the category of non-living things when examining the colour effects in object recognition. This is because there are more objects among living things that are rated high in colour diagnosticity than in the category of non-living things. It is expected that high colour diagnostic objects may elicit stronger colour effects than low colour diagnostic ones when compared with their achromatic version. Results show that there is more agreement that

colour is beneficial for the category of living things than for the category of non-living things. Improved recognition with colour for *natural* objects is found in several studies that used *fruits*, *vegetables*, or *food items* (Price & Humphreys, 1989; Macario, 1991; Wurm et al, 1993; Joseph & Proffitt, 1996; Joseph, 1997; Mapelli & Behrmann, 1997; Tanaka & Presnell, 1999; Delorme et al., 2000; Edwards et al., 2003; Vernon & Lloyd-Jones, 2003; Lloyd-Jones, 2005), *animals* (Price & Humphreys, 1989; Joseph & Proffitt, 1996; Joseph, 1997; Edwards et al., 2003; Vernon & Lloyd-Jones, 2003; Lloyd-Jones, 2005; Wichman et al., 2006), or *faces* (Kemp et al., 1996; Lee & Perrett, 1997; Edwards et al., 2003; Yip & Sinha, 2002; Russel & Sinha, 2007). Only two studies did not find a positive effect for colour with natural objects (Biederman & Ju, 1988; Ostergaard & Davidoff 1985). However, both used only a very small number of natural items, which might be the reason why they did not find any significant effects.

Results about colour effects in the category of non-living things are more controversial than those concerning the category of natural objects. Some studies report no advantages for coloured stimuli in the recognition of non-living things (Biederman & Ju, 1988; Davidoff & Ostergaard, 1988; Brodie et al., 1991; Chainay & Rosenthal, 1996; Delorme et al., 2000; Nicholson & Humphreys, 2001, Exp. 4 in the s*uper*ordinate classification task), while others do find a positive effect. For instance, colour does improve recognition of non-living things that do not have a diagnostic colour in tasks like rapid object detection (Edwards et al., 2003), *sub*ordinate object classification (Nicholson & Humphreys, 2001, Exp. 4), or object naming (e.g. Rossion & Pourtois, 2004). A positive effect for colour is also found for single everyday objects (Zimmer & Steiner, 2003) or for manmade characteristics in scenes (Castelhano & Henderson, 2008) when viewing conditions are unusual (in blurred or partly masked pictures). There is also evidence that colour improves the recognition of *novel* objects despite the fact that novel objects do not have a diagnostic colour and do not belong to any pre-known object

class. For example, it has been shown that same/different (Ling & Hurlbert, 2004) and old/new judgements (Nicholson & Humphrey, 2003) of *novel* objects are faster and less view-point dependent (Hayward & Williams, 2000), when the objects are presented in colour; and identification reaction times decrease for *artificial categories* when colour is part of the learned identity (Hanna & Remington, 1996).

The above mentioned studies show that there are conflicting results for the effects of colour according to *object category* or *colour diagnosticity*. These differences may depend on different task demands and test designs. It has been shown that colour often has a stronger facilitating effect in tasks with *higher* semantic demands such as during object *naming* (see section 1.6 about object naming) or *subordinate* classification than in simple object detection or basic level classification tasks. This is because there is more competition amongst the category members in such tasks to generate an individuated response and additional information such as colour can help the selection process. For example, Rossion & Pourtois (2004) contrasted coloured with black and white line drawings in a *naming task*. They found that nearly all of the objects benefited from colour and there was little difference between the categories of animals, fruits & vegetables, and manmade objects with and without a diagnostic colour.

Their findings may reflect the fact that even manmade objects without a specific diagnostic colour tend to be presented in a limited range of colours (e.g. a hammer rarely appears in purple or orange), or presented in a dominant colour (e.g. many chairs are brown). Furthermore, the colour diagnosticity for a manmade object can vary amongst individuals as colour diagnosticity depends on experience. For example, if one drives the only pink Mini Cooper in town, one will discriminate ones car much faster by concentrating on its colour than on its shape, even though pink is generally not a diagnostic colour for that type of car. In

this case, pink has become the diagnostic colour for the owner of the car but not for the other Mini Cooper drivers. Wurm et al. (1993) and Humphrey et al. (1994) reasoned that testing subjects with their personal items might show advantage for colour in some manmade objects as well. In addition, Tanaka & Presnell (1999) found that even though the majority of the tested objects in their experiments were affected by colour diagnosticity, there were several objects, which were not. Objects with high rated colour diagnosticity were processed slower, and others with low rated colour diagnosticity were processed faster than average. The authors propose that colour diagnosticity may be better described as a continuum, where objects with strong colour association (depending on ones individual memory) are found at the one end, and objects with indifferent or moderate colour association somewhere in between.

1.5.4: Summary of colour effects on object segmentation and object recognition

In summary, research has shown that colour can facilitate object recognition at different processing stages and that inconsistencies in results may depend on test designs. Tasks that require more differentiation to select an individuated response may show stronger effects for colour than simple object detection or classification tasks (e.g., Price & Humphreys, 1989). At a *structural level*, differences in colour may help to locate object boundaries, which aid the segmentation process. At a *conceptual level*, colour associations provide additional information and a direct access to the objects' identity, which can aid object recognition. It is further shown that colour is an intrinsic property of visual representations of objects and that stored colour knowledge can influence object perception and segmentation as top down activation at early stages of visual processing. However, colour associations with an object depend on individual experience. In addition, functional imaging studies by Moore & Price (1997) reveal that human participants show reduced activation levels in object recognition areas when coloured drawings have to be identified compared with black and white line

drawings. This may indicate that identification of the former is computationally less costly than the latter.

Table 1. Review of studies that investigated effects of colour on **object recognition** in adult people

Reference	Object type	Colour manipulation	found significant effects for colour
Detection			
Delorme et al. (2000)	fruits, vegetables, food,	CP vs. BWP	+ (RTs)
	animals	CP vs. BWP	+ (Acc.)
	coldiag. objects		
Wichmann et al. (2006)	animals	CP vs. BWP	+
	coldiag. objects		
Recognition			
Kemp et al. (1996), Exp. 2	faces	CP vs. BWP	+***
Lee & Perrett (1997), Exp. 1	faces	CP vs. BWP	+
		CC vs. BWC	+
Russel & Sinha (2007), Exp. 2, 3	faces	CP vs. BWP	+
Yip & Sinha (2002)	faces	CP vs. BWP	+****
Uttl et al. (2006)	natural / fabricated	CP vs. BWP	+
	coldiag. / non coldiag. objects		
Verification			
Biederman & Ju (1988), Exp. 4	natural / fabricated	CP vs. BWLD	–
	coldiag. / non coldiag. objects		
Biederman & Ju (1988), Exp. 5	natural / fabricated	CP vs. BWLD	–
	coldiag. / non coldiag. objects		
Brodie et al. (1991), Exp. 4	fabricated /	CP vs. BWP	–
	non coldiag. objects	CP vs. BWLD	–
Chainay & Rosenthal (1996)	natural / fabricated	CP vs. BWLD	–
Subjects with Alzheimer's disease	*coldiag. / non coldiag. objects*		
Davidoff & Ostergaard (1988), Exp. 2	fruits, vegetables /	CP vs. BWP	–
	coldiag. objects	CP vs. ICP	–
Davidoff & Ostergaard (1988), Exp. 3	fruits, vegetables /	CP vs. BWP	–
	coldiag. objects	CP vs. ICP	–
Joseph (1997)	animals, fruits, vegetables /	CLD vs. BWLD	+
	coldiag. objects	CLD vs. ICLD	+
Joseph & Proffitt (1996), Exp. 1, 3	natural /	CLD vs. ICLD	+
	coldiag. objects		
Hayward & Williams (2000)	novel objects /	CP vs. BWP	+
	non coldiag.		
Proverbio et al. (2004)	natural / fabricated /	CLD vs. ICLD	+
	coldiag. / non coldiag. objects		
Tanaka & Presnell (1999), Exp. 2	natural / fabricated /	CLD vs. BWLD	+ *
	coldiag. / non coldiag. objects		
Tanaka & Presnell (1999), Exp. 4	natural / fabricated /	CLD vs. BWLD	+ *
	coldiag. / non coldiag. objects	CLD vs. ICLD	+ *
Classification			
Davidoff & Ostergaard (1988), Exp. 1	natural / fabricated /	CLD vs. BWLD	–
	coldiag. / non coldiag. objects		
Ling & Hurlbert (2004)	novel objects /	CO vs. BWO	+
	non coldiag.		
Lloyd - Jones (2005), Exp. 2	animals, fruits, vegetables /	CLD vs. ICLD	+
Healthy subjects and subjects with Alzheimer's disease	*coldiag. objects*		
Lloyd - Jones & Nakabayashi (2009)	natural / fabricated /	CP vs. ICP	+
	coldiag. / non coldiag objects		
Nicholson & Humphrey (2001), Exp. 4	fabricated /	CLD vs. BWLD	+ **
	non coldiag. objects	CLD vs. BWLD	–
Ostergaard & Davidoff (1985), Exp. 3	fruits	CP vs. BWP	–
	coldiag. objects	CP vs. ICP	–
Price & Humphreys (1989), Exp. 1b	natural / fabricated	CP vs. BWLD	+
	coldiag. objects	CP vs. ICLD	+
		CLD vs. BWLD	+
		CLD vs. ICLD	+

Price & Humphreys (1989), Exp. 2	natural objects *coldiag. objects*	CP vs.BWP CP vs. BWLD CP vs. ICLD	+ + +
Vernon & Lloyd - Jones (2003), Exp. 2b	animals, fruits, vegetables/ *coldiag. objects*	CLD vs. ICLD	+
Zimmer & Steiner (2003) Exp. 1,2	natural / fabricated / *coldiag. / non coldiag. objects*	CLD vs. ICLD	+

Notes: **CP** = colour photos; **BWP** = black and white photos; **CLD** = colour line-drawings; **BWLD** = black and white line drawings; **CC** = coloured caricature; **BWC** = black and white caricature; **CO** = coloured object; **BWO** = black and white object; **ICP** = incorrectly coloured photos; **ICLD** = incorrectly coloured line drawings; **RTs** = reaction times; **Acc.** = accuracy; **coldiag**. = colour diagnostic; ***** only for high colour diagnostic objects; ****** in the *sub*ordinate classification task; *** for *un*familiar faces only; **** for blurred images.

1.6: The effects of colour on object naming

What processes govern the naming of objects from pictorial material? There is evidence that pictures and words share a common semantic network and a sensory feature of an object such as colour not only influences visual identification but may also affect verbal processing stages as well. Picture naming entails a number of subject-, object-, and linguistic-related factors, which may influence latencies and accuracy measures. These issues will now be considered.

1.6.1: Naming stages

In the recent decades, there has been important progress in the study of name retrieval and its neural correlates. Several approaches using physiological techniques and/or functional measures including psycholinguistic modelling, try to explain the underlying mechanisms. Naming is a fundamental aspect of language. It activates a wide range of brain areas as is evident from functional neuroimaging (e.g., Moore & Price, 1999; Price, 2000) see figure 7; cortical stimulation experiments (Ojemann, 1991; Salmelin, et al., 1994); intraoperative language mapping (Ilmberger et al., 2001); transcranial magnetic stimulation (TMS) studies (e. g., Stewart et al., 2001) and lesion studies (e.g., Damasio et al. 2004), see figure 8.

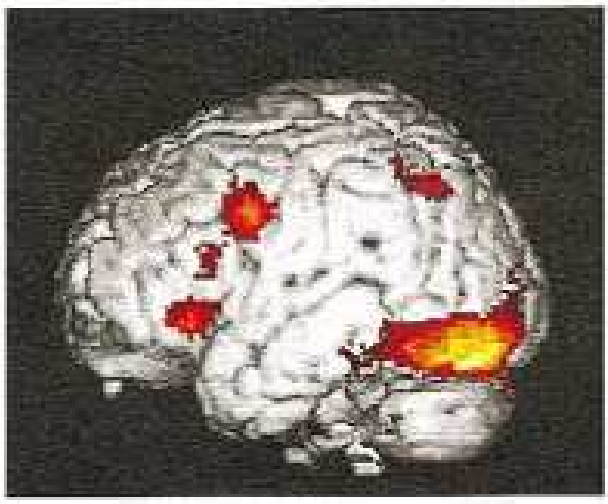


Figure 8. An illustration of areas of the brain that activate during naming visual pictures. The activated brain areas are illustrated in red and yellow. Image taken from Price (2000) with data from Moore & Price, (1999).

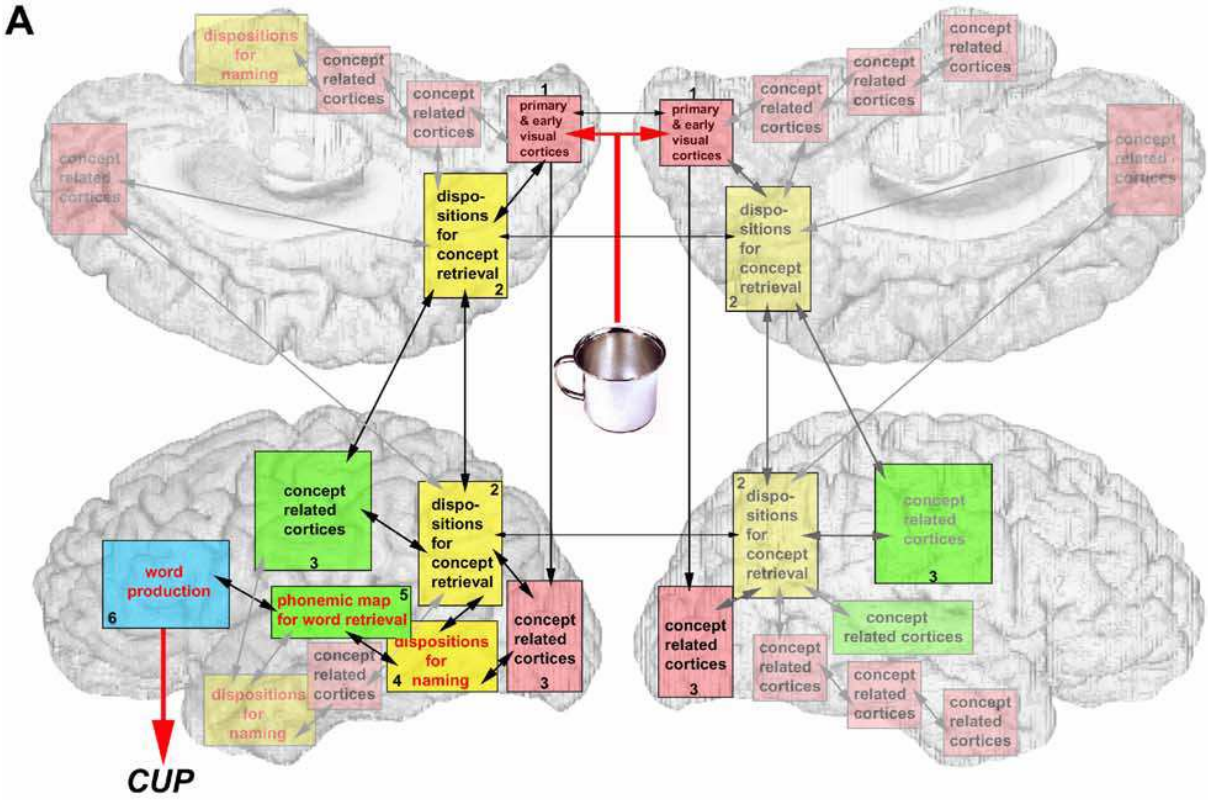


Figure 9. Example of schematic representation of the brain structures involved in the name retrieval of an object presented visually as proposed by Damasio et al. (2004)
Schematic representation of the brain structures involved in the retrieval of concept and production of a word denoting a visually presented non-unique concrete entity, a cup. The image processing begins in primary visual cortices of both hemispheres and continues along a cascade of divergent and later convergent association cortices. Signals related to this process eventually reach motor-related cortices. In this particular example the authors propose the following: (1) bilateral engagement of early visual cortices is followed by engagement of (2) left parieto-occipital cortices (which hold dispositions for concept retrieval); (3) engagement of cortices which hold dispositions related to the concept; (4) bi-directional connections among these areas probably allow for iterative activations and eventually lead to engagement of (5) regions which hold dispositions for naming; (6) engagement of areas capable of phonemic map retrieval, e.g. in the left superior temporal gyrus, necessary to guide (7) the regions in charge of word production to construct the phonetic sequence of the actual spoken word.

Naming an object or its pictorial version aloud entails early sensory visual analyses, access to stored information about object properties, semantic activation, lexical retrieval and the activation of the phonetic-articulatory program needed for oral output (Laiacona et al., 2001; This process can further involve activation of conceptual, psychological, functional, temporal, and psycholinguistic aspects, including grammatical and syntactical functions (Frattali, 2005). In this research, we will not be interested in the generation of words or grammatical and syntactical functions, but focus on the semantic process of naming and how this process can be influenced by colour.

1.6.2: Linguistic models of object naming

Psycholinguistic research has developed models about the underlying structures of naming to provide a framework that researchers can use to test and predict language behaviour. Various neurolinguistic models have been proposed to explain how visual and lexical processing stages might be connected. Some early functional models favoured a *sequential* way of information processing in a discrete and strictly bottom-up manner (Morton, 1979; Levelt, 1989; Dell & O'Seaghda 1991, 1992; Hillis & Caramzza, 1995). These models assume that processing starts at a *structural object description level* and that semantic information of a target object (e.g. CAT) spreads activation of the target and its semantically related competitors (i.e. DOG, RAT) onto the *L level*. The L level contains lexical representations that correspond to words and mediates between the conceptual-semantic level and the level of individual phonemes. Phonological retrieval can take place after a single L level unit (in this example: CAT) has been selected amongst its semantic competitors. See figures 9 and 10 for examples of serial models as proposed by a) Hillis & Caramazza (1995), and b) Dell & O'Seaghda (1991, 1992).

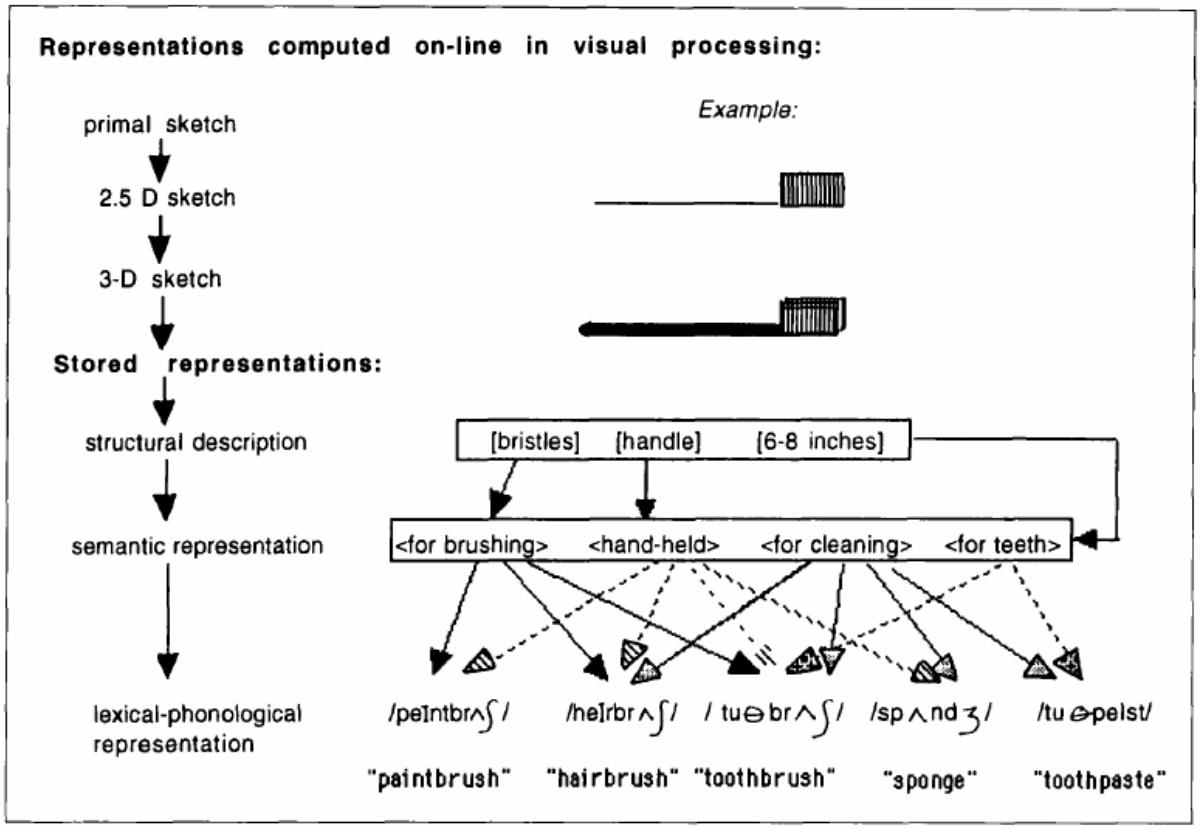


Figure 10. A schematic representation of a *serial* model of visual object naming as proposed by Hillis & Caramazza (1995)

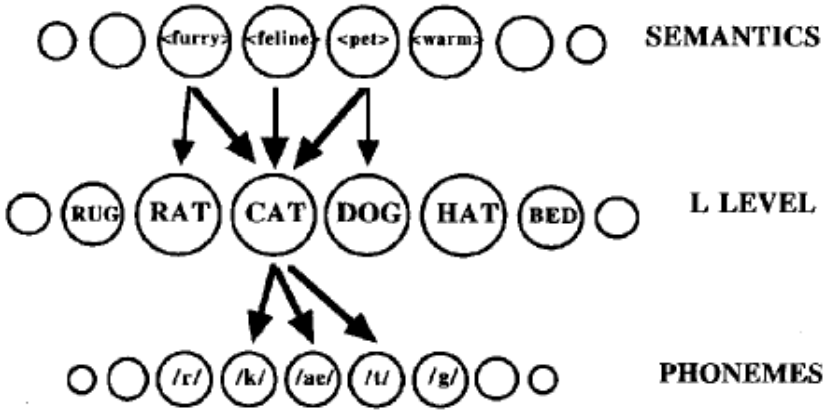


Figure 11. Schematic representation of the discrete forward account as proposed by Dell & O'Seaghda (1991, 1992) adapted by Rapp & Goldrick (2000). Thick arrows denote activation flow involving the target; thin arrows denote activation flow involving its lexical neighbours.

However, such serial models fail to explain the variety of naming errors found in normal subjects and in patients with neurological deficits. Other theories therefore introduced more *interactive* and *competitive* models with *excitatory* and *inhibitory* connections between the levels of structural descriptions, semantic classification, and name representations (Glaser & Glaser, 1989; Glaser, 1992; Davidoff & De Bleser, 1993; Humphreys et al., 1995; 1999). Interactive models with feedback connections not only allow for an explanation of semantic *or* phonological errors, but also the origin of *mixed* naming errors containing semantic *and* phonological components like for example in cat-rat, or fish-dish. In addition, such models also account for the use of synonyms. For example, when one struggles to find the intended phonological form for a certain meaning (e.g. *sofa*), feedback could result in the use a synonym (i.e. *couch*) instead (Rapp & Goldrick, 2000).

One example of a model which includes interactive activation and competition is that of Humphreys et al. (1995) in Figure 11 with feedback flow between all levels of representations, and activation and inhibition connections *between* and *within* the single levels. The model has units at each level that have *excitatory* connections to *related* units and *inhibitory* connections to *unrelated* units at the preceding level. Inhibitory connections *within* each level result in the selection of a single unit that represents the stimulus. In contrast, the restricted interaction account (RIA) model by Rapp & Goldrick (2000) only allows feedback flow between the phonological forms (phonemes) and the lexical representations of words as depicted in Figure 12.

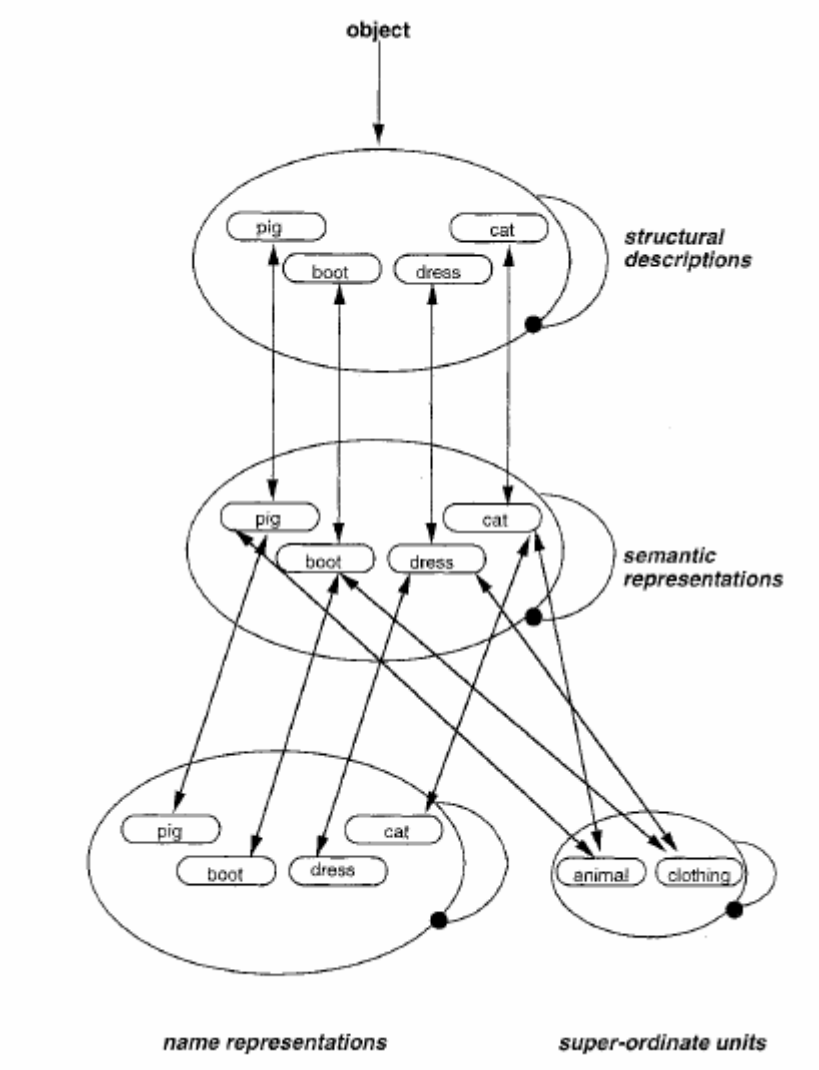


Figure 12. The interactive activation and competition model of object naming proposed by Humphreys et al. (1995). ⟶ indicates excitatory links and —● inhibitory links. Inhibitory links *between* the different levels are not depicted. The model has separate pools for *individual object names* and for *super-ordinate category names*.

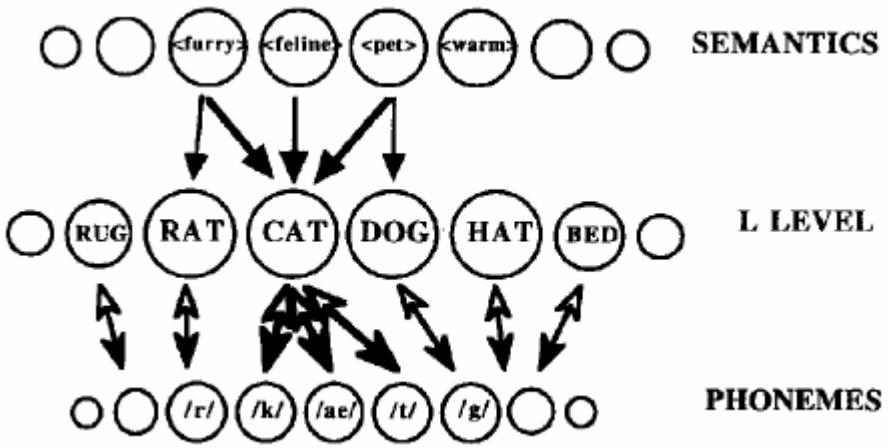


Figure 13. The restricted interaction account proposed by Rapp & Goldrick (2000). Tick arrows denote activation flow involving the target, thin arrows denote activation flow involving its lexical neighbours, and outline arrows denote the feedback flow.

Evidence for interactivity between visual and verbal systems comes from studies on speeded naming (Vitkovich & Humphreys, 1991; Vitkovich et al., 1993; Lloyd-Jones & Nettlemill, 2007) which looked at error types made by normal subjects when forced to respond to a fast response deadline. Speeded naming was used to put constraints on information transmission between visual and verbal systems and to induce errors. If the visual processing stage is discrete, as proposed in earlier models, and if the name selection only starts by the time the visual access to object semantics is complete, then naming errors should be only semantic in nature. However, errors made by the subjects were both *visually* and *semantically* close to the target objects. This indicates that partial transmission of information can trigger object naming and that visual access to semantics is not fully complete before name retrieval starts (Riddoch & Humphreys, 2001).

1.6.3: A common semantic network for pictures and words

Several attempts have been made to understand how words and pictures are linked together with different test designs and evaluation methods. Imaging studies including PET and fMRI tried to link functional models to areas of brain activation. Their results show that visual and verbal processing form a strong relationship and that they share a common semantic system. Evidence was found irrespective of stimulus modality, as in *pictures versus words* (Vandenberghe et al. 1996) or tasks, as in *semantic decision* (Vandenberghe et al. 1996; Price et al., 1997, Mummery et al., 1998; Murtha et al., 1999; Kellenbach et al., 2005) or *word generation* (Wise et al., 1991; Martin et al., 1995). For example, in the *pictures versus words* comparison by Vandenberghe et al. (1996), subjects had to judge whether a target stimulus (e.g. “cow”) is closer in meaning to one of two sample stimuli (e.g. “horse” or “bear”), when stimuli were presented in triplets of either written words or pictures. The measured brain activity showed largely overlapping processing for *pictures* and *words* and revealed only a few specific areas that were differentially active. Furthermore, it was found that semantic

tasks activate representations from picture-specific structural descriptions and word-specific lexical or phonological representations *simultaneously* from modality-specific brain areas. The authors suggest that a distributed semantic network shared by both modalities may have its phylogenetic origin in a pre-existing object-recognition system that has provided the ground for a lexical system attributing meaning to the words.

Similar cortical activations were found in PET studies by Mummery et al. (1998), who compared differences in semantic similarity judgments between the perceptual attribute *colour* (typical colour of the object) and the associative attribute *location* of objects (typical *location* of objects) by using triads of written words.

More support for a strong connection between visual and verbal processing comes from studies measuring eye movements during visual inspection and verbal encoding tasks. Object viewing times depend systematically on the number of syllables in the object's name when subjects are asked to name different objects presented in pairs in a display. For example, subjects look longer at a picture with a 'scooter' than a 'hat'. Subjects also look longer at objects with low-frequency compared with high-frequent names. High frequency words are defined as words that are used more often in conversation (e.g. food, home). Such words have a lower threshold to be activated for selection compared with low frequency words (e.g. igloo, penguin). Word frequency effects arise only during lexical retrieval, but do not appear when subjects categorize objects without naming them, indicating that viewing times during object naming reflect *linguistic* planning processes (Meyer et al., 1998).

In addition, Zelinsky et al. (2000) showed that subjects often automatically sub-vocalize object names to supplement their visual representation when trying to remember objects in a multi-item display. In a free viewing task subjects had to remember four objects that were presented simultaneously in displays without explicitly naming them. Viewing times corresponded with the time required to sub-vocalize object names and gaze was only shifted

to the next item after this process was completed. Findings show that depending on the task, people may use implicit verbal strategies to supplement their visual memory and that the linguistic process may then constrain the ocular inspection of the object.

Shepard (1964, p 59) argues that colours differ from the representation of other object attributes as they seem to appear only as *images* and *names* in long-term memory, because they are 'reacted to as homogeneous unanalyzable wholes' that cannot be further fractioned into perceptually discrete parts like geometrical forms. The perception of a form can be decomposed into different parts of its shape for example into straight or curved lines, whereas the *sensation* of a colour appearance cannot be decomposed into its physical components brightness, hue, or saturation (Pavio & te Linde, 1980).

Knowledge about colour is stored holistically and as a continuous representation that can be triggered either by the perceptual appearance of an object during object recognition, or by its lexical label during mental imagery (Tanaka et al., 2001). Pavio & te Linde (1980) suggest that colour knowledge is not stored any closer to knowledge about *shape* than to knowledge about object *names*. They showed in their studies that subjects spatial imagery skills can be related to outcome scores of symbolic comparisons on size, and that reaction times are faster with pictures than with words in such tasks. In addition, individual verbal fluency can be related to outcome scores of comparisons of size when stimuli consist of words. In contrast, no correlation to spatial or verbal abilities is found when subjects have to *imagine* colour during decisions about brightness and hue. Furthermore, Stuart, (1994) found that subjects need equal times to judge whether colours differ from an object's real-life colour when colours are presented tachistocopically beside either uncoloured *line drawings* or objects *names*.

Lantz & Steffire (1964) have also shown that the ease with which a colour can be *recognized* in an object is directly correlated to the ease with which the colour can be *described verbally* between subjects. These results indicate that colour knowledge can be assessed equally quickly from pictures as from words.

In summary, there are a number of studies with evidence for a common semantic system that is accessed by pictures and words. A sensory feature of an object such as *colour* may therefore not only influence visual identification when the task involves naming but may affect verbal processing stages as well.

1.6.4: Colour in the semantic selection process

In fact, there is less disagreement about colour playing a role in object *naming* than it is for object *identification* or *categorisation*. It is generally agreed that it requires more semantic information to find the correct name of an object than it is needed to identify or sort objects into categories. Retrieving the name of an object from a picture involves perceptual analyses of the visual input and the mapping from an objects semantic concept to its name. The ease of access at an early stage will subsequently affect activation and processing at later stages (Humphreys et al., 1999). Furthermore, the degree of visual and semantic similarity between objects constrains the demand of semantically related selection processes until only one lexical item survives to be ultimately articulated as a response (Levelt, 1991). The left inferior frontal gyrus (LIFG) has recently been associated with such selection processes in fMRI studies by Kan & Thompson-Schill (2004). The authors point out that damage to the LIFG can be a possible source of linguistic deficits in some forms of aphasia. Colour as an intrinsic property of the object is found to play a crucial role in this semantically related selection process as it speeds up naming reaction times and enhances naming accuracy compared with achromatic pictorial material as shown in several studies of different subject groups.

A linguistic model of object naming that particularly incorporates *colour* is that by Davidoff & de Bleser (1993) and Davidoff (2001) and depicted in Figure 14 on page 62. The model consists of four main stages: the first stage comprises the processing of shape boundaries that contain surface information including *colour* at a temporary register. This information is then mapped onto stored structural descriptions of the object (visual object knowledge). The third step contains the access to associated object knowledge including object-colour knowledge. In a forth step this information is then mapped onto phonological representations for the lexical item (name of the object).

The model implies that colour can influence naming at *different* processing levels. The 'temporary register' in Davidoff's model holds information derived from spatial and temporal variations in wavelength in the form of boundaried surfaces (shape). Boundaries can be formed by variations of several domains such as luminance, binocular disparity, motion, texture, and *colour* (Cavanagh, 1987). At this level, *colour can affect form*. It has been shown that wavelength information referring to colour contains shape forming properties and that colour can form boundaries by itself (Heywood et al., 1991; Kentridge et al., 2004).

The 'internal colour space' is a system for representing colour category information such as red, blue or green. The internal colour space has a one-directional information flow to the temporary register, which itself has bidirectional connections with the 'entry level of stored structural' descriptions'; and there is a direct line from the internal colour space to colour names.

The entry level of stored structural descriptions holds information about the visual form of an object. The term 'structural description' is usually used to distinguish between a perceptual visual form of an object and the associative knowledge about the object. There is no consensus in the literature as to whether structural descriptions contain colour information or not, as there are different views of whether structural knowledge is holistic (e.g., Graf &

Schneider (2001) or implies a solely parts-based representation of the object (e.g., Biederman, 1987). Structural descriptions have access to other object knowledge including 'associated knowledge', 'function knowledge', and 'sensory knowledge' as illustrated by the bidirectional arrows. Stored *object-colour knowledge* is located in the sensory knowledge space and may influence lexical access (Davidoff, 1991; Davidoff et al., 1997).

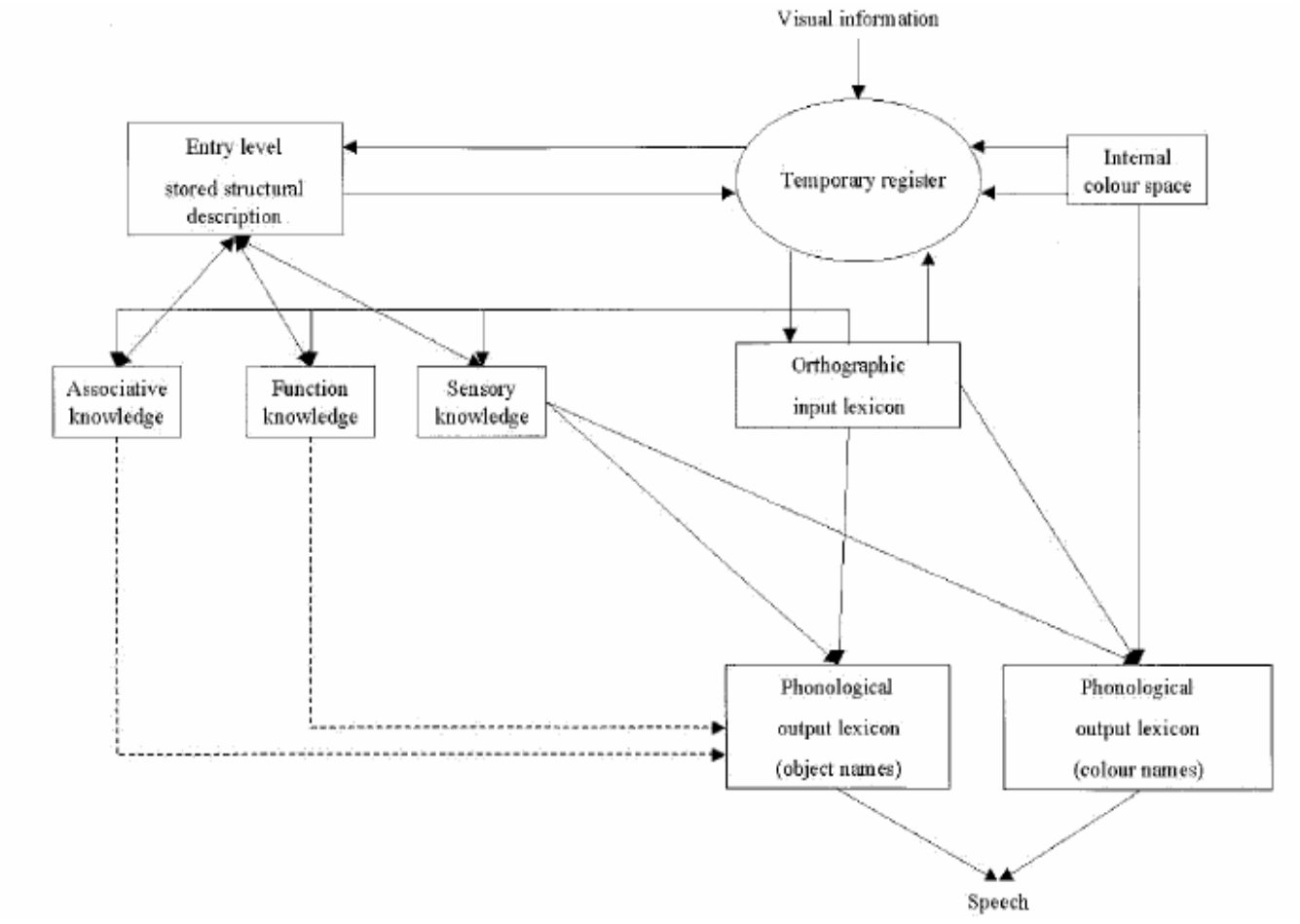


Figure 14. A model of object naming from Davidoff & de Bleser (1993), adapted by Davidoff (2001), taken from Humphreys & Forde (2001).

A positive effect of colour on naming has been shown in several studies of different subject groups. For example, *normally developed children* aged four, six or eight name coloured pictures for new vocabulary faster and more accurately than black and white ones, when the vocabulary level of the picture is within their developmental range. For items that exceed the child's developmental level, colour aids accuracy, but not speed (Barrow et al., 2000). Similar

results are reported by Johnson (1995) indicating that colour may add saliency to the names that are known but still developing, leading to a greater number of names to be retrieved. Other studies with different *adult* subject groups show that colour enhances accuracy and/or speeds up reaction times in *healthy adults of different age* (Ostergaard & Davidoff, 1985; Davidoff & Ostergaard, 1988; Biederman & Ju 1988; Price & Humphreys, 1989; Brodie et al., 1991; Wurm et al., 1993; Humphrey et al., 1994; Montanes et al., 1995; Tanaka & Presnell, 1999; Nicholson & Humphrey, 2001; Vernon & Lloyd-Jones, 2003; Rossion & Pourtois, 2004; Laws & Hunter, 2006), in *people with conditions of low visibility* (Wurm et al.,1993) and in *elderly illiterates* (Reis et al., 2006).

Furthermore, colour improves naming in patients with *neurological deficits*, as shown in patients with *Alzheimer's disease* (Montanes et. al 1995) and when the objects are of natural categories (Chainay & Rosenthal, 1996), in *patients with visual agnosia* when the colour is diagnostic for the object (Humphrey et al., 1994) and also in *patients with aphasia* (Bisiach, 1966; Benton et al., 1972). See table 2 on page 64 for an overview.

In the latter two studies, aphasic subjects demonstrate less impaired naming with coloured stimuli when real coloured objects, presented in the form of toys (Benton et al.,1972) or realistically coloured pictures (Bisiach, 1966), are contrasted with the same objects presented as two-dimensional black and white line drawings. The authors suggest that naturally coloured three-dimensional objects and realistically coloured pictures might carry more redundant information to facilitate an objects name by arousing a wider range of associations and thereby helping to access the objects lexical representation. Two-dimensional representations may activate a weaker 'concept', which may fail at certain levels to support lexical access (see also Goodglass et al., 1968). This view fits with the findings by Reis et al. (2006) who tested elderly illiterates and a matched literate control group with four different colour conditions, including colour- and black and white photographs and coloured- and black

and white line drawings. They found that illiterate participants perform better with coloured stimuli and that effects are independent of the photographic detail. The observed colour effects were more prominent in the illiterate group than in the literate control group, showing that naming abilities of the illiterates depend more on perceptual information, as they had fewer opportunities to practice interpreting visuo-symbolic representations compared with the literate population (Reis et al., 2006).

Table 2. Review of studies that investigated effects on **object naming** in adult people

			significant	effects
Reference	Object type	Colour manipulation	Accuracy	RT
Healthy adult subjects				
Biederman & Ju (1988), Exp. 1	4 natural and 25 fabricated	CP vs. BWLD	–	–
Biederman & Ju (1988), Exp. 2	4 natural and 25 fabricated	CP vs. BWLD	–	–
Biederman & Ju (1988), Exp. 3	4 natural and 25 fabricated	CP vs. BWLD	–	+
Brodie et al. (1991), Exp. 3	12 fabricated objects	CP vs. BWLD	–	+
		CP vs. BWP	–	–
Davidoff & Ostergaard (1988), Exp. 2	32 natural and 32 fabricated	CLD vs. BWLD	–	+
Humphrey et al. (1994), Exp. 1	11 natural and 109 fabricated	CP vs. BWLD	Ø	+
		CP vs. BWP	Ø	–
		RO vs. ROG	Ø	+
Humphrey et al. (1994), Exp. 2	11 natural	RO vs. BWP	Ø	+
		RO vs. BWLD	Ø	+
		CP vs. BWP	Ø	+
		CP vs. BWLD	Ø	+
	11 natural and 68 fabricated	RO vs. BWP	Ø	–
		RO vs. BWLD	Ø	–
		CP vs. BWP	Ø	–
		CP vs. BWLD	Ø	–
Humphrey et al. (1994), Exp. 3	30 natural	CLD vs. BWLD	+	+
		CLD vs. ICLD	+	+
		CLD vs. BWLDT	–	+
Laws & Hunter (2006)	20 natural	CLD vs. BWLD	+*****	Ø
Lloyd - Jones & Nakabayashi (2009)	65 natural and 10 fabricated	CP vs. BWP	+	+
		CP vs. ICP	+	+
Montanes et al. (1995), Exp. 2	24 natural and 24 fabricated	CLD vs. BWLD	+	Ø
Moore & Price (1999)	natural and fabricated	CLD vs. BWLD	+	+
Nicholson & Humphrey (2001) Exp. 2	54 fabricated	CP vs. BWP	–	+*
		CLD vs. BWLD	+	+*
Nicholson & Humphrey (2001) Exp. 3	54 fabricated	CP vs. BWLD	+	+
Ostergaard & Davidoff (1985), Exp. 1	24 natural	CP vs. BWP	Ø	+
Exp. 3	4 natural	CP vs. BWP	Ø	+
		CP vs. ICP	Ø	+
Price & Humphreys (1989), Exp. 1a	100 natural and fabricated	CP vs. BWP	+	–
		CP vs. BWLD	+	+
		CP vs. ICLD	+	+
		CLD vs. BWLD	+	+
Reis et al (2006)	70 objects	CP vs. BWP	+**	–
		CLD vs. BWLD	+**	–
Rossion & Pourtois, (2004)	260 natural and fabricated	CLD vs. BWLD	Ø	+
Sanocki et al. (1998)	16 fabricated	CP vs. BWLDC	+	Ø
Tanaka & Presnell (1999), Exp. 3	11 natural and 13 fabricated	CP vs. BWP	+****	+****
Vernon & Lloyd - Jones (2003), Exp.1a, b	40 natural	CLD vs. BWLD	+	+
Exp.2 a, b, c	40 natural	CLD vs. ICLD	+	+
Wurm et al. (1993), Exp. 1	21 natural	CP vs. BWP	+	Ø
Wurm et al. (1993), Exp. 2	21 natural	CP vs. BWP	+	+

Patients with aphasia				
Benton et al. (1972)	4 natural and 12 fabricated	RO vs. SBWLD	+	Ø
		RO vs. LBWLD	–	Ø
Bisiach (1966)	30 objects	CLD vs. BWLD	+	Ø
Patients with Alzheimer's disease				
Chainay & Rosenthal (1996)	20 natural and 20 fabricated	CP vs. BWLD	+***	Ø
Montanes et al. (1995), Exp. 2	24 natural and 24 fabricated	CLD vs. BWLD	+	Ø

Notes: **CP** = colour photos, **BWP** = black and white photos; **CLD** = colour line-drawings; **BWLD** = black and white line drawings; **BWLDC** = black and white line drawings produced by computerized edge extractor (Canny, 1986); **BWLDT** = black and white line drawings with texture; **SBWLD** = small black and white line drawings (3.5 x 4.7 cm); **LBWLD** = large black and white line drawings (8.9 x 12.0 cm); **ICP** = incorrectly coloured photos; **ICLD** = incorrectly coloured line-drawings; **RO** = real objects; **ROG** = real objects grey sprayed; **Ø** = not reported, ***** only in the non-canonical presentation; ****** only in the illiterate population; *******only for the natural objects; ******** only for high colour diagnostic objects; ***** only for blurred objects.

A problem with many of the studies evaluating colour effects on naming is that their results are difficult to compare (see table 1). Different methods and test designs are used to measure the effects (accuracy, latencies, or both) with some results deriving from a single exposure with the target objects and others from multiple exposures. People contrasted different types of stimulus manipulations such as *photos* or *line drawings* in colour or black and white, *incorrectly* coloured line drawings or *real objects*. Line drawings were presented either with or without additional *texture information*. Stimuli appeared in varying numbers and belonged to different categories. They derived from different sources such as real objects, toys, self-made photos or drawings or were taken from the Snodgrass & Vanderwart (1980) picture set. Furthermore, the number of participants involved in a task varied between two (Humphrey et al. (1994), Exp. 1) and 220 (Rossion & Pourtois, 2004), which may have affected significance levels in some of the results. Another problem is that a majority of the studies provides incomplete information about their stimulus sets like object class or surface details of the pictures, and does not report precise results such as averages of accuracy measures or reaction times for each condition.

1.6.5: Factors affecting picture naming

A number of studies examined variables other than colour that may affect latencies and accuracy of picture naming at different processing levels. A list of these factors is described below. However, some of these factors do not show robust effects in all of the test designs (e.g., word length effects; Levelt, 1989) or have a clear locus of effect (e.g., age of acquisition; Lewis, 2006).

Several *subject*-related background factors may need to be considered when seeking interactions between participant characteristics and stimulus attributes (e.g. colour effect). These factors include age and education, general health status and effects related to language such as bilingualism or cultural effects (Gollan et al., 1995; Johnson et al., 1996; Laine & Martin, 2006, pp 95-96). *Age*-related performance, where older people perform worse than younger ones, have been reported in the majority of studies on this matter, but not in all of them (e.g. Benton, 1967; Ally et al., 2008). It is assumed that executive functions may decline with age making spontaneous name retrieval less effective. *Education* and *cultural effects related to language* have often shown a positive correlation with naming success, as subjects with a broader education may posses a larger vocabulary (Laine & Martin, 2006, p 94-95). However, in their review, Laws et al. (2007) found little effect of years of education on naming when common stimuli are used as they are generally known and readily named by the majority of healthy people (see also Benton, 1967). *General health issues* (e.g. depression, neurological impairments) can influence performance and need to be examined, especially when dealing with an elderly population (Laine & Martin, 2006 p 94-95; Wingfield et al., 2006).

Object identification can be affected by variables such as *stimulus quality* where image degradation such as blurring or spatial filtering (e.g., Viggiano et al., 2004; Laws & Hunter,

2006) or removal of information of key features of the object lead to poorer recognition (Biederman, 1987; Biederman & Cooper, 1991). *Stimulus size* seems to be optimal when pictures are presented foveally in a range of 4° to 6° (Biederman & Cooper, 1992). *Canonical perspective* (Palmer et al., 1981; Viggiano & Vanucci, 2002) and *stimulus realism* (Bisiach, 1966; Benton et al., 1972; Leder, 1996; Nicholson & Humphrey, 2001; Viggiano et al., 2004; Tatler & Melcher, 2007) have been shown to ease perception. *Image agreement*, which refers to the degree of a match between a picture and its stored canonical representation in memory, may affect object recognition in that objects with higher ratings in image agreement elicit faster naming RTs (Barry et al., 1997; Alario et al., 2004). *Visual complexity* refers to the number of visual attributes/details of a picture and *familiarity* to the experience and frequency with which participants use or encounter a given object. Both variables affected scores in some studies (e.g., Cuetos et al., 1999; Kremin et al., 2003), but not in others (Snodgrass & Vanderwart, 1980; Barry et al., 1997; Laiacona et al., 2001; Alario et al., 2004). Results may vary because *familiarity* scores depend on the selection of the exemplars, for example, whether a chosen picture of a bird is perceived as representing a *typical* exemplar of the category 'birds' for a given population (Snodgrass & Vanderwart, 1980; Jolicoeur et al., 1984; Tanaka & Corneille, 2007). In addition, Viggiano and her colleagues (2004) found that familiarity differs among object categories with animals and musical instruments having significantly lower familiarity ratings compared with other categories such as tools or food. Ratings may also differ depending on whether they derive from pictures or from words. Kremin et al. (2003) published a cross-linguistic data bank for oral picture naming (PEDOI) with data from ten different languages. Their scores producing 'a high correlation for the degree of concept familiarity' derived from 98 French subjects who were rating black and white line drawings. The scores from the French subjects varied considerably from those of 107 German subjects, who performed the same rating task with words.

Variables affecting naming at the *semantic and lexical level* are age of acquisition, word frequency, name agreement, and word length. There is a substantial literature on how *age of acquisition* and/or *word frequency* affects lexical tasks (e.g., Morrison et al., 1992; Barrow, 2000; Barry et al. 2001) with different conclusions (see Lewis (2006) for a critical review). Objects can have lower or higher ages of acquisition and words can be used more frequently in one or the other language community, depending on their cultural habits (Benton, 1967). The major findings are that words which have been acquired early in life and which have been used more frequently are easier to produce than words learned later in life and used less frequently.

Word length effects (i.e. number of letters, syllables, phonemes in a word) showed only a significant effect for the number of phonemes for strictly defined correct naming rates in the study by Snodgrass & Yuditsky (1996) and no effects when correlated by Barry et al. (1997) and Szekely et al. (2005). It is suggested that word length effects arise during the assembly of the phonetic program for a verbal response (Johnson et al., 1996). However, length effects are difficult to measure, because they cannot be seen in isolation; they depend, at least partly, on other variables such as age of acquisition and word frequency (Morrison et al., 1992). In addition, word length effects diminish when people have enough time to prepare a naming response before pronouncing it, suggesting that the effects are influenced by time (Levelt, 1989).

Name agreement refers to the most dominant (or frequent) name of a picture given by a (native) speaker of the studied language. It is argued that it may affect competition amongst *incorrect* responses at the level of structural description of an object or competition amongst *correct* responses at a more post-semantic level where the translation between semantics and phonology takes place (Barry et al., 1997). Support for the latter explanation comes from

studies where name agreement influenced naming, but not object decision reaction times (Johnson et al., 1996).

Controlling name agreement can be difficult as there exists only very few objects that come with a single name. In addition, names can have more than one meaning (homonyms) and this varies across different languages and populations (e.g. *bank* or *clip*, in English; and *Pfeife* = a whistle or a pipe in German). Differences in name agreement have been observed between objects belonging to the same category and among different categories (Viggiano et al., 2004). The authors found the highest name agreement for the category of animals and the lowest for the category of food. Levelt et al. (1991) found a full name agreement on only 78 out of 300 target pictures, when 20 different students labelled them and subjects came up with 18 alternative names for a single object in the study by Szekely et al. (2005).

Furthermore, cross-linguistic studies show a substantial variation of name agreement scores when different languages and/or populations are considered (Kremin et al., 2003; Viggiano et al., 2004). These findings come as no surprise, as many objects and their names have been prone to changes over time. Industries such as food and fashion launch new item specifications and labelling to sell their products. The use of language is not static with some names coming out of fashion and new ones being created all the time. For instance, the basic word ‘shoes’ can refer to sandals, slippers, ballerinas, loafers, sneakers, trainers, boots, flip-flops, wedges, moccasins, stilettos, high heels, pumps, mules, and so forth. Some food items may have an additional (dominant) regional name, e.g. ‘tatties’ for potatoes in the north east of England. Those names may be used more often by an older generation than among younger people.

In summary, there are many factors that appear to influence subjects' performance when measuring behavioural effects on picture naming of objects. However, not all of them have shown robust effects in all of the test designs or across all participant groups. It is important to establish which are crucial when conducting a cross-language study and to involve a wider range of objects and participants than is planned for the current research.

1.6.6: Summary of colour effects on naming

Several studies have been conducted to evaluate colour effects on naming. Results are often difficult to compare as different studies use different subject groups, stimuli, visual presentation modes, methods and test designs to measure the effects. In addition, the reported statistical analyses and results often do not provide sufficient data to make these studies comparable. It is therefore difficult to draw a general conclusion at which levels of processing colour might interfere with the naming process. However, there is evidence that pictures and words share a common semantic system, it is therefore reasonable to assume that colour might not only affect visual identification but verbal processing stages as well. In fact, the model by Davidoff & DeBleser (1993) and Davidoff (2001) suggests that colour may affect form at an early visual perceptual level. At another level, surface colour information may activate sensory knowledge and may influence associative knowledge about the object. This object-colour knowledge in turn may influence lexical access.

1.7: The effects of colour on priming

Research measuring priming effects when naming single objects has chiefly used achromatic stimuli and very few studies have included colour. These latter studies have produced mixed results and provided no clear picture about the role of colour in the priming process of picture

naming. However, there are at least some findings that colour improves priming when subjects are verifying scenes.

1.7.1: Multiple forms of memory

Memory is composed of different forms (short-term / long-term memory) and systems (conscious / unconscious processes) that can be dissociated from one another. Short-term and long-term memory are distinguished by the amount of time that has passed before recall takes

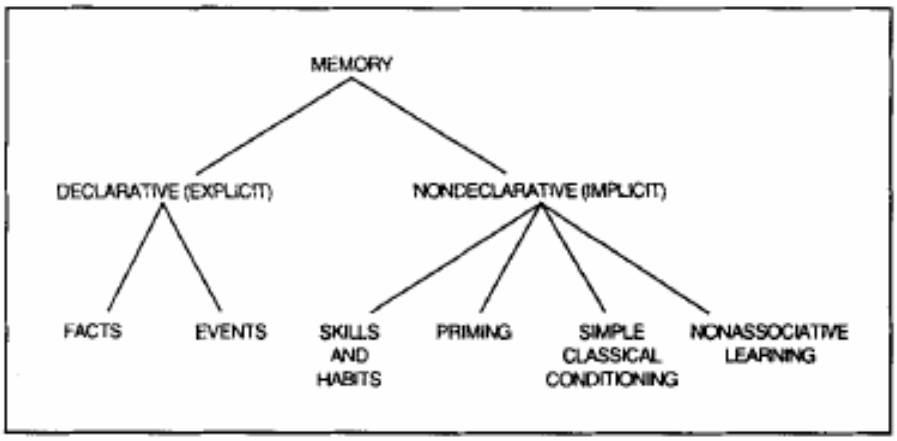


Figure 15. Classification of memory. Declarative (explicit) memory refers to conscious recollections of facts and events. Nondeclarative (implicit) memory refers to a heterogeneous collection of abilities whereby experience alters behaviour nonconsciously without providing access to any memory content. Image taken from Squire (1992).

place. Priming is a type of memory where a perceptual token laid down during initial encoding of a stimulus affects encoding of a following stimulus presentation. This can occur either by implicit or explicit memory processes. See a model of components of memory by Squire 1992 in figure 14.

1.7.2: General definition of priming

Implicit memory is defined as an unconscious and unintentional retrieval of past experience on a current behaviour, whereas explicit memory is a conscious and intentional recollection of facts or events in a recent experience (Schacter & Buckner, 1998). Implicit memory can be

seen as a more primitive and pre-linguistic form of memory structure; because it can be observed even in animals that do not possess developed explicit memory systems (Squire et al., 1993). A further differentiation is that memory effects in implicit memory are long-lasting and can last for many years (Mitchell, 2006), whereas memory effects in explicit memory are short-lived and prone to a much faster decay. Priming is a part of implicit memory that defines a certain type of *learning* that can operate without attention and in the absence of conscious memory of earlier experiences. This form of learning occurs regardless of either its behavioural significance or any particular stimulus attributes and serves to speed up *encoding* processes with an object. In contrast, learning mechanisms in the explicit memory system require attention to the task and involve processes where new material is encoded in forms of meaning and related to one's knowledge base. Explicit memory serves to provide intentional information about specific *events* that occurred with an object (Baddeley, 2004, p 34). Another form of learning is called 'perceptual learning', which can occur either explicitly or implicitly. It is suggested that the neural mechanisms of priming may differ from those supporting perceptual learning in that priming may correspond to a *temporary* multiplicative gain change (Reinitz et al., 1989), whereas perceptual learning may correspond to more long-lasting changes in synaptic weighting (Karni & Bertini, 1997). Mechanisms of priming are discussed further below in paragraph 1.7.4.

1.7.3: Visual priming

Visual priming refers to the process where a prior visual exposure to an object speeds up its subsequent identification, classification, or naming and where the greatest effects are observed when an identical view of an object is repeated in a subsequent encounter. During visual priming, each encounter with an object sets up an object file, which includes the specific features that were registered during presentation. The content of each object file is stored automatically and in a long-lasting form (Treisman, 1992). During retrieval, features of

the past object file are matched to the features of the present object file in an automatic and unconscious way, rather than by an explicit (intentional) search for a specific memory. As a result, features that were part of the original encoded object file provide better retrieval cues for recall compared with features that were not part of the original file (Tulving & Thomson, 1973). Consequently, changing object properties from study (first encounter) to test (at second presentation) may result in reduced priming effects.

Research has shown that visual priming can occur at different levels of processing. For instance, it has been demonstrated that visual primes may influence very early perceptual processes and that they can affect the encoding of initial, perceptual information from a picture (Loftus et al., 1988; Loftus & Hogden, 1988). Breitmeyer, Ogmen, and Chen (2004) and Breitmeyer, Ro, and Singhal (2004) observed unconscious colour priming effects already at early wavelength-dependent levels, probably at the levels of V1 and V2. In their experiments using metacontrast-masking paradigms, a green prime followed by a green mask elicited faster choice reaction times for the identifying the colour of the mask than a green prime followed by a mask of a different colour (Breitmeyer, Ogmen & Chen, 2004). In another metacontrast-masking experiment, a white disk and a desaturated blue and green disk were used as primes and the blue and green disks were also used as masks. The white disk had more similarity to the green colour at the *physical* (wavelength-dependent) level, but was *perceptually* more similar to the blue one. Pairings of unmasked and masked primes reveal that the white prime tends to act more like a green prime when followed by a blue mask, indicating that this colour confusion must have occurred at *physical* rather than *perceptual* levels of colour perception (Breitmeyer, Ro & Singhal, 2004). Results show that visual information of a prime that is suppressed from consciousness perception by a metacontrast mask can nevertheless affect choice reaction times to the colours of the following consciously perceived stimulus and that unconscious colour priming effects can happen before conscious

colour perception takes place (Leopold & Logothetis, 1995; Schmidt, 2000; 2002). Further evidence comes from studies with patients with left visual neglect and distinction, who show intact colour priming in visual search tasks, when stimuli are presented in their left neglected hemifield, even when the patients are not consciously aware of what they have seen (Kristjánsson et al., 2005). It follows that the *physical* attributes of colour information can prime subsequent encounters with a stimulus at low-level visual processing stages and that this can happen without any awareness.

In contrast, Mecklenbräuker et al. (2001) found colour priming effects caused by high-level processing stages at the level of *conceptual* colour representations when using a different colour choice task. In their experiment, participants were asked to select the most appropriate colour for a black and white drawing of an object after they had seen the same object coloured in an arbitrarily colour. Participants were more likely to select colours previously *associated* with the object, although they were not instructed to attend to colours at the initial presentation of the objects. These observations are consistent with findings from other studies showing that implicit memory systems are able to bind *arbitrarily* different features into representations that mediate priming, and that priming can be observed after one single trial (Musen & O'Neill, 1997). New association learning for *colour* that implicitly primes following encounters has been demonstrated in several studies. It is shown in pairings of arbitrary colours with artificial objects (Murphy, 1991; Hanna & Remington, 1996; Nicholson & Humphrey, 2003), human artefacts (Marks, 1991; Cave et al., 1996; Wippich & Mecklenbräuker, 1994; 1998), abstract shapes (Musen & O'Neill, 1997), different scenes (Marks, 1991), and written words (Logan et al., 1996; Musen & O'Neill, 1997; McKelvie et al., 2001). Advertisers, who are seeking to link separate drawings to brands, and products, use such techniques. One example is the 'Coca Cola' brand where the colour red cues the response product (McKelvie et al., 2001). Furthermore, priming new associations with colour

is found to be easier than with other object attributes, as stimuli like objects and words can be stored separately from colour, while colour cannot be stored independently of the stimuli of which they are part (Musen & O'Neill, 1997). The ability to bind arbitrarily different features into representations that mediate priming makes behavioural sense. Such cognitive flexibility in the use of object information in implicit memory allows for rapid adaptation to environmental situations and different task demands.

1.7.4: Cognitive models for visual object recognition priming

Research has shown that not all changes in object properties influence priming effects in a similar way. This might mean that the implicit memory has some flexibility for certain object attributes according to processing demands in the encoding and retrieval operations. For instance, changes in the *left-right reflection* (e.g. Srinivas, 1996) or in the *size* of an object between study and test shows little or no effects on priming (Biederman & Cooper, 1992; Lueschow et al., 1994; Fuhrmanski & Engel, 2000; Vuillemier et al., 2002; Sawamura et al., 2005). In contrast, changing the *position* (Bar & Biederman, 1998; Grill-Spector et al., 1999), *orientation* (Murray et al., 1993; Tarr 1995; Uttl & Graf, 1996; Tarr et al., 1997), *shape* (Bartram, 1974; Biederman & Cooper, 1991; Cave & Squire 1992; Zimmer, 1995; Cave et al., 1996; Simons et al., 2001; Yago & Ishai 2006), or the *colour* of an object (Hanna & Remington, 1996; Uttl & Graf, 1996; Suzuki & Takahasi, 1997; Gegenfurtner & Rieger, 2000; Wichmann et al., 2002; Nicholson & Humphrey, 2003; Vernon & Lloyd-Jones, 2003; Zimmer & Steiner, 2003; Lloyd-Jones, 2005; Fanini et al., 2006; Spence et al., 2006; Uttl et al., 2006; Lloyd-Jones & Nakabyashi, 2009) reduces priming effects in most of the reported cases.

Sensitivity to such recent object features including colour is not a part of object recognition theories such as Marr & Nishihara's (1978) or Biederman's 'recognition-by-components

theory' (1987). Both models assume that structural descriptions (object files) contain only basic information of the object representation, which is mainly based on shape, and that structural descriptions are not associated with any colour or other incidental attributes that are unique to a particular occurrence of an object. According to these views, priming occurs because the perception of an object strengthens its structural description and by this facilitates the perception of the same object at a second encounter. Consequently, repetition priming should not be affected by any changes in surface details including colour or incidental attributes of an object such as size, spatial location, or left-right orientation. However, several studies have shown that priming effects decrease when object *colour* is changed between study and test. Such results suggest that colour is bound automatically as an *integral* part of object identity during encoding (Maljkovic & Nakayama, 1994; Logan et al., 1996; Spence et al., 2006) and processed automatically during retrieval (Engelkamp et al., 2000). Stimulus characteristics that can affect priming are considered to be important for stimulus identification (Biederman & Cooper, 1991b ; Cave et al., 1996) and must therefore represent a configuration of the object's parts (structural description). Shape based accounts to describe priming mechanisms like those proposed by Marr & Nishihara or Biederman fail to explain the observed colour effects.

What other models are there in the literature to explain the underlying mechanisms of priming effects? Behaviourally, priming can be considered either as a temporary activation of pre-existing object *representations*, or as a transfer of task relevant *processes* that allow a more specific decoding of a stimulus when the stimulus is repeated. The former view would only hold for short-lived priming effects (immediate recall), whereas the latter would also incorporate the relatively long-lasting priming effects observed (Moscovitch et al., 1993).

At the neural level, theories can be divided broadly into five different assumptions: the 'fatigue model', the 'sharpening model', the 'facilitation model', the 'stimulus adaptation model', and the 'rapid response learning model'. These theories are described below. A schematic description of possible neural tuning curves for the first three theories, the 'fatigue model', the 'sharpening model', and the 'facilitation model' are shown in figure 16.

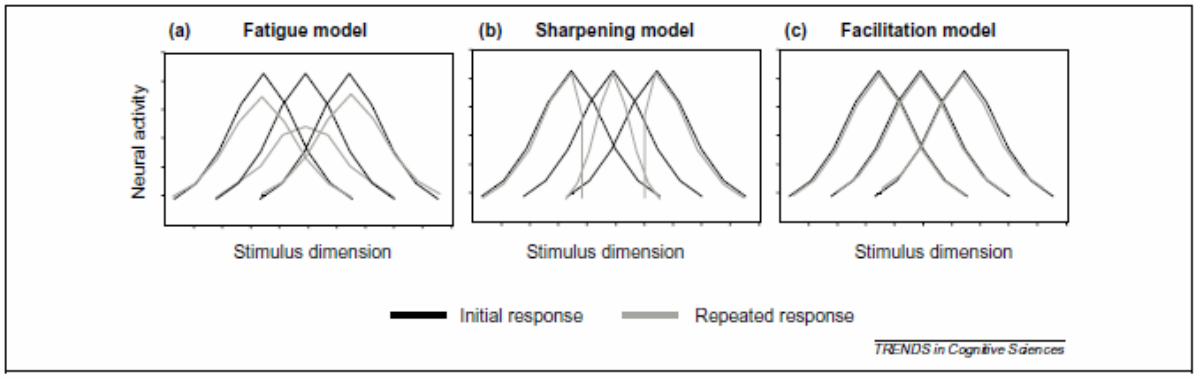


Figure 16. Implications of models for neural tuning following repetition. Tuning curves before (black) and after (gray) repetition. Image taken from Grill-Spector, Henson & Martin (2006).

The '*fatigue model*' is similar to 'the temporary activation of pre-existing object representations model' proposed by Moscovitch et al. (1993) in that it only holds for immediate repetition effects reflecting transient stimulus specific effects. The major assumption of the fatigue model is that there is no change in pattern relative to the response across neurons in the brain, but the mean firing rate declines. The decline of the firing rate may be explained by synaptic efficacy where the neurons that respond optimally at the first encounter with the stimulus will reduce activity towards the repeated stimulus in order to increase capacity for a mechanism of novelty detection (Li et al., 1993; Muller, et al., 1999). This view would fit with the suggestion by Ringo (1996) that priming occurs to reduce interference from neuronal activities elicited by already experienced stimuli to enable the brain to focus and process *novel* images. Ringo called this mechanism '*stimulus adaptation*'

and highlights that it would allow the visual system to deal with any possible new situation or threat by ignoring familiar objects that have been dealt with earlier.

The '*sharpening model'* is opposite to the 'fatigue model' in that it focuses on a learning process. It implies that neurons that respond optimally at the first encounter are tuned again when the stimulus is repeated whereas neurons that encode features that are irrelevant for the stimulus identification are reduced and inhibited. Because fewer neurons respond to a repetition of a stimulus, neurons become more sensitive to changes of stimulus properties. A sharpening mechanism has the advantage to reduce metabolic costs and to allow a faster read out of the stimulus information (Desimone, 1996; Wiggs & Martin, 1998, van Turennout et al., 2000; 2003; Vernon & Lloyd-Jones, 2003). However, a different view about '*rapid response learning'* comes from Dobbins et al. (2004) and Horner & Henson (2008). They claim that prior exposure to a stimulus leads to stimulus-response associations. At a second encounter, those associations automatically cue the response, bypassing some of the various processing stages that were active during the first representation. Such mechanism would make sense from an evolutionary point of view as recently encountered stimuli in the environment are likely to be encountered again (Roediger, 2003; Marsolek, 2008). The difference between the 'rapid response learning model' and the 'sharpening model' is the *level* of response learning. In the sharpening model, response learning occurs at feature level whereas learning in the model proposed by Dobbins et al. and Horner & Henson happens as a transfer of task relevant processes.

Another explanation for the neural mechanisms of priming is stated in the 'facilitation model'. The key effect is synaptic potentiation. This model states that in the beginning, neurons fire robustly to both first and repeated representations, but firing stops sooner when the stimulus is repeated. Because repetition of stimulus attributes improves prediction, synaptic changes

accelerate (synaptic potentiation), leading to shorter duration of neural processing. This model highlights changes mainly across the dimension of time (James et al., 2000; Grill-Spector 2003; Henson & Rugg, 2003; James & Gauthier, 2003; Friston, 2005).

To summarize, many questions about the underlying mechanisms of visual priming are still left open. The current models that try to explain priming effects differ in qualitative and quantitative changes of neuronal activity and in relevance across space, time and task. To date, none of them seems to offer a final solution. Different approaches might be useful to explain the variation of neuronal responses observed in different tasks during visual priming (Grill-Spector et al., 2006).

1.7.5: Mechanisms of priming in object naming

Priming in *object naming* can derive from qualitatively different types of information processing. This has been demonstrated with different test designs. For instance, van Turennout and colleagues (2000; 2003) measured brain activity with fMRI during repeated object naming at different time intervals (1h, 6h, and 3 days) and found long lasting changes in cortical activity with different patterns in posterior and anterior brain regions. These changes showed decreased activity in occipitotemporal and left inferior frontal regions, and increased activity in the left insular and basal ganglia, suggesting that long- lasting priming is mediated by two distinct neural mechanisms. The first may represent changes in object processing in the occipitotemporal cortices to improve object recognition. The second may represent a kind of procedural learning, which involves reorganization of pathways in the brain to support the name retrieval for that specific object. The authors state that it remains unclear how these increasing and decreasing brain activities can be related to either implicit (unconscious) or explicit (conscious) memory processes (van Turennout et al., 2003). Accordingly, priming may originate at the level of *perceptual* representation (Tulving &

Schacter, 1990) and / or at the level of *lexical-semantic* representations (Weeldon & Monsell, 1992), or as an *interaction* of both (van Turennout et al., 2000). Different priming effects in naming according to the task modality at study have been demonstrated by Carroll (1985), Mitchell & Brown (1988), and Vernon & Lloyd-Jones (2003). It was observed that prior exposure to an object as *recognition* task can facilitate subsequent *naming* but that priming effects are stronger when naming and renaming the object. Results indicate that switching task between study and test may reduce but not abolish priming, and would fit with the assumption that priming in object naming may originate at qualitatively different levels of processing and brain areas.

1.7.6: Priming effects in naming pictures of single objects

Priming in object naming is typically assessed without asking individuals to engage in recollection. Participants are usually left naïve about the real focus of the experiment to prevent them to memorize any particular object details explicitly. Priming effects can be measured in two different ways. One method compares naming measures in the test phase for pictures that were repeated from the study phase against those for pictures shown for the first time in the test session. This method can have disadvantages as latencies of new items can be biased by fatigue effects, because the number of items at test (old *plus* new items) is usually double the amount of number of items at study (only old items). Another method uses a between-item calculation where *first* minus *second* latency of *old* items are compared (i.e. comparing naming measures in the test phase with naming measures in the study phase for pictures that were repeated in the test phase) (Lachman & Lachman, 1980; Moscovitch et al., 1986). This latter method enables a more item specific comparison. The few studies that reported numbers for both between-item calculations show slightly smaller priming effects with ‘the first minus second latency of old items’ method.

Most of the studies examining priming effects in picture naming have used achromatic stimuli and only a few (Cave, 1996; Nicholson & Humphrey, 2001; Vernon & Lloyd-Jones, 2003; Lloyd-Jones, 2005) used coloured materials. The overall results show that priming effects are little or not affected by number of lags or time elapsed between the first and second presentation. However, results show quite a variation across *studies*, which may reflect differences in test designs and task demands. For instance, the highest priming effects for unchanged pictures and conditions (-179ms to -243ms) are found in the studies by Francis & Saenz (2007), who compared repetition-priming endurance in picture naming and translation. The task in their experiment involved bilingual participants who had to rename half of the items in the same language and to translate the names of the other half into a different language. The task difficulty of dealing with two different languages may have increased subject's attention thereby causing higher priming effects (for the pictures in the same language) than observed in other studies. Priming times in the other studies varied between -30ms and -131ms, with an average of -66ms for *achromatic* pictures (Sperber et al., 1979; McCauley et al., 1980; Carr et al., 1982; Mitchell & Brown, 1988; Cave, 1997; Lloyd-Jones & Humphreys, 1997; van Turennout et al., 2003; Alario et al., 2004; Lloyd-Jones, 2005; Wingfield et al., 2006), and with an average of -76ms (-56ms to -115ms) for the *coloured* pictures (Cave, 1996; Nicholson & Humphrey, 2001; Vernon & Lloyd-Jones, 2003; Lloyd-Jones, 2005). Cave (1996), Nicholson & Humphrey (2001), and Vernon & Lloyd-Jones (2003) directly contrasted priming effects of chromatic and achromatic stimuli in their studies and found no differences in *priming* times attributed to colour, although objects in the Vernon & Lloyd-Jones experiments were faster *encoded* in colour during *recognition* compared to their black and white counterparts, and Nicholson & Humphrey (2001) found larger priming effects for colour when objects were rotated. These interesting findings and the results from studies with achromatic stimuli seem to suggest that there is no difference in priming times

between chromatic and achromatic stimuli when objects are presented in a canonical position. This may further indicate that *general* priming mechanisms are unaffected by *colour*, as long as the colour information remains unchanged between study and test.

1.7.7: Colour priming effects in verification tasks with scenes

In contrast to observations that colour makes little difference in general priming when *naming* pictures of *single* objects repeatedly, are findings that colour enhances priming when subjects are *verifying scenes*. Old / new, or matching to sample tasks clearly show enhanced accuracy scores of 5-10% when the scenes are presented in colour during study and test compared to when they are shown in black and white. These effects are independent of whether the scenes are represented immediately (Gegenfurtner & Rieger, 2000; Wichmann et al, 2002), with intervening delays (Spence et al., 2006), or after a delay of 1 day to 12 weeks (Homa & Viera, 1988; Suzuki & Takahashi, 1997). Furthermore, the enhanced accuracy with colour was independent of any *explicit* memory about particular colour details. For instance, Suzuki & Takahashi (1997) show in their experiments that colour improves the recall of scenes about 10% after a one-week interval, even though the subjects could not recall the colour information about particular parts of the scene , or the colour mode the scene was presented at study (colour or black and white). The scenes depicted images such as train stations and shopping malls, and contained many different objects. Images were presented for five seconds with a two-second interval and subjects were asked to memorize the scenes. The authors suggest that the colour benefit may be a *saliency* effect during encoding and retrieving by highlighting the distinctiveness of the features of the pictures, but not due to specific memory about the colours themselves. Hanna & Remington (1996) draw a similar conclusion. In their studies, subjects responded more accurately to the coloured scenes but were generally bad in recalling the particular colour in which objects of the scenes were initially presented, even

when they remembered that they had seen that object before. The scenes in this study where made of geometric shapes depicted either in front of a white background or a background for which the top half was sky blue and the bottom half green. Because colour enhanced recognition memory only for whole scenes but not for objects that were part of it, the authors suggest that colour and shape are independent parts of memory representation and that they can be assessed independently. Binding up colour information from memory with shape information, would require focal attention, and therefore not be a natural consequence of processing visual stimuli. Colour may aid a preattentive segmentation of a scene into distinct regions and this coarse information may be extracted before a conscious identification of the particular elements of the scene can take place. This coarse first layout may than prime an explicit identification of the scene and its elements.

In contrast to this view are findings by Wichmann et al. (2002) who contrasted congruent with incongruent coloured scenes in a recognition memory task (Exp. 4). If colour only aids segmentation processing through saliency or increased attention (by highlighting the distinctiveness of the features of the pictures), than performance (priming) for congruent and incongruent coloured scenes should be the same. However, they found decreased recognition memory for the falsely coloured images, which indicates that the memory system must have used a kind of “reality filter” at a high level processing stage that involves object *colour knowledge*. Furthermore, Homa & Viera (1988) investigated recognition memory for scenes under four different conditions of foil discriminability (coloured and black and white photographs, elaborated and unelaborated line drawings) with four different delays (1 day, 1 week, 4 weeks, and 12 weeks). They found that performance was best with the coloured photographs and that recognition accuracy was based on physical similarity of the images between study and test. Since recognition accuracy was best for the more detailed stimuli, the authors concluded that the additional details inherent in the more complex scenes (including

colour) were encoded and stored over time. Their findings speak against the view that priming is mediated solely by a coarse first layout of the scene gist capturing an abstract meaning of the picture, instead, it suggests that *analogue* information including colour is encoded and retained.

1.7.8: Summary

To summarize, theories about the role of colour in priming are controversial. It is still unclear whether colour information is stored and retained or whether priming is mediated mainly by shape. However, the reviewed studies provide evidence that priming is not mediated solely by a coarse first achromatic information as suggested by edge-based accounts, instead analogue information including colour seems to be encoded and retained. It has been shown that colour is bound automatically as an integral part of object identity during encoding and processed automatically during retrieval. This means that colour is part of the object file (i.e. an intrinsic object property) and bound with shape during early visual processing stages. In fact, research on visual recognition priming has shown that colour can prime at different visual processing levels ranging from very early perceptual levels to later conceptual levels. It seems that colour can prime following representations implicitly with long lasting effects. Such priming effects for colour have been demonstrated in studies on new association learning and in studies on verifications of scenes. However, little research has been done on colour effects during priming of object *naming*. The majority of studies on priming during repeated picture naming have used achromatic stimuli and few studies have used coloured stimuli to evaluate colour specific effects. Such studies on colour have produced mixed results. It seems that the underlying mechanisms for priming effects on object naming and specifically the role of colour are not yet fully understood. Hence, more research is needed to measure colour effects on repeated naming of objects.

1.8: Thesis outline

The research of this thesis aims to establish the role of colour at the interface between the visual analyses and the lexical access and incorporates a cross-linguistic design. Experiments are designed to explore the influence of colour on object naming in healthy people and in aphasic patients with anomia. Experiments 1 and 2 are designed to address (a) how colour contributes to image *segmentation* and object *identification* in the process of naming common real objects, and (b) how colour affects *priming* measures when objects are named a second time after a delay. Experiment 3 was constructed to measure time differences on object segmentation *before* semantic processing can take place by varying (a) object colour, (b) background colour, and (c) background context in a *fast object detection paradigm*. Test stimuli used in the three experiments were from a newly created picture set.

There is evidence for a widespread anatomical network in the brain subserving object naming. In a system in which information is continuously fed forward and backward, the effects of a particular variable such as colour may be felt throughout the system and may influence some processing stages more than others. Studies have shown that there is ample *inter* and *intra* subject variation in measures of picture naming speed and naming accuracy. This may be because there are multiple factors at different processing levels that can influence the results. It is therefore often difficult to elaborate a one-to-one subject and/or item-based correspondence between the effects of a particular variable and a specific processing stage. Therefore, the research reported here aims to primarily search for an *overall pattern* of influence of the variable colour on object recognition, naming and priming during repeated object naming.

Chapter 2: The stimulus set

2.1: Introduction

The aim of this research is to determine how colour influences processes entailed in object recognition. Three experiments addressed this issue. The first two experiments were designed to investigate (a) how colour contributes to object *segmentation* and object *identification* in the process of naming common objects, and (b) how colour exerts a *priming* effect when objects are named a second time after a delay. The third experiment assessed how colour influences object segmentation *before* semantic processing can take place by varying (a) object colour, (b) background colour, and (c) background context in a *fast object detection paradigm*. All the experiments in this thesis used a newly created picture set described below in section 2.3.

2.2: Background

In previous research, stimuli used to investigate colour effects on object identification, naming or priming have varied greatly between studies, ranging from line drawings to coloured drawings, photographs, and real objects. It has been often assumed that the way that information is extracted and retained from a simplified image of an object, such as a line drawing, is equivalent to the way in which information is extracted from a real scene. However, it has also been questioned whether these different types of object presentations are equally ecologically valid and suitable to measure colour effects. Indeed, findings from several studies suggest that line drawings such as those from the often used Snodgrass & Vanderwart picture set (1980) permit only poor manipulation of physical variables when measuring effects of surface properties such as colour or texture on object segmentation and

identification (Humphreys & Riddoch, 1987; Brodie et al., 1991; Humphrey et al., 1994; Leder, 1996; Sanocki et al., 1998; Nicholson & Humphrey, 2001; see also Shevell & Kingdom, 2008). It was argued that real-world objects or their photographic depictions provide more information including colour, luminance, and texture, specularities and shading cues. There is evidence that these additional cues facilitate object recognition in a more economic way as they provide depth information and may help coding and parsing objects into their correct parts and this has been shown in both normal (Humphrey et al., 1994; Leder, 1996; Nicholson & Humphrey, 2001) and brain-damaged subjects (Humphreys & Riddoch, 1987; Humphrey et al., 1994; Chainay & Humphreys, 2001). In addition, studies measuring recognition memory of pictures showed that recognition memory is sensitive to manipulations of low-level details such as luminance (Loftus, 1985) and contrast (Loftus & McLean, 1999) and that photographic scenes are better encoded than similar drawings (Tatler & Melcher, 2007). Thus, it seems that stimulus realism has an influence on the underlying processes of object-memory formation. Furthermore, studies focussing on object naming suggest that realistic stimuli result in richer semantic associations (Bisiach, 1966), which in turn may ease the retrieval of that object's name (Levelt et al., 1991). Using stimuli that are more naturalistic than simplified drawings allows for a better evaluation of how the visual system encodes and retains information about objects in the environment.

2.3: Description of the new stimulus set

To separate the influence of *colour* attributes from other visual attributes that can affect the process of segmenting an object from its background and the processes of identifying and naming the object, a new stimulus set was created. We decided not to use images of common real objects freely accessible from the net or from commercial image libraries because most of these images are presented in different semantic contexts, photographed in front of different backgrounds, with varying viewpoints, and under different lighting conditions and so would

have confronted us with too many confounding variables. A stimulus set was constructed where pictures were produced under the same lighting conditions and controlled for viewpoint and background. All test stimuli used in the three experiments were from this newly created picture set.

2.3.1 Stimuli for experiment 1 and 2

We started by photographing 144 common real objects; four of them were used as practice items (see object list in Appendix 3). The Snodgrass & Vanderwart picture set (1980) inspired the selection of the objects. This widely used picture set comprises 260 black and white outline drawings of so-called “concepts” of common objects from several different categories. We used only those objects from their set that could be easily placed on a table and photographed and added additional items to the categories fruits & vegetables and manmade things. To minimize possible vocabulary differences among subjects in the naming task, objects were chosen that were common and that participants of different gender, age, and educational background could easily name.

One hundred and forty-four objects were used in experiment 1 and one hundred and fifty-four in experiment 2 because asking subjects to name a larger number of objects in a row can cause fatigue effects and confound the results (see Snodgrass & Yuditsky, 1996, pp 517).

To allow us to maintain the same settings between photo sessions no objects were bigger than 60 x 40 cm. All items were *real* objects and in their real size, except the four vehicles and the road sign (car, double-deck-bus, fire engine, tank, no-entry sign) which were taken from toys, and the 28 animals, which were plastic figures. The animal figures were mainly from the manufactures Schleich (Germany) and Papo (France) and selected for having the most typical and naturalistic looks. Fruits, vegetables, and food items were presented in their most typical

colours and shapes. The objects from the manmade category were selected to be as uniformly coloured as possible so that their surface texture variation would not be obscured by arbitrary colour variation. All objects represented a typical exemplar of their kind, easily identified by both older and younger participants.

Half of the objects of the set for experiment 1 belonged to the category of *living things* (72) composed of the sub-categories of fruits (21), vegetables (18), animals (28), food items (3), and other living things (2). The other half was *non-living things* (68) and belonged to the category of manmade objects including household utensils, tools, clothing, and toys (see object list in Appendix 3). For experiment 2, ten additional objects were created that consisted of physical representations of geometric abstract forms (cylinder, trapezoid, sphere, hemisphere, pyramid, square, cube, pentagonal-prism, cone and rhomboid). These abstract forms were introduced because we were interested in how colour affects naming of objects which have no relationship with particular colours and which do not therefore generate any specific colour associations. All abstract forms were 3-dimensional objects made of wood and painted in arbitrary colours of either yellow, orange, red, green or blue.

All objects were either classified as having high colour diagnosticity if they are almost always encountered in one particular colour (e.g. cucumber (green), mandarin (orange), fire extinguisher (red)), or as having low colour diagnosticity when they may appear in arbitrary colours (for example clothes pegs or shirts). Eighty-seven of the objects in the set had a high colour diagnosticity and 53 (63 in Experiment 2) were low colour diagnostic. For those objects that were similar to the ones used in the study of Rossion & Pourtois (2004), colour diagnosticity was defined according to the colour diagnostic values that the authors published online (retrieved online August 12, 2004, from Web site: hhtp://www.perceptionweb.com/misc/p5117/, appendix 5). The scores on the list derived

from eleven subjects (seven females, four males, mean age 24 years) who were asked to rate each colorized item of the Snodgrass & Vanderwart picture set on a 5-point scale ranging from whether the object can appear in more than one colour to whether the object exists exclusively in a particular colour (=5). Values greater than 3 reflected high colour diagnosticity, and below 3 low colour diagnosticity. All ten abstract forms for experiment 2 where classified as low (non) colour diagnostic.

Each object was photographed in a photographic studio with the help of a professional photographer using a Canon E0S 5D digital still camera. The objects were placed in the centre of the background and photographed oriented in their canonical position. The photos were taken under simulated daylight conditions to give every object a natural shadow and equipped with a horizon line (formed by the fold in the backdrop between floor and wall) to provide cues of depth and to ensure that the images were obviously of real three dimensional objects. All objects were photographed in exactly the same position against two different backgrounds, one plain white one and the other consisting of coloured fractal noise. We used the two different backgrounds to manipulate the ease with which the objects could be segmented from their background. The fractal noise was made of three superimposed independent channels (red, green and blue) of Perlin noise (Perlin, 2002). The noise has a pseudo-random appearance, but appears similar no matter what scale it viewed at because its statistical features are scale-invariant. This scale invariance means that the same noise background can be used as a backdrop for objects of different sizes, photographed at different viewing distances without giving any hints of size information of the object.

After the pictures were taken, each photograph was manipulated using the Paint Shop Pro 8 software package. To create the different versions of each photograph the image of each coloured object was digitally cut out from its background and transformed into a grey-scaled

version equated in luminance with the original colour version of the image. These isolated object images were then placed, in exactly their original positions, against coloured or grey-scaled versions of their backgrounds. In this way, we created six different picture versions of every object (see colour plate in Appendix 1):

1. cocn = **coloured object** in front of a **coloured fractal noise**
2. gocn = **grey-scaled object** in front of a **coloured fractal noise**
3. gogn = **grey-scaled object** in front of a **grey-scaled fractal noise**
4. cocp = **coloured object** in front of a **plain background**
5. gocp = **grey-scaled object** in front of a **plain background**
6. gogp = **grey-scaled object** in front of a **grey-scaled plain background**

Legend: c = coloured, g = grey-scaled, o = object, n = noise background, p = plain background

The six different picture versions were created to measure colour effects on object segmentation and on the lexical selection process by manipulating object colour (colour vs. grey-scaled), background condition (plain vs. noise), and congruency of object and background colour. Research has shown that incorrectly coloured objects are named slower when compared with correctly coloured objects or with their greyscale images (Vernon & Lloyd -Jones, 2003; Castelhano & Henderson, 2008). In our research, we did not use incorrectly coloured objects (e.g., a blue banana or a yellow pig) but created two picture versions where we violated the congruence between object and background colour (cogp = coloured object in front of a grey-scaled plain background, and cogn = coloured object in front of a grey-scaled fractal noise). This was done with the aim to measure whether incongruence between object and background colour has an effect on the segmentation and lexical selection process and whether the effects differ from pictures with congruent object

and background conditions. Because the violation of the congruence between object and background colour is the same whether it is done with a grey object in front of a coloured background or with a coloured object in front of a grey background, we included only the former version in the stimulus set for the naming tasks and neglected the latter one.

The total image set for experiment 1 comprised 840 different stimuli (140 objects x 6 versions) plus 4 training items. The 840 different images were divided into six different sets of 140 images each. Every set contained all the 140 objects in the same order, but in each set, the object occurred in a different picture version. The sets were counterbalanced across subjects to assure an equal number of items for each condition. In this way, every subject was presented with all of the 140 objects, but subjects named different picture versions of the object. The image set for experiment 2 consisted of the same stimuli as used in experiment 1 plus 10 abstract forms prepared in 6 different picture versions. The total image set for experiment 2 comprised therefore 900 different stimuli (150 objects x 6 versions) plus 4 training items and the images were sorted into six different sets as described for experiment 1.

2.3.2: Stimuli for experiment 3

For the rapid object detection task in experiment 3, we selected 40 different objects from the original set and created four images that contained only backgrounds. The images of the 40 different objects contained only one single object. Half of the objects were from the manmade category with low colour diagnosticity, the other half were fruits (6), vegetables (7), and animals (7) and had high colour diagnosticity (see object list in Appendix 4). All objects were presented in eight different picture versions, an additional two to those used in experiment one. These two additional picture variations contained the object in its original colour, but the backgrounds were transformed into grey. The backgrounds for the four new background

images were photographed under exactly the same conditions and equipped with the same horizon line as the rest of the set. The four backgrounds were a coloured plain background, a grey-scaled plain background, a coloured fractal noise, and a grey-scaled fractal noise. The eight different object picture conditions and the four different background conditions are shown in the colour plate in Appendix 2 and explained down below.

Pictures with objects

1. cocp = **coloured object** in front of a **coloured plain background**
2. cogp = **coloured object** in front of a **grey-scaled plain background**
3. gocp = **grey-scaled object** in front of a **coloured plain background**
4. gogp = **grey-scaled object** in front of a **grey-scaled plain background**
5. cocn = **coloured object** in front of a **coloured fractal noise**
6. cogn = **coloured object** in front of a **grey-scaled fractal noise**
7. gocn = **grey-scaled object** in front of a **coloured fractal noise**
8. gogn = **grey-scaled object** in front of a **grey-scaled fractal noise**

Pictures with backgrounds only

9. cp = **coloured plain background**
10. gp = **grey-scaled plain background**
11. cn = **coloured fractal noise**
12. gn = **grey-scaled fractal noise**

Legend: c = coloured, g = grey-scaled, o = object, n = noise background, p = plain background

The six different picture versions were created to measure colour effects on object segmentation and on the lexical selection process by manipulating object colour (colour vs. grey-scaled), background condition (plain vs. noise), and congruency of object and background colour. Research has shown that incorrectly coloured objects are named slower when compared with correctly coloured objects or with their greyscale images (Vernon & Lloyd -Jones, 2003; Castelhano & Henderson, 2008). In our research, we did not use incorrectly coloured objects (e.g., a blue banana or a yellow pig) but created two picture versions where we violated the congruence between object and background colour (cogp = coloured object in front of a grey-scaled plain background, and cogn = coloured object in front of a grey-scaled fractal noise). This was done with the aim to measure whether incongruence between object and background colour has an effect on the segmentation and lexical selection process and whether the effects differ from pictures with congruent object and background conditions. Because the violation of the congruence between object and background colour is the same whether it is done with a grey object in front of a coloured background or with a coloured object in front of a grey background, we included only the former version in the stimulus set for the naming tasks and neglected the latter one.

The total set for experiment 3 consisted of 640 images and a block of 28 practice items that were not analyzed. Half of the 640 images contained an object (40 objects x 8 different versions = 320), the other half was made of the four different background versions that did not contain any object. The 640 images were divided into eight blocks of 80 pictures each randomized for picture condition with the constraint that each object version appeared only once.

Chapter 3: Experiment 1 - Colour effects on naming and priming

3.1: Introduction

The aim of experiment 1 was to explore the influence of colour on object naming in healthy people and in aphasic patients with moderate to medium severe anomia. The experiment was designed to measure how colour contributes to image *segmentation* and object *identification* in the process of naming images of common objects, and how colour affects *priming* measures when objects are named a second time after a delay. A further aim of experiment 1 was to compare naming measures with respect to colour across different populations/language communities (English and Germans) to establish whether there is an effect independent of cultural differences and linguistic variables such as word length and name agreement.

Patients with more severe naming impairments such as patients with severe Broca's- , Wernicke's- or Global-aphasia were excluded from the study because such patients fail to produce enough correct answers to allow for valid statistical comparisons on accuracy and naming latencies (Mohr, 2004). Therefore, only patients with moderate to medium severe anomia who are able to name at least 50% of the pictures of the stimulus set correctly were included.

Aphasic patients with even a mild form of anomia perform considerably worse in naming tasks than non-aphasic speakers of the same age (Goodglass et al, 1968; Mills et al., 1979; Wingfield et al., 2006). Marshall (1976) and Mitchum et al. (1990) suggest that aphasic patients with relatively mild naming impairments ('higher level' aphasics) may use delay strategies to allow time for interpretation by internal *association* processes when searching for a target name that they find hard to retrieve. Mills et al. (1979) also made similar observations; they found a *quantitative* difference between aphasic and normal subjects in

picture recognition performance when naming objects. They suggest that this difference would lie in the *processing* of the lexical retrieval (i.e. impaired strategy for the lexical search) and not in an impairment of the lexical store itself. According to these findings, we expect to find an increased vulnerability during object naming in the group of aphasic subjects with overall longer naming latencies and a higher number of errors when compared with the healthy control group, even though we include only aphasic subjects with moderate to medium severe anomia in this research.

Models of picture naming involve several processes that can be activated in parallel with feedback flow between the different levels, which can be either facilitating or inhibiting (Humphreys et al., 1995; Rapp & Goldrick, 2000). These processes include the segmentation of the object from its background and the parsing of object features into meaningful parts (visual processing), the categorizing and recognition of the object as a member of a particular class, and access to stored conceptual knowledge about the object's individual identity (semantic processing). This knowledge has then to be verbally encoded (lexical processing) before the name can finally be articulated (phonological and articulatory processing) (e.g., Levelt, 1992). There is evidence that name retrieval can start before the visual access to semantics is fully completed, which means that partial activation of visual information can trigger object-naming (Vitkovich & Humphreys, 1991; Vitkovich et al., 1993; Riddoch & Humphreys, 2001; Lloyd-Jones & Nettlemill, 2007). There is no clear picture to date at which levels of processing colour may interfere and influence the naming process. However, there is evidence that colour helps to segment objects from their surroundings (e.g., Rivest & Cavanagh, 1996; Gegenfurtner et al., 1998; Heywood et al., 2001; Wichmann et al., 2002; Fine et al., 2003; Kentridge et al., 2004). It is also shown that the combination of texture and colour cues helps to parse objects into their correct parts, which in turn facilitates object recognition (Humpreys & Riddoch, 1987; Humphrey et al., 1994; Leder, 1996; Sanocki et al.,

1998; Funt & Cardei, 2000; Chainay & Humphreys, 2001; Nicholson & Humprey, 2003). Furthermore, colour is bound as an intrinsic part of the object file (object identity) and stored automatically in memory when the object is first attended to (e.g., Joseph, 1997; Mausfeld, 1998; Zimmer & Steiner, 2002; Naor-Raz & Tarr, 2003; Ecker at al., 2007). This colour knowledge is supplied involuntarily by the semantic memory system and activated automatically in *any* task that requires semantic description about objects (Joseph, 1997). It is further shown that object colour knowledge has the potential to interact with perceptual visual input by either facilitating or interfering with the object (e.g., Joseph, 1997; Naor-Raz & Tarr, 2003).

A model that nicely incorporates the different levels at which colour might influence the naming process is that by Davidoff & de Bleser (1993) and Davidoff (2001). This model implies that colour can affect form at the earliest stages of visual processing as colour contains shape-forming properties and has the potential to form object boundaries by itself (Cavanagh, 1987; Heywood et al., 1991; Kentridge et al., 2004). Consequently, colour can be a part of the structural descriptions, which contain the basic *form* information of an object representation. At later stages, object-colour knowledge, as part of the sensory object knowledge, may influence the lexical selection process. However, theories of object recognition differ as to whether primary object processing is mainly based on shape (edge-based accounts) or whether it is also based on surface details such as colour (shape *and* surface based accounts). As can be seen in table 1 on page 50, results deriving from semantically *simple* tasks like basic object detection, basic verification, or *super*ordinate object classification are inconsistent concerning the role of colour. In contrast, there is more evidence that colour can facilitate object *naming* as more semantic differentiation is required to select an object's name for articulation to take place. In fact, positive effects for colour on object naming have been demonstrated in several studies on healthy participants (Ostergaard & Davidoff, 1985; Davidoff & Ostergaard, 1988; Price & Humphreys, 1989; Brodie et al.,

1991; Wurm et al., 1993; Humphrey et al., 1994; Montanes et al., 1995; Tanaka & Presnell, 1999; Nicholson & Humphrey, 2001; Vernon & Lloyd-Jones, 2003; Rossion & Pourtois, 2004; Laws & Hunter, 2006) and on patients with neurological deficits such as Alzheimer's disease (Montanes et. al 1995; Lloyd-Jones, 2005) or aphasia (Bisiach, 1966; Benton et al., 1972), see table 2 on page 64. However, the literature provides controversial results as to whether colour aids object recognition and naming only in certain categories of objects and whether the colour of an object has to be diagnostic of that object for such an advantage to occur.

The majority of studies on object recognition or object naming found *significant* colour effects chiefly with objects belonging to the category of living things (e.g., Price & Humphreys, 1989; Wurm et al, 1993; Joseph & Proffitt, 1996; Joseph, 1997; Mapelli & Behrmann, 1997; Tanaka & Presnell, 1999; Delorme et al., 2000; Vernon & Lloyd-Jones, 2003; Lloyd-Jones, 2005). Living things include objects such as body parts, food items, plants, or animals and often tend to have diagnostic colours. However, a few studies also found facilitating effects for colour on naming of objects that belong to the category of non-living things (manmade objects) and that do not possess a diagnostic colour (Brodie et al., 1991, Exp. 3; Nicholson & Humprey, 2001, Exp. 3; Rossion & Pourtois, 2004). Facilitation by colour was also found in the recognition (Hanna & Remington, 1996; Hayward & Williams, 2000; Nicholson & Humphrey, 2003; Ling & Hurlbert, 2004) and *sub*ordinate object classification (Nicholson & Humphrey, 2001, Exp. 4) of *novel* objects despite the fact that novel objects do not have a diagnostic colour and do not belong to any pre-known object class.

Such diverging results in the literature about the effects of colour comes as no surprise. It is commonly known that neurocognitive operations involved in the process of picture naming are complex and that they can be influenced by many factors including picture stimuli, word-,

and concept properties (e.g., Frattali, 2005; Szekely et al., 2005). Consequently, variations in tasks, modality, and stimulus properties can lead to different conclusions about the observed effects (Szekely et al., 2005). Indeed, there are considerable variations of latencies and/or accuracy measures in respect to colour across tasks (Brodie et al., 1991; Tanaka & Presnell, 1999; Nicholson & Humphrey, 2001; Zimmer & Steiner, 2003), items (Goodglass et al., 1968; Davidoff & Ostergaard, 1988; Humphrey et al., 1994; Zimmer & Steiner, 2003), and across subjects (Delorme et al., 2000; Zimmer & Steiner, 2003; Laws & Hunter, 2006). Furthermore, variation of performance has been observed even *within* subjects indicating that subjects may use different strategies on colour cues to reach a decision even within the same task (Tanaka, 2001; Lloyd-Jones & Nettlemill, 2007). In the present study, groups of subjects (English vs. Germans; aphasic vs. non-aphasic) are compared on their ability to name different categories of objects (living vs. non-living items; animals vs. fruits & vegetables vs. manmade objects) with different colour diagnosticity (high vs. low).

Other factors that may influence the outcome of a study on picture naming are sample sizes and numbers of participants. For instance, Snodgrass & Yudistky (1996, p 524), compared their results with studies that used subsets of the Snodgrass & Vanderwart pictures set (1980) to determine whether results from smaller sample sizes can generalize to this larger set. They found that small sample sizes may sometimes produce “spurious and nonreplicable results”. This could be one of the reasons why Rossion & Pourtois (2004), using a much higher number of objects and participants than most of the other studies, did find a positive effect of colour on non-colour diagnostic manmade objects, while other studies did not. For those reasons, it was planned to use an appropriate number of target stimuli per condition (70/140 in Experiment 1, and 75/150 in Experiment 2) and an appropriate number of participants per target group in this research to evaluate the colour effects.

Part two of the experiment aims to evaluate the influence of colour on priming measures during repeated object naming. Studies on priming during repeated naming of pictures of objects have shown robust effects with average priming times of -66ms. However, most of the studies have used *achromatic* picture stimuli (Sperber et al., 1979; McCauley et al., 1980; Carr et al., 1982; Mitchell & Brown, 1988; Cave, 1997; Lloyd-Jones & Humphreys, 1997; van Turennout et al., 2003; Alario et al., 2004; Lloyd-Jones, 2005; Wingfield et al., 2006), and relatively few studies coloured material (Cave, 1996; Nicholson & Humphrey, 2001, Vernon & Lloyd-Jones, 2003; Lloyd-Jones, 2005). Of those latter studies, only two directly contrasted *realistically* coloured pictures with achromatic ones to evaluate whether colour improves priming. Vernon & Lloyd-Jones (2003) used only natural objects and found no difference in *priming* measures between the achromatic and chromatic stimuli, but faster naming for the coloured pictures during *encoding* and *recall*. In contrast, Nicholson & Humphrey (2001), using mainly fabricated (manmade) objects, found little difference in priming times between the chromatic and achromatic picture conditions when pictures were presented in an upright position, but large advantages for colour when the same images were rotated. No clear conclusion about the role of colour during repeated picture naming of objects can be drawn from these few results. There is, however, evidence that colour can prime object *recognition*. Visual priming effects for colour have been found at different levels of processing and are reported in several studies. For instance, Breitmeyer, Ogmen & Chen (2004) and Breitmeyer, Ro & Singhal (2004) demonstrated priming for colour during recognition already at early wavelength-dependent levels such as V1 and V2, while Mecklenbräuker et al. (2001) showed that colour also primes at later stages such as at the level of conceptual colour representations. There are also reports that colour improves the recognition of scenes and that such priming effects can be independent of whether subjects are able to recall the colour details of the scenes explicitly (e.g., Hanna & Remington, 1996; Suzuki & Takahashi, 1997). The present study aims to shed a light on how colour influences

priming during repeated picture naming by contrasting chromatic with achromatic stimuli and by using two different subject populations.

3.2: Method

3.2.1: General method

Experiment 1 was designed to address (a) how colour contributes to image *segmentation* and object *identification* in the process of naming common real objects, and (b) how colour affects *priming* measures when objects are named a second time after a delay. The basic structure of experiments 1 and 2 was the same; both contained a study session with an immediate naming task and a test session where subjects had to perform a repeated naming task after a certain delay. Data of the immediate naming task from experiment 2 was included in the analysis of the immediate naming task from experiment 1. Experiment 1 involved aphasic patients and healthy control subjects. In this experiment, the delay between study and test was 12 days on average (between 7-17 days). It was not possible to do the repeated naming task with every aphasic patient exactly after 14 days as planned. Patients were not always available because most had demanding time schedules for their rehabilitation. Testing was generally not allowed on weekends and, in some cases, patients were discharged earlier than expected. Repetition priming was measured with a between-item calculation where *first* minus *second* latenc*y* of *old* items are compared (i.e. comparing naming measures in the test phase with naming measures in the study phase for pictures that were repeated in the test phase).

3.2.1: Participants

Experiment 1 was conducted in four different German rehabilitation clinics with aphasic patients and a group of healthy German control subjects who were matched in age.

Experiment 2 was conducted at Durham University in the UK with healthy English speaking participants. Results of experiment 1 and 2 were compared across subject groups and across the two languages, English and German. Participants from experiment 2 were used as additional control subjects for the immediate naming task of experiment 1.

Aphasic subjects

Thirty-one patients with aphasia took part in the experiment. The patients were recruited from four different German rehabilitation clinics, where they took part in rehabilitation programs that included language therapy. The clinics participating in the research were the Neurological Rehabilitation Clinics Kliniken Schmieder in Allensbach, Gailingen and Konstanz and the Special Aphasia Unit, MediClin, Klinikum Soltau. All patients were selected by their speech and language therapists according to our criteria of inclusion and asked for their consent to participate in the study.

Patients were included in the study who spoke German as their current dominant language. Snodgrass & Yuditsky (1996, p 518) suggest that it is more effective in multinational societies to discard subjects according to their *performance characteristics* (error rates and / or naming latencies) rather than according to whether they are monolingual and native speakers of the language. In many areas of Germany, non-native speakers make up 25% of the population and some immigrants live in Germany for long periods. Some immigrants may even be in the fourth generation of their families to live in Germany. Increasing numbers of patients in German hospitals and rehabilitation clinics with aphasia speak more than one language; to include only monolingual native German speakers would have halved the sample size available to us for testing. Further details about the criteria of inclusion are specified below.

Eleven of the subjects were female and 18 were male, 25 were right handed, one left handed, and three were ambidextrous. Subjects were between 39 and 79 years old with a mean age of 59.06 years (patient details see in Appendix 5). The time elapsed between the onset of aphasia and testing varied between 1 and 401 weeks (mean 46.5 weeks).

The study was conducted according to German ethical regulations and with the consent and cooperation of the administrative authorities of each clinic. Two of the participants had to be excluded after they had finished the first part of the test; as they did not meet the minimum criterion we applied to naming accuracy of a rate of 50% picture naming.

Twenty-four of the remaining 29 aphasic patients were available for *both* parts of the experiment and were included in the analysis of the priming task. All of the 29 subjects performed the first part of the experiment and were included in the analysis of the initial unprimed naming task.

Nineteen of the patients presented with post-acute aphasic syndromes (one Broca's Aphasia, one Thalamic Aphasia, one non-classified Aphasia, one Transcortical Motor Aphasia, and 15 Anomic Aphasias) with a mean post onset of 6.63 weeks (between 1 and 22 weeks). The other ten patients presented with chronic aphasic syndromes (two Broca's Aphasias, one non-classified Aphasia, one Global Aphasia, and six Anomic Aphasias) and were in the clinic to repeat their rehabilitation program, with a mean post onset time of 122.3 weeks (between 34 and 401 weeks).

Our criteria for inclusion in the patient group of the study were as follows. Patients had to be diagnosed with a moderate to medium severe anomia, having been pre-tested by their speech and language therapists with the AAT (Aachener Aphasie Test, 1983), a standard German test

battery for the evaluation and classification of aphasia syndromes. All subjects had to name at least 50% of our stimuli correctly in the course of the current experiment. Patients with more severe cases of anomia, or who failed to meet our accuracy criterion were excluded. In addition, subjects had to possess sufficient language comprehension to understand the very simple test instructions and a minimum attention span of 40 minutes to accomplish the tests. Patients with additional articulation disorders including Dysarthria and AOS (apraxia of speech) were accepted, when the symptoms had been assessed as less than medium severe according to the intelligibility of the patient. The speech and language therapists, who worked with the patients, assessed the language comprehension, attention span, and the articulation.

To make sure that the participants did not have any visual deficits which might have affected their ability to identify the picture stimuli, all patients' visual abilities were also tested. Because all of the patients were anomic, only tests were chosen that did not require any verbal responses.

Correct *colour associations* were tested with the "Colouring of Pictures Test" (DeRenzi et al., 1972; Damasio et al., 1979). Subjects had to choose a crayon from a multicoloured set and fill in the outline drawing of familiar objects that have strong colour associations for instance, sun – yellow; lips – red. None of the subjects made any errors in this test.

Accuracy of colour perception was tested with the Farnsworth Panel D-15 Test and the Lanthony15 Hue Desaturated Panel D-15 d Test (Richmond Products Inc., Albuquerque). To detect any form of colour blindness (deuteranomaly, protananomaly or tritananomaly) subjects were asked in both tests to sort a set of 16 colour caps into rows systematically varying in colour. In these tests, all of the caps have the same brightness, while they differ in hue. Caps were randomly distributed on a black sheet of paper and the examiner placed the

reference cap in front of the subject. The subject was instructed to select the colour cap, which most closely matches the reference cap, and place it in the bottom of a plastic box and slide it next to the reference cap. This process was repeated until all caps were aligned in a row.

All subjects were tested with the “Three Pictures” component of The Pyramid and Palm Tree Test (Howard & Patterson, 1992) in order to exclude those with deficits in access to object semantics from picture stimuli. The “Three Pictures” component consists of fifty-two triads of pictures in which subjects have to decide whether one of a lower pair of pictures is associated with the single picture above, for example, a picture of a *pyramid* has to be matched to one of the pair of pictures of a *pine tree* or a *palm tree.* The test does not require any verbal responses, as participants just need to point at the matching picture. Two picture triads were excluded from the scoring because they were not common for German subjects as they pictured soldiers in British uniform and a figure representing a British mayor.

Control subjects

Ten healthy German-speaking participants matched in age and 60 English-speaking participants who had taken part in experiment 2 were used as control subjects. The data from the 60 English-speaking participants could also be included because the procedure of the first part of experiment 2 is identical to the first part of experiment 1. All subjects in the control groups spoke English and German, respectively, as their current dominant languages. Seven of the German-speaking subjects were female and three were male, all were right-handed and between 23-78 years old with a mean age of 58.8 years. The English-speaking participants were between 19-64 years old with a mean age of 30.5 years, 38 were female and 22 male, 53 were right-and seven were left-handed (control subject details see Appendixes 6 and 7). All subjects had normal or corrected to normal vision, no colour vision deficits and no deficits in the access to object semantics from picture stimuli. In common with the patient group, all

control subjects were tested with the “Colouring of Pictures Test”, the Farnsworth Panel D-15 test and the Lanthony15 Hue desaturated panel D-15 d test, and the “Three Pictures” component of The Pyramid and Palm Tree Test in order to assess whether they met the criteria for inclusion in the main experiment (scores see Appendixes 5-7).

3.2.2: Stimuli

The stimulus set consisted of photographic depictions of 144 common real objects and each object appeared in six picture different versions: a coloured object in front of a coloured fractal noise, a grey-scaled object in front of a coloured fractal noise, a grey-scaled object in front of a grey-scaled fractal noise, a coloured object in front of a plain background, a grey-scaled object in front of a plain background, and a grey-scaled object in front of a grey-scaled plain background. The full details of the stimulus set are described in chapter 2. The total image set for experiment 1 comprised 840 different stimuli (140 objects x 6 versions) plus 4 training items. The 840 different images were divided into six different sets of 140 images each. Every set contained all the 140 objects in the same order, but in each set, the object occurred in a different picture version. The sets were counterbalanced across subjects to assure an equal number of items for each condition. In this way, every subject was presented with all of the 140 objects, but subjects named different picture versions of the object.

The presentation order of pictures was random in terms of design (picture version), but controlled for other aspects such as category, colour of the object and naming similarity.
It is well established that prior presentation of a stimulus related in meaning to a following target affects accuracy and speed with which the target is named. All items were therefore controlled for *category* to avoid any interference (semantic inhibition) between items that are semantically related. For instance, a fruit was not followed by another fruit. Several authors

(e.g., Humphreys et al. 1995; McCarthy & Kartsounis, 2000; Howard et al., 2006; Marsolek, 2008) have shown that successive presentation of two exemplars of the same semantic category slows down naming reaction time as a result of semantic inhibition. The semantic inhibition effect stems from priming of previously accessed representations of semantically related objects. When naming another object of the same category that has overlapping information with the previous item, the old representations are activated again (priming). This leads to competition between the old and new representations and slows down the identification process.

All pictures were also controlled for the (original) colour of the object to avoid unwanted colour priming effects (perceptual or imaginary) between the pictures. Showing an object in colour can prime the colour of a consecutive object and these colour priming effects may act at an early wavelength- dependent stage of colour processing (Breitmeyer, Ogmen, and Chen, 2004; Breitmeyer, Ro, and Singhal, 2004) well before conscious colour perception takes place (Schmidt, 2000; 2002). Colour is an attribute that becomes activated automatically when the semantic description of an object is accessed (Joseph & Proffitt ,1996; Joseph,1997). Even when the object is shown in grey, stored colour knowledge about the object becomes activated and can prime the colour of a consecutive trial. For those reasons, objects were separated by their original colour even when they appeared in their grey version. For instance, a strawberry did not follow a fire engine, as both are originally red.

All items were also controlled for similarity of name. Objects with names that began or ended with the same phonemes/syllables were separated to avoid any phonological priming between the images (see for e.g. Collins & Ellis, 1992; Wilshire & Saffran, 2005). For instance, nut-cracker did not follow peanut, and alligator did not follow almond.

3.2.3: Apparatus

In experiments 1 and 2 stimuli were displayed on a Belinea LCD 17 inch flat screen computer monitor and viewed at a distance of 50 cm. The size of the pictures was a height of 27 cm and a width of 34 cm, with a resolution of 1048 x 699 pixels. Participants' speech was recorded with a Labtec stereo 342 headset that was connected to a Medion MD 40100 Notebook PC. The head set was used to ensure that all participants maintained the same distance to the microphone and to minimize any unwanted noise.

A software program with a voice-key was used to detect and record the voice onsets of participants' speech and to determine the offset of the images. The program used a very short input buffer to minimize the latency when recording the audio signals by checking intensity against a chosen trigger threshold every 10ms. The offset of the images was determined by the start of a vocal response. Speech onset latencies were measured using sound waveforms displayed using the Adobe Audition 1.5 software.

3.2.4: Procedure

All participants were tested individually in a quiet place. They were told that the aim of the study is to measure how information about pictures of objects is stored in memory. Because we wanted to evaluate how *incidental* processing of physical attributes of stimuli may affect later performance, participants were left naïve to the real purpose of the study and were never directed to attend to particular attributes of objects such as colour. At the beginning of the experiment, participants were presented with a written standard test instruction and the experimenter ensured that all subjects understood the test procedure. Participants were instructed to find the best possible name for each object and to name each picture as quickly but also as accurately as possible. Subjects were told to respond purely with the name of the object without using any definite articles like "a" or "the" and to avoid any other utterances like "hm", "I think", or "that is".

The test started with a practice block of four items to familiarize the subjects with the task. Responses to the practice items were not analyzed. Each subject named a set of 70 pictures during the initial study session and 140 pictures during the subsequent test session. Half of the pictures used in the test session were identical to those seen in the study session, but presented in a different order and mixed with 70 new pictures (70 old and 70 new). The time interval between study and test session was 12 days on average (between 7 and 17 days), depending on the availability of the patients. By the end of the experiment, each participant had named each of the 140 objects once in an immediate naming task, and had named 70 of the objects (study items) twice in a repeated naming task.

The pacing of image onset was controlled by the experimenter and each stimulus remained in view until the voice key was triggered. A blank screen appeared immediately after the voice key was triggered and remained until the next image was initiated. The next trial was initiated immediately after the previous trial had been completed. The maximum stimulus exposure time was 10 seconds, consistent with the time-out used in the Snodgrass & Yuditsky, (1996) study. If subjects could not respond within this period, the experimenter ended the stimulus exposure manually and initiated the next picture. This method was chosen to reduce time-stress for both subject groups, but especially for the aphasic patients, in order to maximise the number of correct responses. Marshall, (1976) and Mitchum et al., (1990) have shown that a common compensatory mechanism of anomic patients is to use a delay strategy during name retrieval that allows time for interpretation by internal association processes. If this mechanism is interrupted, they fail to retrieve the correct name (Brookshire, 1971; 1972). Healthy subjects seem to behave in a similar way; they make fewer correct responses (Vitkovitch & Humphreys, 1991; Vitkovitch et al., 1993; Lloyd-Jones & Nettlemill, 2007)

and produce naming errors that can correspond to those produced by aphasic subjects (Tew, 1990) when pressurising time constraints.

All participants' answers were written down in parallel to audio recording in a naming protocol and the experimenter corrected and discussed every error that occurred during the task immediately with the participants after each error trial by asking them why they had failed to produce the correct name for the object. This method was chosen for four reasons. First, giving subjects the expected name for the object often stops them dwelling on the failed trial and makes them attend more to the task at hand. Clinical practice has shown that subjects often continue to search for the correct name if they fail during the first attempt. This may disturb the word retrieval and bias naming latencies on following trials. Second, several subjects used names for some objects that were only common in their specific dialects. Discussing such name agreement issues directly helped to distinguish those answers as either correct or incorrect. Third, instead of having errors categorized after the test and rated later by independent scorers, errors were identified and classified directly with the help of the participants (see details about error classification in the result section). Subjects, including the aphasic patients, were generally very good at explaining *why* they failed to produce the correct name of an object. Fourth, it also allowed us to detect any picture designs that subjects may have found ambiguous and to relate those ambiguities to specific participants and subject groups. When dealing with a clinical population this approach is more practical and yields more useful insights into stimulus ambiguities than having the objects rated for image agreement prior to the test by a different subject group.

3.3: Results experiment 1

3.3.1: Design

Experiment 1 was conducted as a repeated measures design to determine (a) whether colour has any influence on naming common real objects, (b) whether colour affects priming, and (c) if so, what role colour plays in the naming and priming process. The first part of experiment 1 was designed to investigate whether colour influences the object segmentation process and the lexical access in parallel or in an additive manner by systematically varying the properties of object and background colour and the context of the background.

The second part of the experiment addressed the question of how colour affects priming effects. Naming accuracy and naming latencies were the dependent variables in both parts of the experiment and repetition priming was assessed with a between-item calculation where *first* minus *second* latency of *old* items are compared (i.e. comparing naming measures in the test phase with naming measures in the study phase for pictures that were repeated in the test phase).

3.3.2: Immediate naming task

3.3.2.1: Analysis

Scoring of correct responses

Responses were included or excluded from analysis using the following criteria. Responses with noise interference or in which the voice-key malfunctioned were excluded (1.63% of all trials). A response was counted as correct if (1) it corresponded to the correct name of the picture, as determined by the Oxford English Dictionary (2005) for English or the Wahrig Deutsches Wörterbuch (2002) for German, and (2) if it was the first attempt to name the

picture, and (3) if the response was initiated within the first 5 seconds of the trial. All attempts for correction and all responses that were outside the 5 seconds time limit were classified as failure to find the correct name. Further scoring criteria were similar to those described by Snodgrass & Yuditsky (1996). A response was counted as correct if (4) it was part of that name (*peg* or *lighter* instead of *clothes-peg* or *firelighter*); or if (5) it was an abbreviation (*Wellies* or *hippo* instead of *Wellington boots* or *hippopotamus*); or if (6) it was a superordinate of the name and more frequently given than the subordinate (*nuts* or *berries* instead of *almonds* or *red currant*). In addition, a response was counted as correct if (7) it was a synonym or dialect of the correct name and occurred at least twice in the naming protocols of the respective language (for example in English: *Jaffa's* instead of *mandarins* or *bunny* instead of *rabbit;* in German: *Träuble* instead of *Johannisbeeren* or *Stumpe* instead of *Zigarre*).

The scoring criteria for correct responses used for the aphasic participants differed slightly from those of the healthy controls, as it also included responses with *minor* phonological or semantic errors as correct. In this respect, the scoring system for naming correctness of the widely used German aphasia test battery AAT (Aachener Aphasie Test, 1983) was adopted. Scoring in the AAT defines a response with *phonological paraphasias* as correct if two-thirds of the word are correct, for example if participants say "Bl*au*stift" instead of Bl*ei*stift or "*S*taschen*b*esser" instead of *T*aschen*m*esser (1.48 % of the analysable data); and defines a *semantic paraphasia* as correct if it is closely related to the target's name, for example *Languste* instead of *Krebs*, or *Kaffee*kanne instead of *Tee*kanne (1.74 % of the analysable data).

Scoring of errors

For both control participants and aphasic patients, errors were classified as (1) naming attempts where participants reported that they identified the object but could not retrieve the

name in time, were classified as *lexical access errors* (failure to retrieve the name) (2) naming attempts where the response was incorrect and where the name did not fulfil the criteria mentioned above, were classified as *errors of misnaming the object* (semantic paraphasia) (3) naming attempts were participants reported that they could not identify the object were classified as *failure to identify the picture*.

In addition, for aphasic patients, naming attempts where participants unintentionally repeated names of previous trials or were they produced responses that contained more than one-third of phonological paraphasias where classified as *perseveration/Jargon error*.

Reaction times for naming

Only trials with correct naming responses were included in the reaction times analysis. The software voice-key that was used for recording the participant's responses was programmed to evaluate the voice onset times by intensity measures. To test the reliability of the voice-key measurements, a number of randomly selected participants were chosen to conduct a comparative analysis of the voice onsets gained by the voice-key and those obtained by visual inspection of the waveform displayed using the Adobe Audition 1.5 software. The comparison showed that measurements by the voice-key were not always sensitive enough to discriminate between noise caused by breathing or speech muscle movements, such as mouth opening or tongue movements, and a real onset of an utterance. In those cases, the intensity thresholds to detect the beginning of an utterance were too low. In contrast, intensity thresholds to detect onsets of soft consonants like *h*, *g*, *m* or *n* were often too high and words starting with such consonants were detected too late. The voice onset detection by the voice-key also varied in some cases according to the articulation and/or frequency of the participant's voice (male or female, high or deep voice). Lowering or increasing intensity thresholds to distinguish breathing from the onset of an utterance *and* to capture the correct

onset of soft consonants, worked for the voices/articulation of some participants, but not for others. All naming onsets were therefore determined individually using sound waveforms displayed by the Adobe Audition 1.5 software in combination with the sound. This method ensured a highly precise measurement of each voice onset within a frame of 5 ms.

Seven aphasic patients presented with an additional apraxia of speech. They were included in the study because apraxia of speech is a deficit that is often associated with aphasia. Patients with such motor speech disorders often needed more than one attempt to articulate the full name. Voice onsets of those patients were counted with the start of the *first syllable* of the correct utterance. For example the onset of the first syllable "*Ba*" of the response *Ba-na-tabane* (German: Banane) was counted as correct and taken as start of the correct name.

Mean reaction times were calculated for each subject and picture condition as a *subject-based analysis* (*F*1), and for each object and picture condition as *item-based analysis* (*F*2). Naming latencies more than 2.5 standard deviations from the mean of the participant or object respectively were classified as outliers and excluded.

3.3.2.2: Results

Reaction times for healthy participants.

Data were analysed using a repeated measures ANOVA with Picture design (six levels) as a within-subjects Factor, and Language (German vs. English) as the between-subjects Factor. Greenhouse-Geisser correction was used when data violated the assumption of sphericity. Treatment means were compared using *LSD* (*Least Significant Difference*) Tests.

Analyses revealed that there was no effect of Language ($F(1,68) = 1.78$; $p = 0.186$) indicating that there was no difference between the 60 English- and 10 German-speaking participants. The two groups were therefore pooled to provide a control group for the aphasic participants.

One-way repeated measures ANOVAs on subject-based ($F1$) and item-based reaction times ($F2$) were conducted for healthy participants, results are presented in graphs in figures 17 a ($F1$) and 17 b ($F2$) on page 117. Results showed that the main effect for Picture design was highly significant ($F1(4.0, 280.6) = 15.64$; $p<0.0001$; $F2(4.3, 594.5) = 18.82$; $p<0.0001$).

For the chromatic object and the *plain* background differences were as follows: (+69ms ($F1(1,69) = 31.70$; $p<0.0001$; +91ms ($F2(1,137) = 49.28$; $p<0.0001$)) with the grey object and the coloured plain background, and (+81ms ($F1(1,69,) =30.80$; $p<0.0001$); +91ms ($F2(1,137) = 41.11$; $p<0.0001$)) with the grey object and the grey plain background, and (+42ms ($F1(1,69) =14.47$; $p<0.0001$); +51ms ($F2(1,137) = 13.22$; $p<0.001$)) with the chromatic object and the coloured noise, and (+119ms ($F1(1,69) = 51.71$; $p<0.0001$); +128ms ($F2(1,137) = 79.39$; $p<0.0001$)) with the grey object and the coloured noise, and (+78ms ($F1(1,69) = 35.44$; $p<0.0001$); +92ms ($F2(1,137) = 36.97$; $p<0.0001$)) with the grey object and the grey noise.

Differences for the chromatic object and the coloured *noise* background were (+26ms ($F1(1,69) = 4.11$; $p<0.046$)); +40ms ($F2(1,137) = 7.36$; $p<0.008$)) with the grey object and the coloured plain background, and (+38ms ($F1(1.69) = 8.11$; $p<0.006$)); +39ms ($F2(1,138) = 5.33$; $p<0.022$)) with the grey object and grey plain background, and (+76ms ($F1(1,69) = 23.55$; $p<0.0001$)); +77ms ($F2(1,137) =22.20$; $p<0.0001$)) with the grey object and the coloured noise, and (+35ms ($F1(1,69) = 7.31$; $p<0.009$); +40ms ($F2(1,137) = 8.96$; $p<0.003$)) with the grey object and the grey noise (see figures 17 a and 17 b on page 117).

These results show that the achromatic object was named significantly slower in all its conditions and this effect was even found for the picture design where the coloured object had to be segmented from a coloured noise background. It was named significantly faster than the easy to segment picture versions where the object is grey and the backgrounds are plain. This striking finding suggests that the influence of *object colour knowledge* at the conceptual level has a stronger effect on naming latencies than the influence of *perceptual colour* at the structural level of object descriptions, i.e. the advantage of an object possessing the attribute of colour outweighed the difficulty of segmenting the object from a noisy background. The slowest named picture versions among the plain and noise background conditions were the pictures that contained a combination of a *grey* object and a *coloured* background. If colour only facilitates segmentation during naming than these two picture versions should have been the fastest because the enhanced colour contrast of the border between the grey object and the coloured background should have speeded up the segmentation process. However, the incongruity between object and background colour may have caused interference with object colour knowledge and provides further evidence that object colour knowledge can have a stronger effect than any segmentation benefit.

There was a significant difference between the *noise* and the *plain* background condition when the object was in colour of (+42ms ($F1(1,69) = 14.47$; $p<0.0001$); +51ms ($F2(1,137) = 13.22$; $p<0.001$)) which can be interpreted as the additional cost to *segment* a coloured object from coloured noise. Surprisingly, no such segmentation costs were found when objects and backgrounds were both in grey (-3ms ($F1(1,69,) = 0.68$; $p<0.795$) and +1ms ($F2(1,137) = 0.05$; $p<0.945$)).

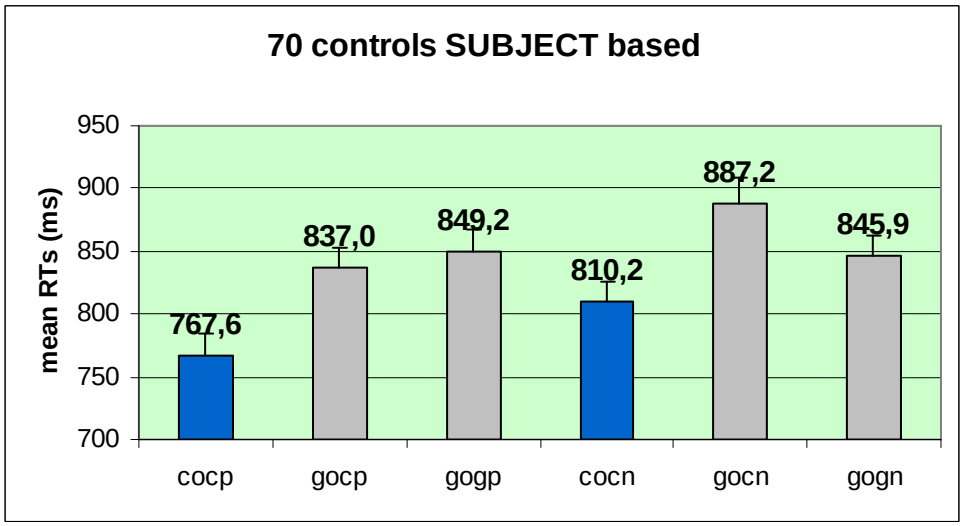


Figure 17 a. Experiment 1. Mean naming reaction times in ms for the control group in the immediate naming task, results are shown a) subject based and b) item based. The two picture conditions that are presenting the object in colour are shown as dark columns (**cocp** and **cocn)**. Legend: **c** = coloured, **g** = grey-scaled, **o** = object, **n** = noise background, **p** = plain background. **cocp** = coloured object in front of a plain background; **gocp** = grey-scaled object in front of a plain background; **gogp** = grey-scaled object in front of a grey-scaled plain background; **cocn** = coloured object in front of a coloured fractal noise; **gocn** = grey-scaled object in front of a coloured fractal noise; **gogn** = grey-scaled object in front of a grey-scaled fractal noise.

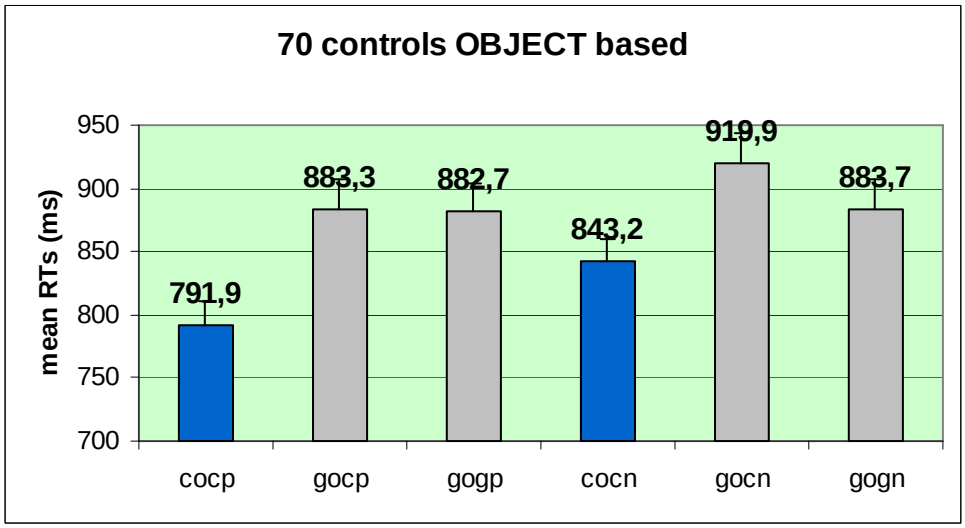


Figure 17 b. Experiment 1. Mean naming reaction times in ms for the control group in the immediate naming task, results are shown a) subject based and b) item based. The two picture conditions that are presenting the object in colour are shown as dark columns (**cocp** and **cocn)**. Legend: **c** = coloured, **g** = grey-scaled, **o** = object, **n** = noise background, **p** = plain background. **cocp** = coloured object in front of a plain background; **gocp** = grey-scaled object in front of a plain background; **gogp** = grey-scaled object in front of a grey-scaled plain background; **cocn** = coloured object in front of a coloured fractal noise; **gocn** = grey-scaled object in front of a coloured fractal noise; **gogn** = grey-scaled object in front of a grey-scaled fractal noise.

Reaction times aphasic subjects

For aphasic participants, there were again significant differences among the six Picture designs ($F1(3.2,91.5) = 6.47$; $p<0.0001$) and ($F2(5,585) = 5.72$; $p<0.0001$). Pairwise comparisons again showed an effect for *Object colour* in a noise background. Naming was faster for a picture of a coloured object in a coloured noise background than an achromatic object in colour or grey noise (-175ms ($F1(1,28) = 32.57$; $p<0.0001$); -147ms ($F2(1,117) = 11.63$; $p<0.001$)), and (-115ms ($F1(1,28) = 7.66$; $p<0.10$); -112ms ($F2(1,117) = 7.16$; $p<0.009$)), respectively (see figures 18 a, b). However, the effect for Object colour was less pronounced in the plain background conditions. Coloured objects, presented against a coloured plain background, were named faster than their achromatic counterparts, presented against a grey background but this was only significant for the subjects-based analysis (-82ms ($F1(1,28) = 4.76$; $p<0.038$)) (see figures 18 a and b on page 119).

Unlike the control group, aphasic patients showed little evidence of slower responses to images presented against a noise, compared with a plain, background. Such a segmentation cost was only apparent in the item-based analysis when objects and backgrounds were grey (+85ms ($F2(1,117) = 4.94$; $p<0.028$)) but not in the subject-based analysis (+39ms ($F1(1,28) = 1.65$; $p<0.209$)) or when the object was in colour: (+5ms ($F1(1,28) = 0.31$; $p<0.862$); +29ms ($F2(1,117) = 0.406$; $p<0.525$)). These findings differ from those found in the control group, where segmentation costs were only evident for responses to coloured objects presented against coloured noise, but not for the equivalent achromatic picture.

As with healthy participants, the slowest named picture version in the subject- and item-based analysis was the grey object in front of a coloured noise. The incongruence between object and background colour increased naming latencies significantly compared with when the object and the noise background were both in colour: (+175ms ($F1(1,28) = 32.57$; $p<0.0001$);

+147ms ($F2(1,117) = 11.63$; $p<0.001$)) indicating again that the interference with object colour knowledge has a stronger effect than the segmentation benefit.

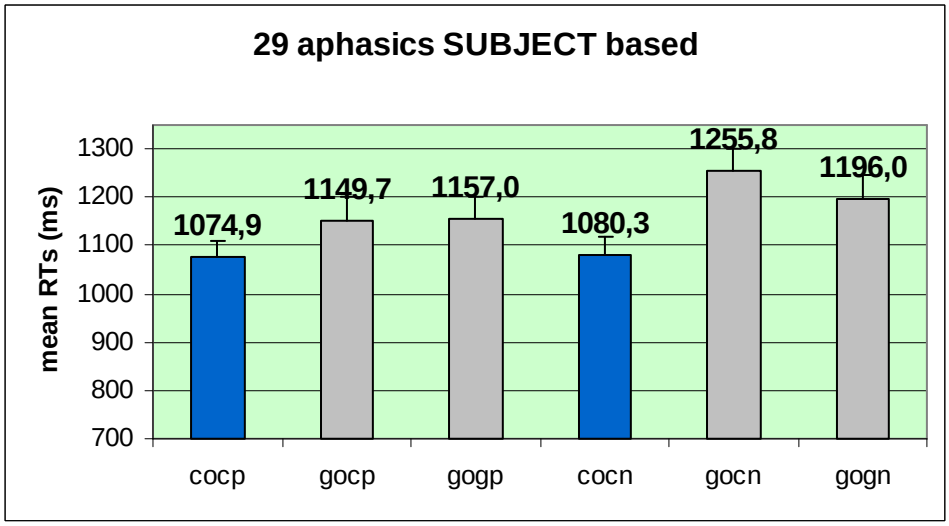


Figure 18 a. Experiment 1. Mean naming reaction times in ms for the aphasic group in the immediate naming task subject based. The two picture conditions that are presenting the object in colour are presented as dark columns (**cocp** and **cocn)**. Legend: **c** = coloured, **g** = grey-scaled, **o** = object, **n** = noise background, **p** = plain background. **cocp** = coloured object in front of a plain background; **gocp** = grey-scaled object in front of a plain background; **gogp** = grey-scaled object in front of a grey-scaled plain background; **cocn** = coloured object in front of a coloured fractal noise; **gocn** = grey-scaled object in front of a coloured fractal noise; **gogn** = grey-scaled object in front of a grey-scaled fractal noise.

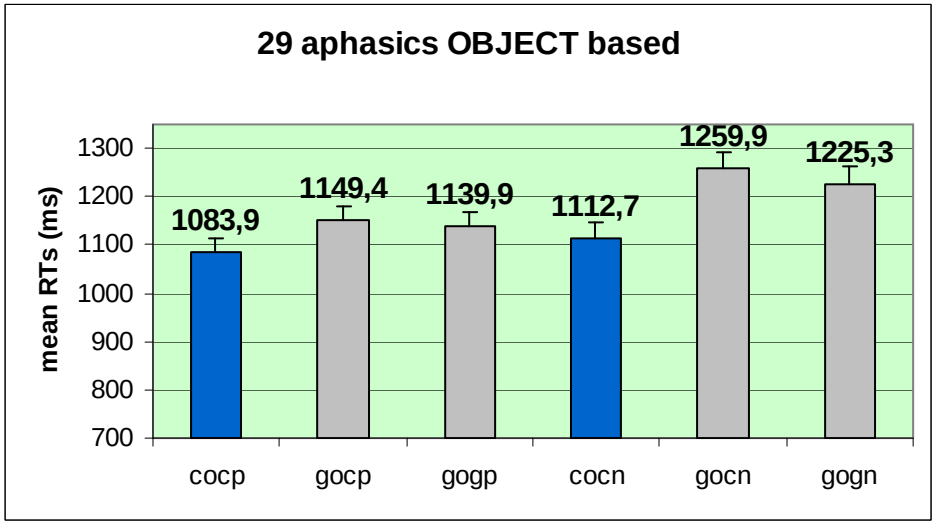


Figure 18 b. Experiment 1. Mean naming reaction times in ms for the aphasic group in the immediate naming task item based. The two picture conditions that are presenting the object in colour are presented as dark columns (**cocp** and **cocn)**. Legend: **c** = coloured, **g** = grey-scaled, **o** = object, **n** = noise background, **p** = plain background. **cocp** = coloured object in front of a plain background; **gocp** = grey-scaled object in front of a plain background; **gogp** = grey-scaled object in front of a grey-scaled plain background; **cocn** = coloured object in front of a coloured fractal noise; **gocn** = grey-scaled object in front of a coloured fractal noise; **gogn** = grey-scaled object in front of a grey-scaled fractal noise.

An overall ANOVA was conducted using Picture design (six levels) as a within-subjects Factor, and Group (Control, Aphasic) as the between-subjects Factor. The control group in this group comparison (Control vs. Aphasic) included 10 German-speaking healthy participants from experiment 1 and 60 English-speaking healthy participants from experiment 2. These two subject groups were combined as control group because the immediate naming tasks of experiment 1 and experiment 2 had the same design and used the same pictures of the 140 common real objects except that the object lists in experiment 2 contained 10 additional images of abstract forms. The naming reaction times analysis and error analysis for those 10 additional abstract forms in experiment 2 were conducted separately from the analysis of the 140 common real objects and were not part of this group analysis. As described on page 115, there was no effect of Group ($F(1,68) = 1.78$; $p = 0.186$) in the group analysis of the 60 English- and 10 German-speaking participants indicating that there was no difference related to Language (English, German) or Age (English mean age 30.5 years, Germans mean age 58.8 years) between the 60 English- and 10 German-speaking participants. In addition, a within group analysis for the 60 English-speaking participants (19-30 years old vs. 31-64 years old) showed no effect related to age (see Figure 32 a on page 161). The 60 healthy English- and 10 healthy German-speaking participants were therefore pooled to provide a control group for the aphasic participants.

Results of the ANOVA showed that there was a highly significant difference between the two groups, with the aphasic subjects being on average 319ms slower in naming the pictures than the healthy participants ($F_{group}(1,97) = 95.01$; $p<0.0001$). The main effect of picture design was significant ($F(4.2,409.6) = 20.87$; $p<0.0001$) and the Picture design x Group interaction approached significance ($F(4.2,409.6) = 2.21$; $p<0.064$) and is likely to arise as a result of aphasic participants depending more on colour than healthy participants, especially in the noise background condition (see figure 19). To examine this further, a further analysis was

carried out using Group (Control, Aphasic), Object colour (colour vs. grey) and Background condition (plain vs. noise) as Factors. Data for the incongruent object-background variations (gocp and gocn) were excluded. Results show a main effect of Object colour where pictures in colour were named on average 78.75ms faster than their grey counterparts ($F(1,97) = 37.13$; $p<0.0001$) (see figure 20 a), and an effect of Background condition with objects embedded in noise backgrounds named on average 21ms slower than in plain backgrounds ($F(1,97) = 6.31$; $p<0.014$) (see figure 20 b). The other interactions (Object colour x Background condition; Object colour x Group and Background condition x Group) were not significant, however, the interaction between Object colour x Background condition x Group approached significance at $p<0.064$, suggesting that aphasic subjects rely more on colour when segmenting an object from a noise background than the healthy controls.

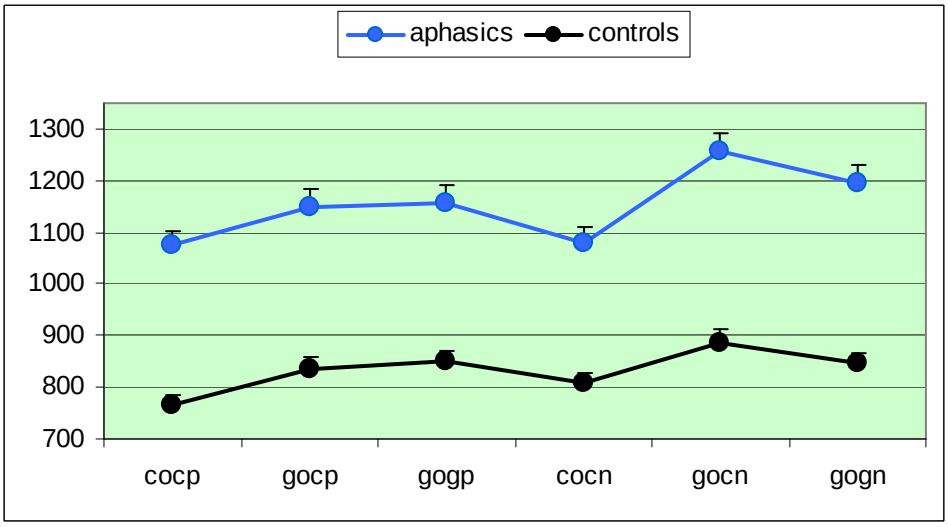


Figure 19. Experiment 1. Mean naming reaction times in ms for the aphasic group and the control group in the immediate naming task. The blue line represents the aphasic group and the black line the control group.

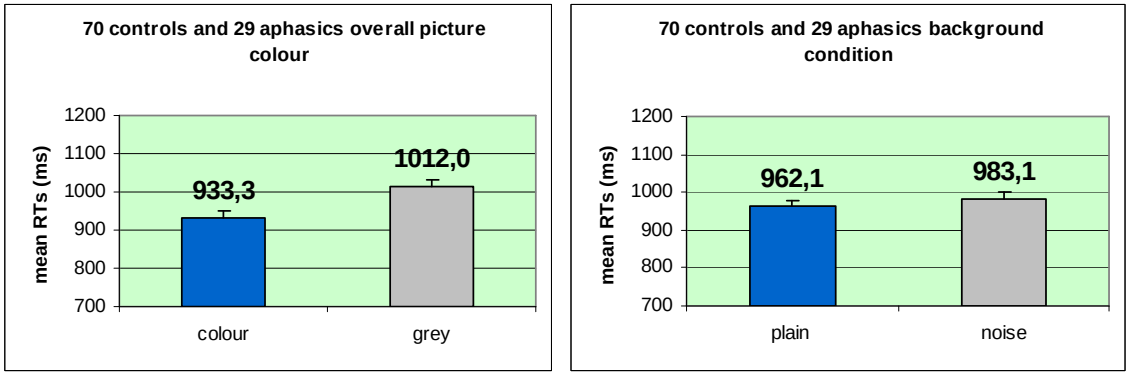


Figure 20 a shows the mean naming reaction times in ms for the aphasic group plus the control group for the comparison of the overall picture colour. The blue column represents the two conditions where the picture presents the object and the background both in colour (cocp and cocn), and the grey column represents the two conditions where the object and the background are both in grey (gogp and gogn). **Figure 20 b** shows the mean naming reaction times in ms for the aphasic group plus the control group for the comparison of the two background conditions: plain (cocp and gogp) versus noise (cocn and gogn).

The role of object category and colour diagnosticity

The majority of the studies examining the influence of colour on object-naming report positive colour effects predominantly in the category of living things and/or when the colour of the object is diagnostic of that object We therefore performed item-based ANOVAs using Picture design (6 conditions) and Category as Factors. First, we contrasted the two categories living (n=72) versus non-living items (n=68), and second, in another analysis, the three main categories fruits & vegetables (n=39), animals (n=28), and manmade objects (n=68). In a further step, results were analysed using Picture design (6 conditions) and Diagnosticity values (2 conditions: high (n= 87) versus low (n= 53)) for each group.

The analysis showed, for both groups, a main effect of Picture design with coloured objects named more quickly than grey ones ($F_{controls}(4.3, 589.4) = 18.73$; $p<0.0001$); ($F_{aphasics}(5, 580) = 5.72$; $p<0.0001$). This effect was significant in the plain *and* noise conditions for the controls and in the noise conditions for the aphasics. There was a main effect of Category but this was only significant for the control group ($F_{controls}(1,136) = 4.84$; $p<0.029$; $F_{aphasics}(1,116) = 2.5$; $p<0.110$). For the control group, living things were named more slowly across all

picture designs compared with non-living things (+ 85ms, $F_{controls}(1, 136) = 4.86$; $p<0.029$) (see figure 21 a). This difference was not apparent for the aphasic patients (+61ms, $F_{aphasics}(1,116) = 2.59$; $p<0.110$) (see figure 21 b). There was no interaction between Picture design x Category in either Group ($F_{controls}(4.3, 589.4) = 1.18$; $p<0.319$) and ($F_{aphasics}(5,580) = 0.35$; $p<0.885$) indicating that the effects for colour do not differ between these two categories.

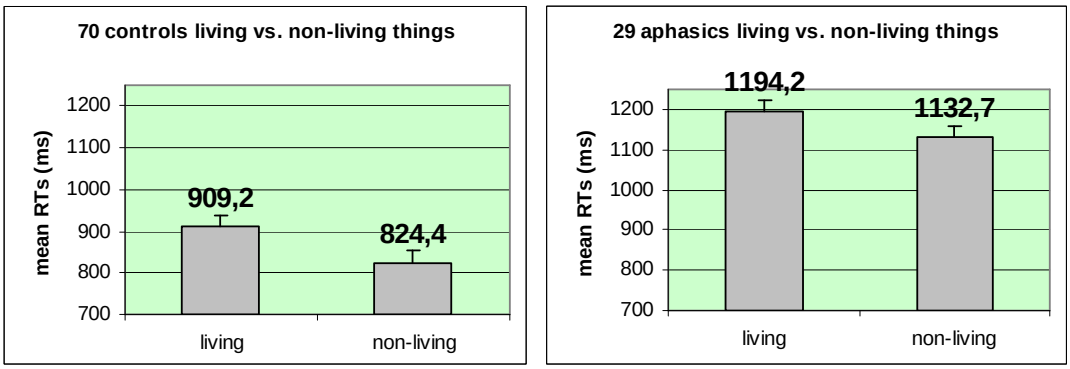
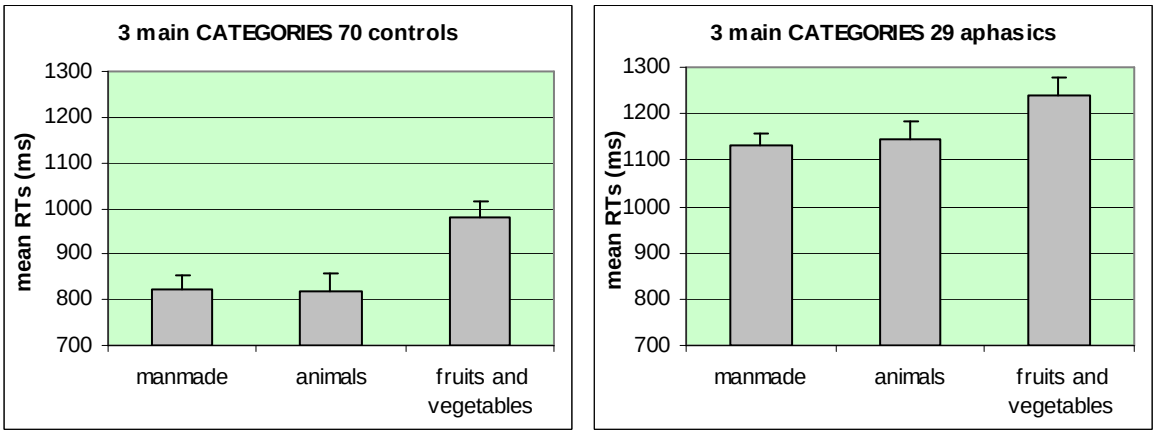


Figure 21 a shows the mean naming reaction times in ms for living versus non-living things for the control group, and figure **21 b** for the group of aphasics.

The analysis with the three main categories fruits & vegetables, animals, and manmade objects showed, for both groups, a main effect of Picture design with coloured objects named more quickly than grey ($F_{controls}(4.3, 565.5) = 17.24$; $p<0.0001$; $F_{aphasics}(4.6, 507.7) = 5.51$; $p<0.0001$). There was a main effect of Category but this was only significant for the control group ($F_{controls}(2,130) = 6.70$; $p<0.002$; $F_{aphasics}(2,110) = 2.4$; $p<0.088$).

The interaction between Picture design x Category was not significant in the group of aphasics ($F_{aphasics}(9.2, 507.7) = 1.21$; $p<0.285$) (see figure 22 b) but showed a significant effect in the control group ($F_{controls}(8.7, 565.6) = 2.62$; $p<0.04$), with fruits & vegetables and manmade objects benefiting the most from object colour (see figure 22 a). A pairwise comparison showed that fruits & vegetables are named significantly more slowly than both manmade objects (+153ms, $F_{controls,}$ $p<0.001$; +105ms, $F_{aphasics,}$ $p<0.031$)) and animals

(+162ms ($F_{controls}$, p<0.04); +94 ($F_{aphasics}$, p<0.105)). The latter result in the aphasic group did not reach significance probably because of lower item number in the statistical analysis as aphasics named fewer items in the category of fruits & vegetables correctly. No significant differences in naming latencies were found between the category of animals and manmade objects: (-8ms ($F_{controls}$, p<0.869); +11ms ($F_{aphasics}$, p<0.825)) (see figures 22 a, b).



Figures 22 a, b show the mean naming reaction times in ms for each subject group and the three main categories fruits & vegetables, animals, and manmade objects.

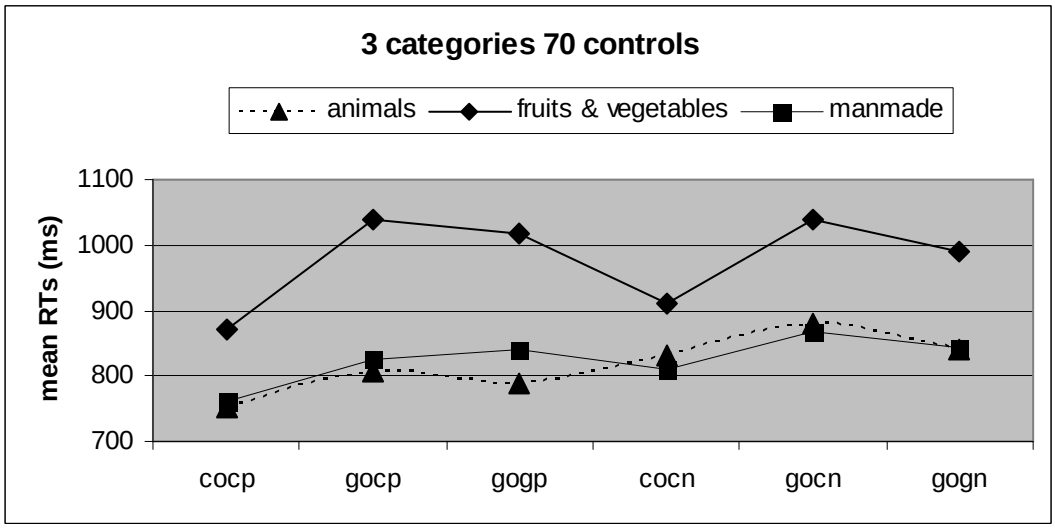


Figure 23 shows the mean naming reaction times in ms for the control group and the three main categories fruits & vegetables, animals, and manmade objects.

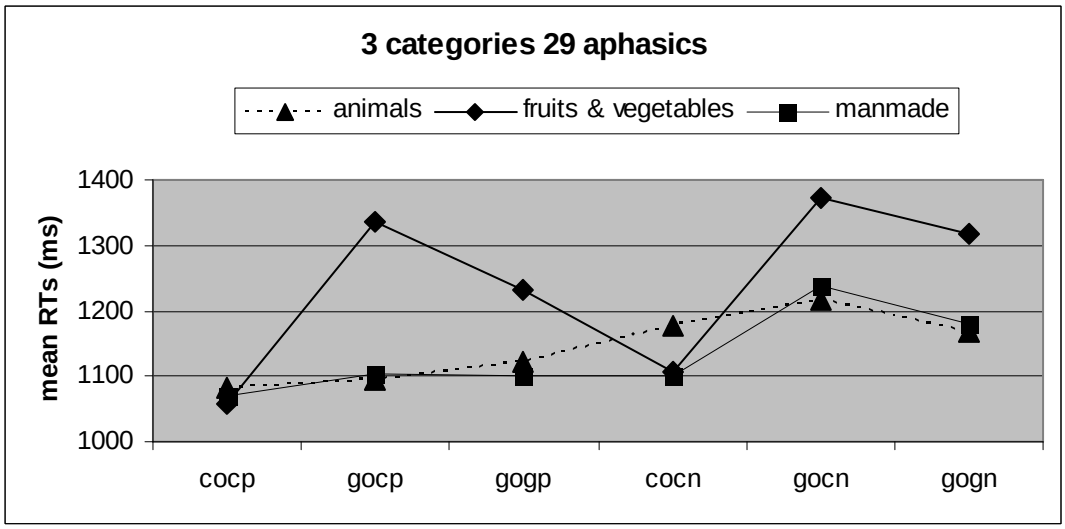
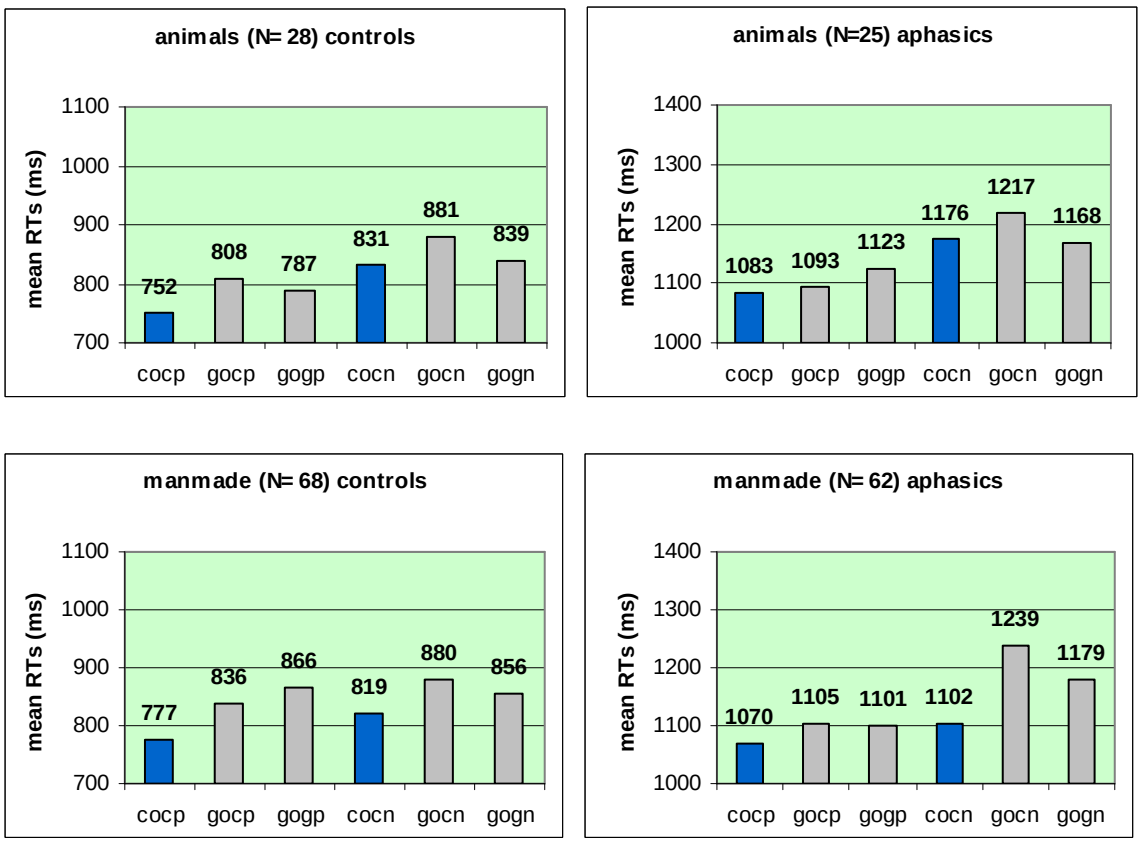
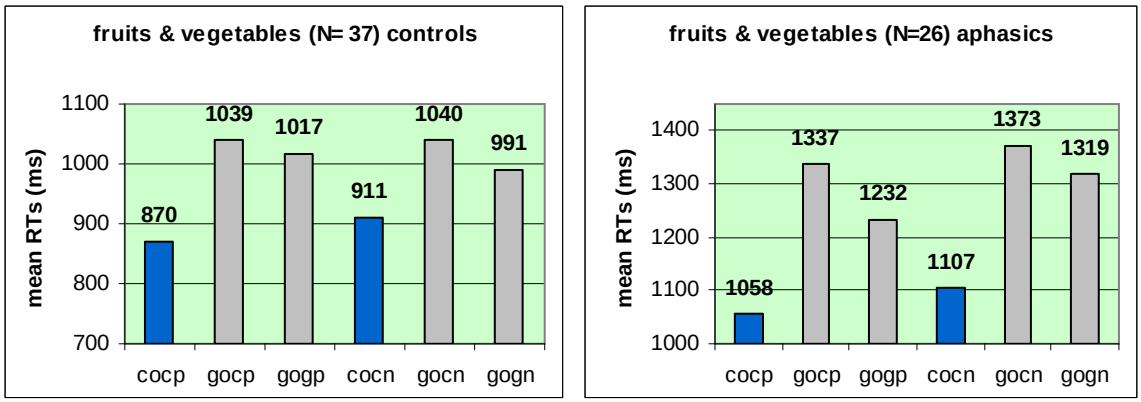


Figure 24 shows the mean naming reaction times in ms for the aphasic subject group and the three main categories fruits & vegetables, animals, and manmade objects.



Figures 25 a-f show the mean naming reaction times in ms for each subject group and the three main categories fruits & vegetables (n= 39), animals (n= 28), and man made objects (n=68) separately per picture design. The dark columns represent the picture versions where the object is presented in colour. The number in brackets in the headline of each graph represent the number of category members named correctly in all of the six picture conditions.

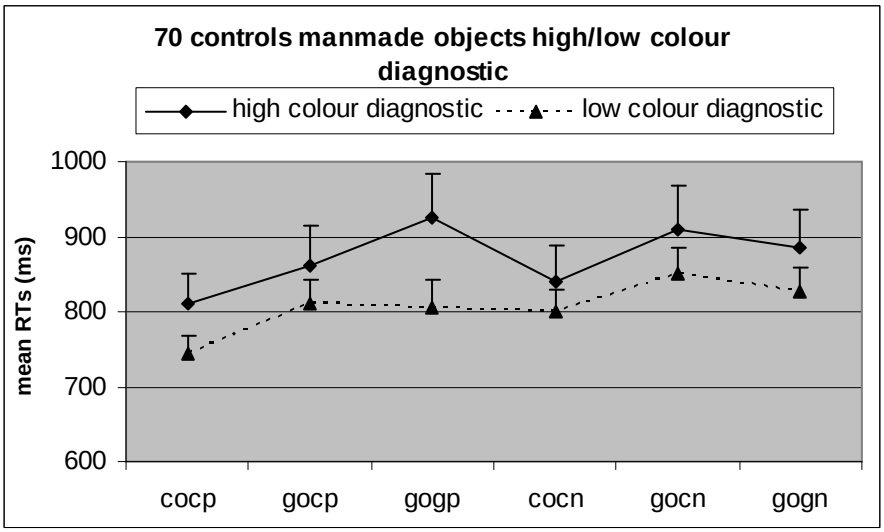


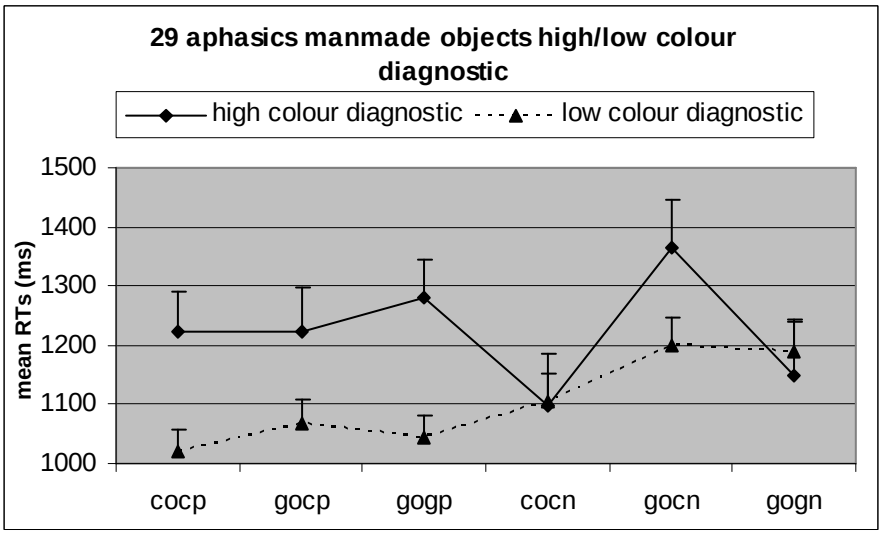
Figures 25 a-f show the mean naming reaction times in ms for each subject group and the three main categories fruits & vegetables (n= 39), animals (n= 28), and man made objects (n=68) separately per picture design. The dark columns represent the picture versions where the object is presented in colour. The number in brackets in the headline of each graph represent the number of category members named correctly in all of the six picture conditions.

To answer the question whether colour effects on naming only occur for high colour diagnostic objects, results were analysed over Picture design (6 conditions) and Colour diagnosticity values (high vs. low) for each group. There was again a main effect for Picture design, for both groups, with coloured objects named more quickly than grey ones in the plain *and* noise background conditions for the control group ($F_{controls}(4.3, 593.5) = 16.44$; $p<0.0001$), and in the noise conditions for the group of aphasics ($F_{aphasics}(5, 580) = 5.62$; $p<0.0001$). The effect for Diagnosticity was also significant, for both groups, showing that high colour diagnostic objects are named more slowly than low colour diagnostic ones (+114ms, $F_{controls}(1,136) = 8.58$; $p<0.004$); (+99ms, $F_{aphasics}(1,116) = 6.85$; $p<0.010$) which corresponds with the longer naming latencies found particularly for the category of fruits & vegetables, which made up the largest number of the high colour diagnostic objects. The interaction *Colour diagnosticity* x *Picture design* was not significant for both groups ($F_{controls}(4.3,593.5) = 1.40$; $p<0.228$); ($F_{aphasics}(5,580) = 1.11$; $p<0.355$).

The occasion where one can look at the effects of diagnosticity is in the manmade category, because the vast majority of objects in the other categories have high colour diagnostic values. The separate analysis of the manmade category where 19 objects had high (e.g., fire

engine, life vest) and 49 low colour diagnostic values (e.g., toothbrush, socks), showed a significant main effect for Picture design with coloured objects named more quickly than grey ones in the control group ($F_{controls}(3.9,261.9) = 6.77$; $p<0.0001$). The effect for Picture design was also significant in the group of aphasics ($F_{aphasics}(5,300) = 2.43$; $p<0.035$) but only the picture design with the incongruity between a grey object and a coloured noise background (gocn) differed significantly from other picture designs. There was an effect of Diagnosticity showing that high colour diagnostic manmade objects are named more slowly than low colour diagnostic ones and this effect was significant for the group of aphasics (+119ms, $F_{aphasics}(1,60) = 5.42$; $p<0.023$) but not for the control group (+66ms, $F_{controls}(1,66) = 1.41$; $p<0.238$). However, the observed differences between high and low colour diagnostic items in the manmade category may be due to other factors such as word frequency as many of the high colour diagnostic manmade objects had low frequency names such as ‘fire extinguisher’ or ‘Santa hat’. There was again no significant Colour diagnosticity x Picture design interaction for both groups in the separate analysis of the category of manmade objects ($F_{controls}(3.9,261.9) = 0.91$; $p<0.455$); ($F_{aphasics}(5,300) = 2.0$; $p<0.079$). The insignificant interactions between *Colour diagnosticity* and *Picture design* in the separate analysis of the category of manmade objects and in the overall item analysis suggest that in our set, colour effects on naming did not dependent directly on colour diagnosticity values (see figures 26 a, b).





Figures 26 a, b show the mean naming reaction times in ms for the category of manmade objects divided into high and low colour diagnostic objects and per picture design for each subject group separately.

In conclusion, the group analysis of healthy and aphasic subjects showed a strong *effect for object colour* with coloured objects named significantly faster, with on average of -78.75ms, than their grey counterparts. This effect was independent of whether objects were easy to segment from a plain background or had to be segmented from a noise. These findings suggest that the advantage of an object possessing the attribute of colour outweighed the difficulty of segmenting the object from a noisy background. There was a positive trend in the Picture design x Background x Group analysis showing that aphasic subjects demonstrate a stronger effect for object colour in the *noise* background conditions. This indicates that

aphasic subjects may depend more on colour information when naming on object embedded in a noisy background than healthy controls. There was also an effect of object segmentation (Background condition) in the group analysis as it took participants on average 21ms longer to name an object that had to be segmented from a noise background than from a plain background. In the separate analysis of the aphasic subject group, these segmentation costs were higher for the grey picture conditions than for the coloured ones, but this was the reverse in the analysis for the healthy control group. Pictures with an incongruity between object and background colour (gocp, gocn) elicited the slowest reaction times in both subject groups despite having a segmentation benefit due to enhanced colour contrast at the borders between object and background. This effect was even stronger in the aphasic subject group. These findings suggest that the interference of *object colour knowledge* has a stronger effect on naming latencies than any *segmentation advantage by colour*.

Further analysis showed that the effect of object colour was unrelated to category effects when contrasting living with non-living items in both subject groups. Living things were named significantly slower than non-living things. However, when contrasting the three main categories fruits & vegetables, animals, and manmade objects, there was an effect for object colour (Object colour x Category interaction) in the healthy subject group. The two categories fruits & vegetables and manmade objects benefited more from colour than the category of animals (see figures 25 a-f). In both subject groups, fruits & vegetables were named the slowest while animals and manmade objects were named equally fast. The analysis of object colour diagnosticity showed that high colour diagnostic objects were named slower than low colour diagnostic ones but *colour diagnosticity* values were not directly related to the observed colour effects on naming in our set.

The cross-linguistic comparison for the healthy control group showed that the observed colour effects were independent of whether objects were named in English or German. This shows that the reported colour effects are robust, as they appeared little affected by differences in language, including factors such as word-length, naming agreement, and cultural differences.

Accuracy

To establish whether object colour influences *picture identification*, *lexical access* or *misnaming the object*, accuracy data were analysed as follows. First, responses were screened for correct naming and error types. The control group performed at close to ceiling with 94.94% correct naming and with error rates below 0.2% in each error category. The most frequent, of the albeit small number, of errors were failures to identify the picture (1.89% of all responses). Because of the low error rates, no further analyses were carried out.

The accuracy rate was lower in the group of aphasic participants, as they produced more errors as a result of anomia, with 78.24% correct naming. Data were transformed into proportion of errors because the number of analysable stimuli was not equal across the three error types. The data were then analysed with a Repeated Measures ANOVA. Follow-up ANOVAs were conducted to measure pairwise Picture condition differences in the Error type conditions. Further analyses were carried out to examine the relationships between Error type and Colour diagnosticity, and Error type and Category.

Accuracy results for the aphasic subject group

The two-factor ANOVA was carried out using Picture design and Error type as Factors. There was a main effect of Error type ($F(1.7, 341.7) = 61.31$; $p < 0.0001$) with the most prevalent error being that of failures of lexical access (55.9% of all errors) and errors of misnaming the object (26.7% of all errors). Picture identification errors were 10.1% of all errors. The effect

of Picture design was significant ($F(4.5, 609.7) = 3.34$; $p < 0.010$) as was its interaction with Error type ($F(9.3,1246.2) = 2.36$; $p < 0.012$). The analyses of *identification errors* showed a highly significant effect of Picture design ($F(5,670) = 6.02$; $p < 0.001$) as the proportion of identification errors was smaller with the coloured (0.43%) than with the grey objects (3.07%). This was a similar pattern to that observed in the control group (0.62% identification errors of all the responses with coloured objects, and 2.49% identification errors of all the responses with grey objects), although the number of identification errors in the control group was much smaller. The statistical analyses of *errors of lexical access* and *errors of misnaming the object* were inconclusive concerning Picture design. Pictures with grey objects showed little difference in eliciting failures of lexical access or causing misnaming errors when compared with pictures in colour. This was largely a result of the small number of errors in some Picture design. Perseverative errors were not further analysed, as they did not fall into the linguistic classifications of interest.

An ANOVA using Picture design, Error type and Diagnosticity as Factors revealed an effect of Diagnosticity ($F(1,133) = 18.14$; $p<0.001$), Error type ($F(2.5,339.1) = 5.38$; $p < 0.005$), and Picture design ($F(4.5,605.1) = 3.22$; $p < 0.012$). The interactions Error type x Colour diagnosticity ($F(3,399) = 3.51$; $p<0.015$), and Picture design x Error type ($F(15,1995) = 2.04$; $p<0.011$) were also significant. These main effects and their interactions show that pictures with an achromatic object elicit more picture identification errors than when the object is in colour. This was especially true for the category of fruits & vegetables where all category members have high colour diagnostic values.

When contrasting the 19 high-colour diagnostic with the 49 low-colour diagnostic members of the category manmade objects separately, Diagnosticity ($F(1,66) = 4.28$; $p<0.043$) and Error type ($F(3,198) = 42.25$; $p<0.001$) and their interaction Error type x Diagnosticity (F

(3,198) = 2.91; $p<0.036$) were significant. Interactions with Picture type failed to reach significance (Picture design x Error type ($F(15,990) = 1.56$; $p<0.077$; Picture design x Error type x Diagnosticity ($F(15,990) = 0.95$; $p<0.507$). The most prevalent error types were again those of failures of lexical access (62.22% of all errors) and errors of misnaming the object (24.44% of all errors). Only a very few errors were made with picture identification in this category (4.44% of all errors). High-colour diagnostic objects caused more errors than low-colour diagnostic ones particularly in the Error type lexical access errors. This effect might have been caused by word frequency rather than by the colour diagnosticity of the object as some of the high-colour diagnostic objects had low frequent names (e.g. Swiss army knife, fire extinguisher, no entry sign). Low frequent words are known to cause more lexical access errors (Vitkovitch & Humphreys, 1991; Montanes et al., 1995).

To analyse the effects of object category an ANOVA using Category, Error type and Picture design was carried out. Picture design ($F(5,320) = 2.35$; $p<0.041$), Category, ($F(2,64) = 3.33$; $p<0.042$) and Error type ($F(3,192) = 27.24$; $p<0.001$) were significant. The interaction Picture design x Error type ($F(15,960) = 2.39$; $p<0.002$) was also significant. Other interactions failed to reach significance. These results show that lexical access errors and errors of misnaming were again the most prevalent errors followed by picture identification errors. Most errors were made in the category of fruits & vegetables across all Error types and there were more errors in *misnaming the object* but fewer *identification errors* when fruits & vegetables were in colour.

In conclusion, the most prevalent errors of the albeit small number of errors made in the control group were *failures to identify the picture* with much smaller error proportions when the object was in colour than when it was in grey. However, as participants in the control group performed at close to ceiling, no further analyses were carried out. The analysis of the

aphasic subject group showed that subjects made the most errors with *failures of lexical access* and *misnaming the object* as a result of their anomia. A further analysis showed that there was a *category effect* with most errors made in the category of fruits & vegetables across all Error types. There was also an *effect of colour diagnosticity* and *object colour* and interactions with Error Type showing that grey objects caused more picture identification errors than coloured ones. This was especially true for the category of fruits & vegetables where all category members have high colour diagnostic values. In the category of manmade objects, more errors were made with high than low-colour diagnostic objects particularly in the Error type lexical access errors. However, this effect might have been caused by word frequency rather than by colour diagnosticity. No effects for Picture design (= colour) were found for lexical access errors and errors of misnaming the object, which was probably because of the small number of errors in some Picture design.

3.3.3: Repeated naming task - priming

3.3.3.1: Analysis

Twenty-four of the 29 aphasic patients participated in both parts of the experiment and were included in the analysis of the priming task. The ten healthy German-speaking participants who were part of the control group in the immediate naming task were used as the control group. Repetition priming was measured by a between-item calculation where *first* minus *second* latency of repeated (*old*) items are compared (i.e. comparing naming measures in the test phase with naming measures in the study phase for pictures that were repeated in the test phase). This method is more precise than the between-item calculation used in some other studies where naming latencies of repeated *old* stimuli presented in the test phase are compared with latencies of *new* stimuli presented in the test phase. Test adaptation was

measured by comparing mean RTs of all correctly named items of day one (study) with mean RTs of all correctly named *new* items of day twelve (test). Only trials were included where pictures were named correctly on both occasions. Naming latencies with more than 2.5 standard deviations from the mean of the participant or the item were classified as outliers and excluded. Mean reaction times were calculated for each subject and picture condition as a *subject-based analysis* ($F1$), and for each object and picture condition as *item- based analysis* ($F2$).

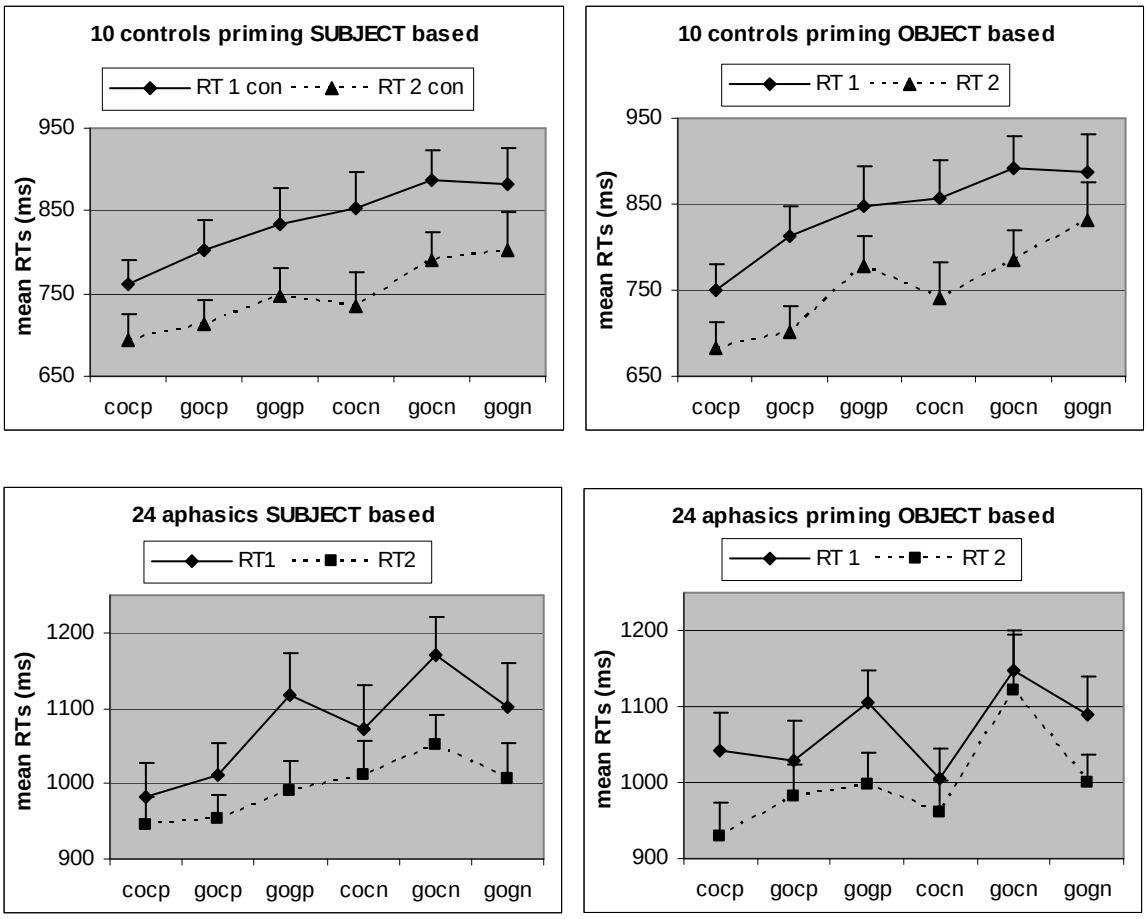
3.3.3.2: Results

Priming in German controls and aphasic subjects

A repeated measures ANOVA was conducted using Group (Aphasics, Controls) and Time (RT1 and RT2), and Picture design (6 conditions) as Factors. Results revealed a strong effect for Time ($F_{group}(1,32) = 18.74$; $p<0.0001$) with on average 86.17ms faster naming latencies for pictures that were repeated from study to test (*priming*). There was no difference in the priming times between the two Groups: Time x Group interaction ($F_{group}(1,32) = 0.26$; $p<0.872$), and Picture design x Time x Group interaction ($F_{group}(5,160) = 0.48$; $p<0.793$) showing that aphasic subjects had the same priming potential for the correctly named pictures as the healthy controls. There was no Picture design x Time interaction ($F_{group}(5,160) = 0.55$; $p<0.734$) indicating that colour did not affect priming times (see figures 28 and 29)

Subject and item-based ANOVAs using Picture design and Time as Factors confirmed that for each Group there was a strong priming effect for the repeatedly named pictures (-89.39ms, $F1_{controls}(1,9) = 12.95$; $p<0.006$); -88.15ms $F2_{controls}(1.0,53.0) = 24.29$; $p<0.0001$, and -82.95ms, $F1_{aphasics}(1,23) = 12.56$; $p<0.002$); -71.98 ms $F2_{aphasics}(1,44) = 11.71$; $p<0.001$).

There was no Picture design x Time interaction ($F1_{controls}(5,45) = 0.53$; $p<0.747$); $F2_{controls}(5,265) = 0.46$; $p<0.802$, and $F1_{aphasics}(5,115) = 1.09$; $p<0.365$); $F2_{aphasics}(5,220) =0.53$; $p<0.749$) indicating again that colour did not affect priming times (see figures 27 a-d).



Figures 27 a-d show the mean naming reaction times in ms for each subject group subject based and object based, the straight line represents the mean naming reaction times for the immediate naming at day 1 (RT 1), the dotted line represents the mean naming reaction times for the repeated naming at day 12 (RT 2).

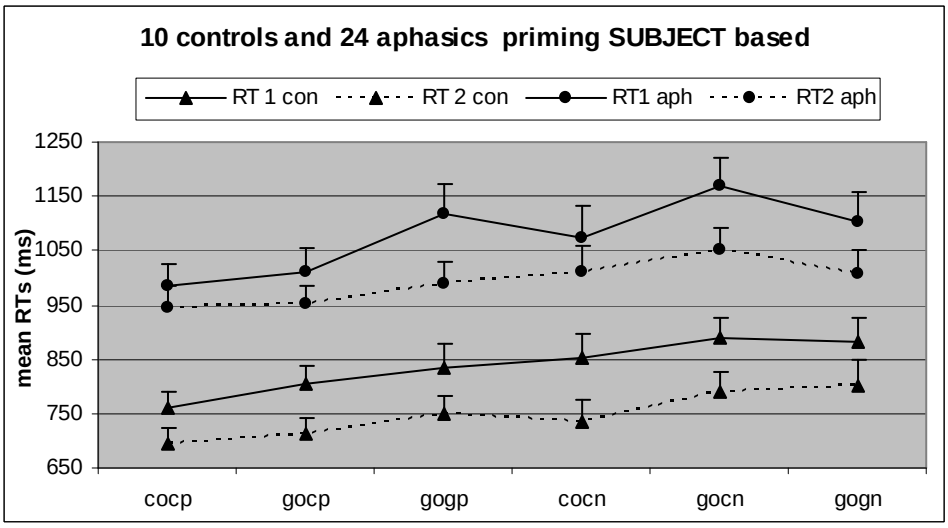


Figure 28 shows the mean naming reaction times in ms for both subject groups subject based, the straight line represents the mean naming reaction times for the immediate naming at day 1 (RT 1), the dotted line represents the mean naming reaction times for the repeated naming at day 12 (RT 2).

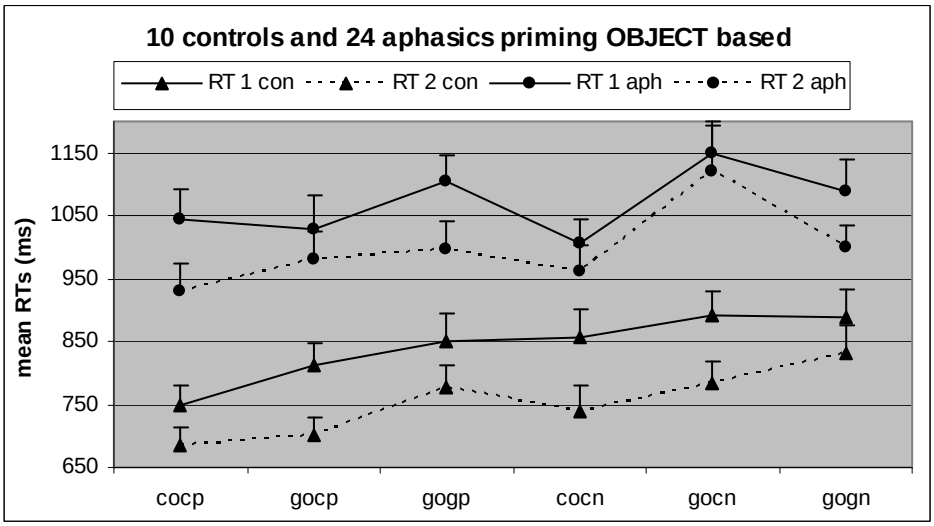


Figure 29 shows the mean naming reaction times in ms for both subject groups object based, the straight line represents the mean naming reaction times for the immediate naming at day 1 (RT 1), the dotted line represents the mean naming reaction times for the repeated naming at day 12 (RT 2).

The role of colour, object category, and colour diagnosticity in priming

To measure how colour affects priming times and whether these effects are influenced by object category or by colour diagnosticity, separate item-based ANOVAs were carried out for each group with (1) the two Times (RT1 and RT2), six Picture designs, and the three Categories as Factors, and (2) Time, Picture design and Colour diagnosticity (high versus low) as Factors. There was no effect for Category ($F_{controls}(8.2,206) = 0.66$; $p<0.761$) and

($F_{aphasics}$ (10,210) = 1.21; p<0.282) or Colour diagnosticity ($F_{controls}$(1,50) = 0.17; p<0.839) and ($F_{aphasics}$ (1,42) = 0.22; p<0.803). No significant interactions were observed in any of these Factors: Picture design x Category interaction ($F_{controls}$(8.2,206) = 0.66; p<0.761) and ($F_{aphasics}$ (10,210) = 1.21; p<0.282); Time x Category interaction ($F_{controls}$(2,50) = 0.44; p<0.645) and ($F_{aphasics}$ (2,42) = 0.11; p<0.890); Picture design x Time x Category interaction ($F_{controls}$(10,250) = 0.85; p<0.583) and ($F_{aphasics}$ (10,210) = 1.59; p<0.110); Picture design x Colour diagnosticity interaction ($F_{controls}$(4.1,216.4) = 0.56; p<0.730) and ($F_{aphasics}$ (5,215) = 0.93; p<0.462); Time x Colour diagnosticity interaction ($F_{controls}$(1,52) = 1.76; p<0.190) and ($F_{aphasics}$ (1,43) = 1.63; p<0.689); and Picture design x Time x Colour diagnosticity interaction ($F_{controls}$(5,260) = 0.57; p<0.718) and ($F_{aphasics}$ (5,215) = 1.49; p<0.194). These results suggest that priming is equally effective regardless of the object category, the picture design or the diagnosticity of the colour of the item when the stimulus remains unchanged between study and test.

To exclude the possibility that the observed priming effects are simply a result of test adaptation, mean RTs of all correctly named items of day one (German controls = 91.71 %, and aphasics = 88.99 % correct) where compared with mean RTs of all correctly named *new* items of day twelve (German controls = 89.28 %, and aphasics = 73.21 % correct). Results show that the new pictures presented at test were named *slower* than the new pictures named at study (Controls -73 ms, and Aphasics -47 ms). *Slower* naming latencies for *new* items at test have been observed in other studies (e.g., Drummery & Newcombe, 1995; Cave et al., 1996; Mitchell, 2006). Possible explanations are that fatigue effects might have caused the slower naming as twice as many items need to be named at test, or that the item selection of the new stimuli at test was more difficult to name, or that the slower naming was caused by a combination of both Factors.

In conclusion, results revealed a strong *priming effect* with, on average 86.17ms, faster naming latencies for pictures that were repeated from study to test with no difference between the two subject groups, showing that aphasic subjects have the same priming potential as the healthy controls. In addition, priming was equally effective regardless of the object category, the picture design or the diagnosticity of the colour of the item. Furthermore, the possibility that these results could have been caused by test adaptation was excluded.

3.4: Discussion experiment 1

The primary goals of experiment 1 were to investigate two related questions: does the surface property colour influence the naming of common objects and does it influence the magnitude of priming effects when such objects are named again after a delay? Research has shown that colour can influence object recognition and naming at different levels of processing including perceptual, conceptual, and lexical levels (e.g., Gegenfurtner & Rieger, 2000; Wichmann et al., 2002; Naor Raz & Tarr, 2003). In order to measure how colour might influence different levels of the naming process, we developed a new sophisticated and naturalistic stimulus set. The stimuli were created to measure colour effects on object segmentation and on the lexical selection process by manipulating object colour (colour vs. grey scaled), background condition (plain vs. noise), and congruency of object and background colour (object and background either in colour or in greyscale vs. object in greyscale and background in colour). The dependent variables were naming reaction times and naming accuracy. Both variables measure different aspects of the naming process (Goodglass et al., 1968). Reaction times provide information about the *processing time* elapsed between the stimulus onset and the successful retrieval (and articulation) of the name. Differences in latency should therefore show which of the stimulus manipulations are speeding up the naming process and which ones are slowing it down. In contrast, accuracy scores measure the *outcome* of the naming

process and should therefore provide information about how the stimulus manipulations contribute to any failure of identification or lexical selection process.

The main findings of experiment 1, evident on participant response times, were clear-cut: (a) object colour reduced latencies on naming pictures of common objects during encoding (study phase) and recall (test phase) in both groups, healthy participants and aphasic subjects with anomia. (b) Theses effects were independent of whether objects were named in English or in German. (c) The colour advantage was observed whether objects were easy to segment from a plain background or had to be segmented from noise. This suggests that the advantage of an object possessing the attribute colour is not limited to the perceptual level of object recognition by simply supporting object segmentation. Instead, the colour advantage seems to extend to the conceptual levels of object representations and thereby speeding up the naming process. (d) Picture designs with incongruence between object and background colour prolonged the naming process, although they possess the highest contrast between object and background colour, which facilitates segmentation. This indicates that the interference of object colour knowledge has a stronger effect on naming latencies than any segmentation advantage of colour. (e) Colour effects were unrelated to colour diagnosticity values and (f) independent of whether objects belonged to the category of living- or non-living things. (g) Object colour did not enhance the magnitude of priming when pictures were renamed after a delay; all stimulus types primed naming in the same way. (h) Priming times did not differ between the two subject groups indicating that aphasic subjects possess the same priming potential as healthy controls.

Evidence from participant accuracy measures on naming were less conclusive and revealed only a few effects. This was mainly because of the small number of errors made per condition, especially in the group of the healthy controls, who performed at close to ceiling.

The main findings showed that: (a) colour decreased the failure to identify the picture for the category of fruits & vegetables and this was valid for both subject groups. (b) Aphasic subjects made the most errors with failures of lexical access and misnaming the object as a result of their anomia, and (c) both error types were unrelated to colour.

3.4.1: Colour effects on immediate naming

We found a substantial effect for *object colour* in the group analysis of the immediate naming task when coloured photographs were compared with their achromatic counterparts. Object colour speeded up naming latencies by, on average, 79ms (36ms to 82ms in the separate analysis of the healthy control group, and 56ms to 112ms in the separate analysis of the aphasic subject group). Our findings generalize the results of other studies to a new testing procedure that incorporates more realistic and better-controlled picture stimuli; they show that colour has a beneficial effect on the naming of both living- and non-living objects; as well as on both colour symptomatic and non-symptomatic objects. In addition, colour is beneficial whether pictures present with a high (noisy background) or low segmentation demand (plain background).

How do these results compare with findings of other studies that have measured naming reaction times in respect to colour by using photographic depictions of real objects? Our findings are in line with other studies that have used objects from the category of living things (Ostergaard & Davidoff, 1985, Exp. 1; Wurm et al., 1993, Exp. 2; Humphrey et al., 1994, Exp. 2; Tanaka & Presnell, 1999, Exp. 3), or objects from both categories (Lloyd-Jones & Nakabayashi, 2009) which found faster reaction times for chromatic stimuli. However, they are at odds with studies that failed to find significant effects for colour either for both categories (Reis et al, 2006) or for the category of non-living things (Price & Humphreys, 1989, Exp. 1a; Brodie et al., 1991, Exp. 3; Humphrey et al., 1994, Exp. 1, 2; Tanaka & Presnell, 1999, Exp. 3; Nicholson & Humphrey, 2001, Exp.2). A closer look at these latter

studies shows that they differ in some methodological aspects from that reported here. All but the study by Reis et al. (2006) used multiple exposures of stimuli (between two and eight times) when testing the effects. Price & Humphreys (1989) even trained their subjects with the expected target names prior to the task in order to familiarize subjects with the set. This method was also used by Biederman & Ju (1988) who only found a very small effect for colour for fabricated objects when comparing colour photographs with black-and-white line drawings. Training subjects with the target names prior to the test might have also tapped into measuring memory for the given names, aside from assessing behaviour with respect to colour. There is evidence that multiple exposures to the same stimuli may cause inhibitory or facilitatory priming effects (e.g., Marsolek, 2008) and may encourage participants to develop strategies including perceptual learning skills when dealing with the tasks (e.g., Fine & Jacobs, 2002; Jiang et al., 2007; Chaumon et al., 2008). It is possible that all of these studies evaluated something other than *immediate* naming in respect to colour, as in the present experiments. The use of small number of items per condition (Price & Humphreys, 1989; Brodie et al., 1991; Humphrey et al. Exp.1, 1994; Tanaka & Presnell, 1999; Reis et al, 2006) and/or small number of participants (Brodie et al., 1991; Humphrey et al. Exp.1, 1994; Reis et al, 2006) may have also influenced the results. See Snodgrass & Yudistky (1996, p 524f) for more empirical data on the possible effects of small item size and participant numbers on picture naming. Another reason why studies may have failed to find reliable colour effects is the choice of stimuli. For instance, Brodie et al. (1991) and Biederman & Ju (1988) used a set of stimuli that were not very distinct in their colour. Most of their fabricated objects were grey, black, or metallic and therefore not substantially different when they were presented in their original colour or in a greyscale version. Likewise, in the studies by Price & Humphreys (1989), stimuli were not matched for luminance distributions of the colour and black-and-white images. As a result, these stimuli might have also differed in contrast and not only in colour. It has been shown that differences in luminance and contrast can influence the

perceptual encoding of pictures (e.g., Gegenfurtner & Rieger, 2000; Wichmann et al., 2002; 2006), a failure to match stimuli when assessing colour may therefore bias the results.

Consistent with other studies (e.g., Humpreys et al., 1988; Lloyd-Jones & Humpreys, 1997), we found a category effect in that living things were named much slower than non-living things, and this effect was significant for the control group, but not for the aphasic subjects. However, contrary to other studies (Price & Humphreys, 1989; Humphrey et al., 1994; Chainay & Rosenthal, 1996; Joseph, 1997; Mapelli & Behrmann, 1997; Vernon & Lloyd-Jones, 2003) this category effect was unrelated to colour. When dividing the categories into the three main categories fruits & vegetables, animals, and manmade objects, a category effect for colour emerged. First, fruits & vegetables were named slower than the two other categories, which were named about equally fast and this was true for the control group but not for the aphasic subjects. Second, for the control group, fruits & vegetables and manmade objects benefited more from colour than the category of animals. The aphasic subject group showed similar differences but their effects did not reach statistical significance probably because of lower item number that was named correctly. Slower processing and more reliance on colour for fruits & vegetables in terms of reaction times have been reported in other studies (e.g., Moore & Price, 1999; Rossion & Pourtois, 2004). Third, both subject groups made more errors with fruits & vegetables compared with animals and manmade objects and identification accuracy increased when fruits & vegetables were named in colour. This was similar to findings by Viggiano et al. (2004). Our results for the category of fruits & vegetables are consistent with the view that fruits & vegetables have many structurally similar neighbours and that their shape alone often cannot differentiate them. During the naming process, many perceptually similar objects from the same category become activated which increases the demands on object processing and semantic differentiation. This in turn leads to increased top down activation for selection to take place and prolongs the processing time,

especially when the objects are shown without their colour (e.g., Humphreys et al., 1999; Moore & Price, 1999; Lloyd-Jones & Nettlemill, 2007). This idea may be generalized to all natural objects including the category of animals (e.g., Humphreys et al., 1988; Lloyd-Jones & Humphreys, 1997). Similarly, manmade objects (non-living things) are considered structurally more dissimilar and do not benefit from colour because they can be recognized mainly by their shape. Furthermore, selection of manmade objects is faster because the more discrepant two items are, the easier it is to disambiguate them (Humphreys et al., 1988; McRae et al., 1997). While this fits with the results obtained here for fruits & vegetables, it does not explain why differences were found between fruits & vegetables and animals, similar naming latencies were apparent for animals and manmade objects and why all of the three categories benefited from colour. We found that animals caused the least errors, unlike the category of fruits & vegetables, where the most errors occurred. Wichmann et al. (2002) also found very few errors for animals when subjects identified them in scenes. Furthermore, our naming latencies for animals were much faster than those for fruits & vegetables (- 162ms for the controls, and -94ms for the aphasics), which was also observed by Delorme et al. (2000) during rapid object detection, and overall faster than those reported in most other studies. There are several reasons why our results for animals and manmade objects may have differed from those found in other studies. First, instead of drawings, we used a stimulus set with photographic depictions of real objects that contained colour, luminance, and texture, specularities and shading cues, which provide more depth information and may help coding and parsing of objects into their correct parts (Humphrey et al., 1994; Leder, 1996; Nicholson & Humphrey, 2001; 2003). These cues also provide details about surface properties such as material (e.g., metal, glass, wood, and cloth) or coats (e.g., feather, fur, skin, and carapace) which may have facilitated the differentiation and recognition not only among members of manmade objects (Funt & Cardei, 2000) but within the group of animals. Furthermore, in our set, manmade objects and animals were both selected for being common and easy to name.

The category of manmade objects was composed of mainly items with simple shapes and low visual complexity (e.g., bowl, pen, and socks), and contained only a few multicomponent objects such as a fire extinguisher or a can opener. This was similar to the category of animals, which contained mostly familiar exemplars with simpler shapes (including two common birds, a hen and an owl), and only a few exemplars with higher visual complexity (e.g., deer, elephant, and crab), but excluded insects and less common birds. The latter ones were excluded because it is known that birds and insects elicit much slower naming RTs (by on average plus 200 ms) than most other (common) animals (Davidoff & Ostergaard, 1988; Snodgrass & Yuditsky, 1996). This is because they are less familiar, have lower name agreements and are therefore more difficult to name (Snodgrass & Yuditsky, 1996). That we excluded these species may have resulted in overall faster RTs for the animal category than found in most of the other studies. Most common animals have a brownish colour, which was reflected in our set where 21 of the 28 animals were brown. In contrast, birds and insects appear in many different colours so that shape can be uninformative and more colour memory is needed for identification and naming to take place (Wurm et al, 1993; Tanaka, 2001). This might explain why the colour effects for animals found in our study were smaller than those found by other people who included more birds and groups of insects in their sets (e.g., Rossion & Pourtois, 2004). Taken together, our results show that colour benefited naming in all of the three categories including manmade objects, although the magnitude of the colour effects differed and was strongest for the fruits & vegetables and lowest for the animals. This indicates that the structural similarity or dissimilarity in respect to other objects is not the only defining factor as to whether an object benefits from being rendered in colour.

Our results further show that colour effects on naming latencies were independent of the colour diagnosticity of the object in both subject groups (see Davidoff & Ostergaard, 1988, Exp. 2; Rossion & Pourtois, 2004; Lloyd-Jones & Nakabayashi 2009, for similar

observations). However, our findings are in contrast to an influential study by Tanaka & Presnell (1999) who found colour advantages more effective for objects that are high in colour diagnosticity than for those that are low. In their study, high colour diagnostic objects were named faster and more accurately when shown as coloured photographs compared with their greyscale counterparts, and also verified much faster than low colour diagnostic items when the coloured photographs were blurred. In contrast, low colour diagnostic objects neither benefited from colour during naming when the images were clear, nor during verification when the images were blurred. It was therefore concluded that low colour diagnostic objects rely more on shape because they did not benefit from colour in both tasks. In contrast, high colour diagnostic objects depend on both shape *and* colour, which made them benefit from colour when images are clear and when they are blurred. However, the results in the study by Tanaka & Presnell were not straightforward as some of the conclusions were based on large colour advantages of four out of eleven 'high colour diagnostic' objects and there was considerable variation within the factors category, colour diagnosticity ratings and reaction time with respect to colour. The authors themselves suggested therefore that the colour diagnosticity of an object might rather be a continuum depending on individual memory of colour associations with the object, rather than referring directly to a specific behaviour of the object or a particular object category. Wurm et al. (1993) evaluated naming of food items with respect to colour and found in their colour diagnosticity analysis that the advantage for colour was not dependent on people's explicit knowledge about the colour of the food. They concluded therefore, that the observed colour effects might arise from a sensory level of object recognition rather than from the conceptual level of object colour knowledge. However, this assumption is likely to be incorrect. Research that contrasted correctly and incorrectly coloured objects with their greyscale versions demonstrated that false colour images are named (Vernon & Lloyd -Jones, 2003; Castelhano & Henderson, 2008) and recognized (Wichmann et al., 2002, Steeves et al., 2004) slower than correctly

coloured objects and greyscale images. This indicates that colour on its own does not mediate recognition (i.e. by supporting the segmentation process); instead, it is the association between specific colours and the particular object that facilitates the identification process and as long as the hue falls within the normal range of variations (e.g., apple in green, red, or yellow but not in blue), colour supports the recognition of all object types (Castelhano & Henderson, 2008).

Indeed, the controversy about the role of colour with respect to object category and colour diagnosticity extends to the more general level of debate as to where and when colour interferes in the processes of object recognition and naming. There are mainly two contrasting approaches about the influence of colour on object recognition and naming process: on one side of the issue, edge-based accounts such as Biederman's recognition-by-components-theory (1987), claim that initial object recognition is mediated solely by shape. Surface properties such as texture and colour do not play a role in basic-level recognition and are filled in later and only if necessary when shape information alone is not sufficient or in pathological conditions such as low vision (Wurm et al., 1993) and visual object agnosia (Mapelli & Behrmann, 1997). Thus, under normal viewing conditions, object identity can be achieved by accessing structural descriptions of the object that contain only shape. In line with this approach, some studies found that colour is particularly helpful in situations where object shape is degraded by occlusion (Wurm et al., 1993), or where shape is blurred (Wurm et al., 1993; Tanaka & Presnell, 1999; Yip & Sinha, 2002; Laws & Hunter, 2006), or where the object is presented in an unfamiliar orientation (Nicholson & Humphrey, 2001), or in a non-prototypical fashion (e.g., sliced apple instead of whole fruit) (Wurm et al.(1993). In contrast, 'surface-plus-edge-based accounts' allow objects to be presented by both shape and colour to form the object representation (e.g., Gibson, 1969; Tanaka et al., 2001). In an even more elaborate model of the 'surface-plus-edge-based account', Davidoff (2001) allows the

influence of colour to occur as early as the ‘temporary register’, a very early stage of visual perception were colour can be part of the shape forming process. As a result, colour can be a part of the structural descriptions of the object and influence the object recognition process at much earlier levels than proposed by edge-based accounts (see the model by Davidoff in figure 14 on page 62).

How do the findings of our research relate to these different theoretical accounts? Confrontation naming recruits both visual and non-visual sources of information; consequently, it may be difficult to establish the specific level or levels of processing (visual, conceptual, or lexical levels), at which the surface property of colour affects the naming process. Our data show that colour speeded up naming by an average of 79ms for objects presented under normal viewing conditions and this was independent of whether objects were easy to segment, form a plain background or had to be segmented from noise. In addition, colour benefited naming not only for structurally similar objects but for structurally dissimilar objects as well. This conflicts with edge-based accounts and findings that colour effects are only significant for structurally similar objects and/or objects in unusual viewing conditions (e.g., with rotated objects) or when the object’s shape is degraded (e.g., blurred or partially occluded). Furthermore, the magnitude of a segmentation advantage by colour on object recognition is about 10-18ms with objects presented in non-blurred and canonical viewing conditions as shown in the rapid object detection task by Delorme et al. (2000) and therefore much smaller than the 79ms colour advantages found in our study. This can be taken as evidence that colour not only supports object segmentation at early visual perceptual levels, but extended its influence to object colour knowledge at higher levels of object recognition. If colour only supports the segmentation process for pictures with enhanced colour contrast then objects in grey against a background in colour (gocn, gogn) should have been named fastest. For instance, it has been shown that enhanced colour contrast augments the saliency of object

features and increases attention (e.g., Wichmann et al., 2002) and speeds up the segmentation process (Gur & Akri, 1992; Rivest & Cavanagh, 1996; Syrkin & Gur, 1997; Kentridge et al., 2004; Kingdom et al., 2004; Kingdom & Kasrai, 2006; in faces: Yip & Sinha, 2002; Russel & Sinha, 2007). However, these pictures were named the slowest. The longer naming latencies for the incongruent picture conditions demonstrate that object colour knowledge was the most influential factor to either facilitate or inhibit the identification and naming process. In the congruent picture conditions, object colour clearly speeded up naming by facilitating object segmentation, object identification and the lexical selection process. In the incongruent picture conditions, the grey object placed in front of a coloured background was leading to an incorrect assumption of object greyness and therefore to a mismatch with the object colour knowledge stored in memory. The object-background colour discrepancy inhibited a fast object identification leading to a more extensive analysis of the local features to discriminate the objects from other competitors and thereby prolonging the lexical selection process. It has been shown in other studies that abnormally coloured scenes (e.g., Oliva & Schyns, 2000; Wichmann et al., 2002; Castelhano & Henderson, 2008) and objects in semantically inconsistent backgrounds (Boyce et al., 1989; Bar, 2004; Davenport & Potter, 2004; Tatler & Melcher, 2007) are processed more slowly. Wilton (1989) and Asch et al. (1960) suggest that objects have a primacy in the recognition of scenes in that the association between the shape and the surface colour of the object becomes primarily activated rather than the shape and the colour of the background to the object. This is in line with Price & Humphreys (1989) who demonstrated that the facilitating influence of colour on object naming is only present when the colour occupies the internal surfaces of the object and does not benefit performance when the colour is part of the surrounding background. The results of the incongruent picture conditions in our experiment therefore suggest that any colour advantage that was gained because of enhanced segmentation was reduced by the later more extensive analysis of the local features to allow object identification. Thus, it shows that the effects of colour on object

naming can occur at different levels of processing independent and in parallel, and not necessarily in an additive manner. It further shows that a later process can reduce effects of apparently earlier stages, if the later process is the more influential determiner of overall reaction time. Taken together, our findings clearly speak against a serial processing of object shape and colour where shape is processed first and colour is filled in later as proposed by edge-based accounts. Instead, our results fit with the model by Davidoff (2001) in that colour can affect the naming process at different levels of processing and to a different extent, which is consistent with surface-plus-edge-based accounts.

Differences in performance between aphasic and healthy subjects

Aphasic subjects produced on average 319ms longer naming latencies because of their anomia and made more errors overall than the healthy controls. In addition, aphasic subjects produced a larger reaction time difference between the chromatic and achromatic picture versions in the noise conditions (cocn vs. gogn) than the controls, indicating that they depended more on object colour when the segmentation demand increased. Furthermore, aphasic subjects needed more time for processing than the controls when object and background colours were incongruent and the semantic selection demand increased. Aphasic subjects also made more identification errors in the category of fruits & vegetables than the healthy controls when more fine-grained visual and semantic differentiation was needed to search for the correct name of the object. There are several possible reasons why aphasic subjects relied more on colour when the degree of difficulty for the naming increased and why they were more affected when object and background colour were semantically discrepant. Naming an object involves different levels of processing including early visual analysis, accessing stored structural knowledge of objects, semantic activation, and lexical retrieval (e.g., Laiacona et al. 2001). These levels are connected either by feedback loops or in a cascading manner (e.g., Humphreys et al, 1995; Davidoff, 2001; Damasio et al., 2004).

Reducing the ease of access at one stage can affect activation and processing at another stage and/or at later stages (Humphreys et al., 1999). Aphasic subjects produced slower responses because their strategy for the lexical search is impaired (e.g., Mills et al., 1979), this is probably because they have problems with parallel information processing (visual and semantic) as required for confrontation naming of pictures. Thus, aphasic subjects may have fewer cognitive resources available than non-aphasic controls to perform the task. There is evidence for such a 'reduced resource allocation theory' in patients with aphasia. Studies have shown that aphasic subjects have fewer attentional- (Murray, 1999) and working memory resources (Miyake et al., 1995; Haarmann et al, 1997), which can intensify their aphasic symptoms under more task-demanding conditions (Goodglass et al., 1968; McNeil et al, 1997; Murray, 1999; Wingfield et al, 2006). Aphasic subjects also have more problems when name retrieval requires a more heuristic search and decision-making process, as it is required when differentiating between structurally similar objects (such as between fruits & vegetables when shown without colour) or when identifying and naming objects in incongruent picture conditions (Mills et al., 1979; LaPointe et al., 2006). Reduced cognitive resources and impaired lexical search seems to make aphasic subjects more dependent on surface information such as colour, as they are more influenced by the form in which the object to be named is presented to them than healthy controls (see also Bisiach, 1966; Goodglass et al., 1968; Benton et al., 1972 for similar conclusions). Our results contribute to earlier findings by Bisiach (1966) and Benton et al. (1972) in that we confirmed their observations by using a larger number of participants and a better controlled stimulus set with a larger number of items.

Cross-linguistic comparison

The group comparisons between English and German speaking participants (healthy and aphasic subjects) showed no difference in respect to colour whether objects were named in

English or in German, which is in line with a study by Viggiano et al. (2004) who compared English with Italian speaking participants. This shows that the observed colour effects in our research are robust and reliable as they occurred across three different subject groups and two different languages independent from factors such as cultural differences related to language and independent from linguistic related variables such as word length and name agreement.

3.4.2: Colour effects on repeated naming

The second part of experiment 1 had two aims: first, to assess how colour affects priming when objects are renamed after a delay of, on average, 12 days and second, to evaluate whether aphasic subjects with anomia differ in their priming behaviour and responses to colour when compared with age-matched non-aphasic, healthy controls. Results showed strong priming effects with, on average, 86.17ms faster naming for pictures that were repeated from study to test with no difference between the two subject groups. This indicates that aphasic subjects have the same priming potential as the healthy controls. Furthermore, priming was equally effective regardless of picture condition, the object category, or the diagnosticity of the colour of the item. This means that colour made no difference as all stimulus types primed naming in the same way. How do these results fit with findings from other studies? Gegenfurtner & Rieger (2000) showed that colour benefited recognition in a delayed match-to-sample tasks of briefly presented images of natural scenes. They found that the benefit of colour occurred at two different levels: first, colour leads to an encoding advantage at a sensory level of object recognition, and second, at cognitive levels, colour leads to an enriched representation of the object in short-term memory. At recognition, colour adds one more cue for the segmentation process at an early level, and one more cue for the retrieval of information from memory at a later level. Hence, priming by colour is generated by both bottom-up and top-down mechanisms when recognizing natural scenes. Wichmann et al. (2002) supported this view by demonstrating that the priming effects by colour in scenes

are not limited to a sensory level of object recognition, as priming decreased when scenes were presented in an unnatural colour. If colour only supports segmentation at a perceptual level of object recognition, than priming should be the same regardless of whether scenes are presented in appropriate or inappropriate colours. However, recognition accuracy decreased with the incorrectly coloured scenes, showing that there was interaction between prior knowledge about the scenes and the influence of colour on memory retention. This means that priming only occurred when the conceptual knowledge about scenes was not in conflict with the actual surface colour of the scenes. These observations fit with computational models implying that repetitive experience with a stimulus can make operations of analogies, associative activation and generation of prediction less effortful (Desimone, 1996; Grill-Spector et al., 2006) if the extracted information from the perceptual representation matches the representation in memory. If there is a match, top-down prediction facilitates the recognition process by reducing the number of possible candidates of object representations that need to be considered thereby speeding up the recognition process (e.g., Ullman, 1995; Friston, 2005).

Although there is evidence, that colour primes recognition in scenes (Homa & Viera, 1988; Suzuki & Takahashi, 1997; Gegenfurtner & Rieger, 2000; Wichmann et al., 2002; Spence et al., 2006); there is less evidence that colour facilitates priming in single object recognition. The few studies that measured priming effects during single object naming resulted in less conclusive results. For instance, Cave at al. (1996) found no differences in priming times when object colour was changed between study and test and the task was naming, but changes in colour affected old/new judgements during object recognition. Furthermore, although changes in colour had no effect on priming during naming, changing the stimulus exemplar diminished priming effects. The authors concluded therefore that priming might be more driven by attributes that are essential to the development of a basic-level object-shape

representation and less influenced by surface details and that priming might rather be sensitive to task demands. However, the stimuli used in this study were pictures of artefacts that were arbitrarily coloured in red, green, blue or yellow with a uniform stippling of the same colour as the outline. These colour manipulations made them appear highly artificial with little similarity to anything that is real. Hence, the results can be better reinterpreted as colour effects on new association learning rather than reveal anything about how colour affects priming of realistic depictions of objects. Instead of using artefacts, Vernon & Lloyd-Jones (2003, Exp. 1A) used coloured line drawings of single coloured fruits, vegetables, and animals and compared them with their black and white counterparts during repeated object naming. They found that the coloured line drawings were encoded faster both at study and at test, but that colour did not enhance priming (-56ms for coloured, and -113 for black and white line drawings). This is in contrast to findings by Nicholson & Humphrey (2001) who found no faster encoding between achromatic and chromatic photographs and coloured line drawings of low colour diagnostic artefacts when the objects were presented in canonical upright orientation. However, they found that coloured photographs were encoded faster at the initial presentation and that coloured photographs produced a sharp increase in the priming effect when the same objects were rotated. The authors suggested that surface colour alone does not facilitate recognition. Instead, it is the combination of colour and other surface cues such as texture and shading that might have helped subjects to determine the three-dimensional structure of parts of the objects, thereby benefiting the object recognition and naming process. The sharp increase in the priming effects with the coloured photographs suggests that subjects used mental rotation to identify the rotated objects when presented as achromatic photographs and coloured line drawings, but that they switched strategy when identifying the objects presented as coloured photographs. Because the coloured photographs provided extra information, objects were easier recognized and did not require a mental

rotation process. It was concluded that full-cue colour images may be particular helpful in difficult situations and that they behave differently than simple coloured line drawings.

The results found in our experiment fit with findings from studies on scene recognition (Gegenfurtner & Rieger, 2000; Wichmann et al., 2002) and with the study of Vernon & Lloyd-Jones (2003) on single object naming in that there was faster processing of coloured objects during encoding and recall. However, if full colour cues depictions (coloured photographs) are particularly helpful in difficult situations as predicted by Nicholson & Humphrey (2001), then we should have found a category effect at least for the category of fruits & vegetables, but that was not the case. One could expect that fruits & vegetables would benefit the most from priming when shown in colour as they are much harder to differentiate and take longer to name when presented in achromatic depictions. However, the priming times in our study were unaffected by category effects or colour diagnosticity of the object, which is in line with observations by Lloyd-Jones & Humphreys (1997) who found that category effects diminished when pictures were named a second time. That colour-specific priming was unaffected by object category and colour diagnosticity was also observed by Uttl at al. (2006) when subjects had to identify coloured photographs in a fade-in paradigm. However, their results must be accepted with caution, as stimuli in this study were not matched for luminance. Vernon & Lloyd-Jones (2003) found a marginal significance for stronger priming of black and white line drawings over the coloured ones when comparing old versus new naming reaction times of just 10 objects in each condition. If priming represents a kind of rapid response learning at a semantic level as suggested by Dobbins et al. (2004) and Horner & Henson (2008), than one should expect that the incongruent pictures that elicited by far the slowest reaction times during study should have been primed the most at test. However, this was not the case. The ‘rapid response learning model’ states that prior exposure to a stimulus leads to stimulus-response associations. At a second encounter, those associations automatically cue the response, bypassing some of the various processing stages

that were active during the first representation. In this way, response learning occurs as a transfer of task relevant processes. Our results do not fit with this model. If on the other hand, priming represents a kind of response learning at a feature level as suggested in the 'sharpening model' (Desimone, 1996; Wiggs & Martin, 1998, van Turennout et al., 2000; 2003; Vernon & Lloyd-Jones, 2003), then priming should have been stronger for achromatic pictures than for the coloured ones. The sharpening model implies that neurons that respond optimally at the first encounter are tuned again when the stimulus is repeated, whereas neurons that encode features that are irrelevant for the stimulus identification are reduced and inhibited, to allow a faster read out of the stimulus information at the second encounter. Evidence for this model was shown, amongst others, in fMRI studies by van Turennout and her colleagues (2000; 2003). They showed that repeated object naming (of black and white line drawings) resulted in decreased activity in occipitotemporal and left inferior frontal regions, and increased activity in the left insular and basal ganglia. It was suggested that changes might represent improved object recognition and reorganization of pathways in the brain to support the name retrieval for that specific object. Our experimental design does not allow us to distinguish between these different levels of processing during priming, as all stimulus types showed the same priming pattern. If there was any kind of rapid response learning occurring in our study, then the same learning process must have occurred whether objects were presented in colour or not and whether object names were easy to name or difficult to retrieve. Hence, rapid response learning would have occurred undifferentiated from perceptual and conceptual object properties. This seems to be rather unlikely, as studies have shown that the magnitude of perceptual learning is dependent on visual attributes such as stimulus complexity and on task demands (see Fine & Jacobs, 2002 for a review). Fine & Jacobs (2002) found that the most learning (priming) occurred for tasks that required discrimination along more than one perceptual dimension. Consequently, if rapid response

learning was responsible for the priming effects observed in our study, we should have found larger priming effects for fruits & vegetables when shown without colour.

Another striking finding of our experiment was that aphasic subjects demonstrated the same priming behaviour as the healthy controls. A study by Wingfield at al. (2006) measured learning effects during repeated picture naming of black and white line drawings on three aphasic subjects with near-to-normal naming ability and compared them with 18 neurologically intact young and older adults. The neurologically intact adults showed a linear decrease of naming latencies over the five consecutive trials. This was in contrast to the highly variable learning curves between trials 3 and 5 of the three aphasic subjects. However, all participants showed similar priming at the second trial, which is similar to our results. In our experiment, priming was found to be equally effective for both subject groups and unaffected by stimulus properties and task demands. Our results would therefore fit best with the 'facilitation model' which states that in the beginning, neurons fire robustly to both first and repeated representations, but firing stops sooner when the stimulus is repeated. Because repetition of stimulus attributes improves prediction, synaptic changes accelerate (synaptic potentiation), leading to shorter duration of neural processing (James et al., 2000; Grill-Spector 2003; Henson & Rugg, 2003; James & Gauthier, 2003; Friston, 2005).

Although the facilitation model would explain best the overall priming pattern observed in our study, it needs to be highlighted that there was considerable variation among and across subjects and items with respect to priming times. It is well-known that naming latencies can show a huge variation across and within subjects and tasks. It is therefore very likely that subjects in our study may have used different strategies to name the pictures even within the same task. Thus, priming may have derived from different strategies and could have involved rapid response learning patterns as well. In fact, recent work has shown that previous experience can influence learning induced memory in early visual areas within 15-20 minutes

when processing visual scenes (Chaumont et al., 2008). Furthermore behavioural observations (Holbrook et al., 2003), neuroimaging techniques (see Grill-Spector et al., 2006 for a review) and computational models (Turk-Browne et al, 2006; Berry et al, 2008) indicate that priming might be a flexible process that is not fixed on a particular process or system but rather determined by task demands.

3.4.3: Conclusion

Picture naming involves several processes including the segmentation of the object from its background (visual processing), the categorizing and recognition of the object as a member of a particular class, access to stored conceptual knowledge about the object's individual identity (semantic processing) and lexical selection of the particular name of the object (lexical processing) before the name can finally be articulated (phonological and articulatory processing) (e.g., Levelt, 1992). Results from experiment 1 show that object colour does affect some of these processing stages and that these colour effects occur at different levels of processing that can be activated in parallel. First, it was shown that object colour eases the segmentation process as objects in colour were named faster in both background conditions (plain and noise) than when they were presented in grey. Second, pictures with an object in colour were named faster independent of any segmentation costs. This was demonstrated with the picture version where the coloured object had to be segmented from a coloured noise, which was named nevertheless faster than grey objects placed in front of plain backgrounds despite them being easier to segment. This indicates that (congruent) object colour facilitates not only segmentation but also object recognition as it provides an additional cue about the objects' identity thereby reducing competition amongst semantically related competitors. Third, pictures with incongruity between object and background colour were named by far the slowest. This shows that incongruent object colour can interfere with the semantic selection process if there is a mismatch between the perceptual information of the object and the object

colour knowledge that is stored in memory and thereby prolonging the identification process. Fourth, results with our stimulus set showed that object colour effects facilitated naming across all three different categories including manmade objects (non-living things) and independent of the colour diagnosticity values of the objects, indicating that the advantage of an object possessing colour was unrelated to object category and colour diagnosticity. However, although object colour benefited naming in all object classes, results also showed that the effects were strongest in the category of fruits & vegetables. This was demonstrated by fewer identification errors in the accuracy analysis and by greater naming time differences in the reaction time analysis when the objects were presented in colour than when they were in grey. This is in line with theories about category effects stating that object colour might be particular helpful in *identifying* structurally similar objects and thereby easing the semantic selection process (e.g., Price & Humphreys, 1989).This was particularly valid in the category of fruits & vegetables where many objects tend to have closely related semantic neighbours and where diagnostic object colour helps distinguishing between them.

No evidence was found for any influence of colour on *post-semantic selection processes* with our test paradigm in both subject groups (healthy and aphasic subjects), as colour was not related to the number of errors of failing to find the name for the object (i.e. failure in name retrieving as a null response), or to the number of errors in misnaming the object (semantic paraphasias). However, the task might have been too easy to evaluate properly any influence of colour on the post-semantic selection processes. The task here involved only common and easy-to-name objects and subjects had 5 seconds time to search for the name. As a result, healthy subjects made very few mistakes and even the aphasic subjects, despite their anomia, were able to name about 78% of the pictures correctly. Hence, there were not enough errors per picture version and error type to draw any further conclusion about how colour might effect the lexical selection *after* object identification had taken place.

The second part of the experiment revealed that colour did not affect priming effects. All six different picture versions showed similar priming magnitudes of on average 86ms when they were renamed after a 12 day delay. This showed that priming was unaffected by surface details and conceptual variables such as colour congruity, object category or colour diagnosticity of the object when stimuli were unchanged between study and test (which was the test design). The comparison between aphasic subjects and the healthy controls showed that aphasic subjects were overall slower in their responses with, on average, 319ms longer reaction times during encoding and recall. However, they showed the same priming magnitudes as the control group indicating that priming during repeated picture naming is mainly perceptual with little mediation by higher-level cognitive processes such as improved lexical selection. Aphasic subjects differed however, from the control group, in that they relied more on colour cues when the segmentation demand increased. They also relied more on object colour when the semantic selection demand increased as they made far more errors in the category of fruits & vegetables when the objects were not shown in colour than the healthy controls. Furthermore, aphasic subjects were also more agitated by colour incongruity between object and background colour compared with the healthy controls. These observations clearly indicate that subjects with anomia depend more on object colour to make a semantic selection in order to identify and name the object. This fits with findings from earlier studies on patients with aphasia by Bisiach (1966) and Benton et al. (1972) suggesting that colour may arouse a wider concept of associations with the object and thereby facilitating the lexical access. Taken together, the results of part 1 and 2 of experiment 1 indicate that during object naming, object colour operates at the perceptual level of visual processing where it eases object segmentation. In a parallel process, object colour operates at a conceptual level where it eases the semantic selection process, thereby mediating object identification. This in turn speeds up the lexical selection process. Both processes can occur in

parallel and independently of each other. It was further shown that a later process can reduce effects of apparently earlier stages, if the later process is the more influential determinant of overall reaction time. Overall results fit with the model by Davidoff (2001) in that colour can affect the naming process at different levels of processing and to a different extent, which is in line with surface-plus-edge-based accounts.

Chapter 4: Experiment 2 - Colour effects on priming during repeated object naming using different delays

4.1: Introduction

Experiment 2 was designed to assess the role of colour on priming during repeated picture naming by using different delays and to specifically address whether there is decay in the priming effects and whether this is related to any aspect of colour. The same design was used as in experiment 1, with the exception that the delays between study and test were either one month, three months, or six months. Participants were 60 English-speaking subjects who had been also used as control group for experiment 1.

Many studies on priming measured priming effects only during immediate recall, either with repeated naming tasks (Durso & Johnson, 1979; Sperber et al., 1979; McCauley et al., 1980; Carr et al., 1982; Lloyd-Jones & Humphreys, 1997; Vernon & Lloyd-Jones, 2003; Alario et al., 2004; Lloyd-Jones, 2005; Wingfield et al., 2006; Francis & Saenz 2007), or with object recognition tasks (Hanna & Remington, 1996; Gegenfurtner & Rieger, 2000; Wichmann et al, 2002; Nicholson & Humphrey, 2003; Spence et al., 2006). All of them found significant priming effects independent of stimulus type. However, studies that specifically contrasted chromatic with achromatic stimuli found a colour effect in that colour increased accuracy (Hanna & Remington, 1996; Gegenfurtner & Rieger, 2000; Wichmann et al, 2002; Spence et al., 2006) or decreased reaction times (Nicholson & Humphrey, 2003; Vernon & Lloyd-Jones, 2003) during both encoding at study and retrieval at test. Newer and older work has shown that priming can persist over even longer periods than just immediate recall. For instance, Cave (1997) showed longevity for priming effects on accuracy and reaction times in picture naming over a period of 48 weeks, and subjects named pictures of famous faces more accurately that they had seen 22 months before (Maylor ,1998). Furthermore, recognition of

photographs was still primed after 360 days (Nickerson, 1968), and Mitchell (2006) could show that picture fragment completion was primed even after a delay of 17 years. All these four studies used achromatic picture stimuli. The observation that priming effects can last for so long may open the question about whether priming is prone to any decay. Studies that have used different delays to measure the persistence of priming by either comparing accuracy, reaction times or both, yielded equivocal results. Stable facilitation of naming latencies for retention intervals of 1 and 6 weeks was found by Mitchell & Brown (1988) using achromatic pictures and Cave et al. (1996) found that recognition rates declined, but response times did not differ, when subjects had to name and recognize artificially coloured line drawings after 1 hour or 48 hours delays. In contrast, other people found a decline in priming for naming achromatic pictures between delays of 30 seconds and 1 hour (van Turennout et al., 2003), 10 minutes and 1 week (Francis & Saenz, 2007), or 6 and 48 weeks (Cave, 1997). Meister et al. (2005), using fMRI, found that although cortical activation differed, priming was behaviourally the same, when subjects renamed black and white line drawings after 1 day or 6 weeks time. The stimuli used in the Meister et al. (2005) study were similar to those used in the previously mentioned studies.

Mixed results also come from studies on scene recognition. For instance, Homa & Viera (1988) found that accuracy declined independently of stimulus type over immediate recall and recalls of 1 day, 4 weeks and 12 weeks (e.g., scenes depicted in colour or in black and white). While Suzuki & Takahashi (1997) observed that the decline was less steep for coloured scenes than for black and white ones between an immediate recall and a recall of 1 week for repeated recognition. As many of the studies and results vary in their observations about the general persistence of priming and in the persistence of priming with respect to colour, no clear picture emerges. The present study measures priming magnitudes over time, using

different delays (one-, three-, and six months), and determines whether effects are different depending on colour and the nature of background and foreground.

4.2: Method

The basic structure of experiment 2 was the same as of experiment 1; both contained a study session with an immediate naming task and a test session where subjects had to perform a repeated naming task after a certain delay. Experiment 2 was conducted with participants and intervals different from those in Experiment 1. We were interested in exploring any *decay over time* in priming which might be affected by the availability of colour information. Subjects were therefore asked to repeat the naming task either after delays of one, three, or six months. Repetition priming was measured with a between-item calculation where *first* minus *second* latency of *old* items are compared (i.e. comparing naming measures in the test phase with naming measures in the study phase for pictures that were repeated in the test phase). Naming latencies and naming accuracy were the dependent variables. Experiment 2 was conducted at Durham University in the UK with healthy English speaking participants. All participants of experiment 2 were used as additional control subjects for experiment 1.

4.2.1: Participants

Sixty-six healthy English-speaking participants took part in the experiment who spoke English as their current dominant language. The study was conducted under the ethical regulations of Durham University. All subjects gave consent to take part in the experiment and were paid £10 for their participation.

Six subjects were excluded from the analysis. Two of whom performed very poorly on the experimental task, one of whose data was lost due to technical problems with the audio recording and four of whom failed to attend the second test session. Of the remaining 60

participants, 32 were students and 28 were professionals with a mean of 18.1 years of education (between 10-25 years). Thirty-eight were female and 22 male with a mean age of 30.5 years (between 19-64 years old), seven of the participants were left-handed and 53 were right-handed (subject details see Appendix 7).

All subjects had self-reported normal or corrected to normal vision. The same tests as described in experiment 1 were used to screen for purely visual deficits and deficits in non-verbal access to image semantics (scores see Appendix 7).

4.2.2: Stimuli

The stimulus sets in experiment 2 were the same as used in experiment 1, but included, in addition, images of ten new objects of physical representations of geometric abstract forms (cylinder, trapezoid, sphere, hemi-sphere, pyramid, square, cube, pentagonal-prism, cone and rhomboid). These abstract forms were introduced, because we were interested how colour affects naming of objects, which have no relationship whatsoever with particular colours and which do not therefore generate any specific colour associations. All abstract forms were 3-dimensional objects made of wood and painted in arbitrary colours of either yellow, orange, red, green or blue. The photographs of these ten new objects were produced in exactly the same way and transformed into six different picture versions as described in experiment 1.

Five of the abstract forms were named twice, first during the study session and then again in the test session; the other five objects were used as new items in the test session and only named once. Experiment 2 comprised 75 different objects plus 4 practice items during study and 150 different objects plus 4 practice items during test. The total image set for experiment 2 comprised therefore 900 different stimuli (150 objects x 6 versions) plus 4 training items and the images were sorted into six different sets as described for experiment 1.

4.2.3: Procedure

The apparatus and the general procedure of experiment 2 was the same as that of experiment 1, except that subjects named the additional ten geometric objects and that the delay between study and test was either one, three or six months. All subjects were tested in a laboratory in the Psychology Department of Durham University.

For the different study-test intervals, subjects were divided into equally sized groups, which were matched for age (1- month group mean age 29.7 years, 3-months group mean age 31.4 years, and 6- months group mean age 30.2 years). There were 20 subjects in each group.

By the end of experiment 2, each participant had named each of the 150 different objects once in an immediate naming task, and 75 of the objects (study items) twice in a repeated naming task.

4.3: Results

4.3.1: Design

In experiment 2, the same design was used as in experiment 1, with the exception that delays between study and test in part two were systematically varied to assess whether there was decay in the priming effects and whether this was related to any aspect of colour.

4.3.2: Immediate naming task

4.3.2.1: Analysis

Scoring of correct responses and scoring of errors

The scoring of correct responses and scoring of errors was the same as described in experiment 1. Errors were classified as (1) naming attempts where participants reported that

they identified the object but could not retrieve the name in time, were classified as *lexical access errors* (failure to retrieve the name) (2) naming attempts where the response was incorrect, were classified as *errors of misnaming the object* (semantic paraphasia) (3) naming attempts were participants reported that they could not identify the object were classified as *failure to identify the picture*.

Reaction times for naming

The analysis of the reaction times was the same as described in experiment 1. Only trials with correct naming responses were included in the reaction times analysis. Mean reaction times were calculated for each subject and picture condition as a *subject-based analysis* ($F1$), and for each object and picture condition as *item-based analysis* ($F2$). Naming latencies more than 2.5 standard deviations from the mean of the participant or object respectively were classified as outliers and excluded.

4.3.2.2: Results

Reaction times

Data were analysed using a repeated measures ANOVA with Picture design (six levels) as a within-subjects Factor. There were two separate analyses, one for the 140 objects of the original stimulus set, and one for the 10 abstract forms that had been added. This was done because the abstract forms elicited only a few correct responses, as subjects found it hard to name them. Greenhouse-Geisser correction was used when data violated the assumption of sphericity. Treatment means were compared using *LSD* (*Least Significant Difference*) Tests. We first did a group analysis with subject group (1-month, 3-months, and 6-months group) as the between-subjects Factor and Picture design (six levels) as a within-subjects Factor. Results showed a main effect for Picture design ($F_{group}(3.9, 225) = 14.95$; $p<0.0001$) but no

main effect for Group (F_{group}(2, 57) = 1.86; p<0.164) and no Picture design x Group interaction (F_{group} (7.9, 225) = 0.42; p = 0.932) showing that there was no difference between the 3 different subject groups in the immediate naming task (see figure 30). The following analyses for the immediate naming task were therefore conducted with all 60 participants as group. One-way repeated measures ANOVAs on subject-based (F1) and item-based reaction times (F2) were conducted. Results showed that the main effect for Picture design was highly significant (F1(3.9, 232) = 14.23; p<0.0001; F2(4.5, 618) = 19.47; p<0.0001). For analyses of F1 or F2, there was an effect of *Object colour*, where items in colour were named faster regardless of whether the object was easy to segment from a plain background or had to be segmented from a noise background. The slowest named picture versions were the pictures that contained a combination of a grey object and a coloured background. This incongruity between object and background colour caused interference with object colour knowledge and slowed down the naming process and this was especially apparent in the noise condition. There was a significant segmentation cost between the *noise* and the *plain* background condition when the object was in colour (+40ms (F1, (1,59) = 10.73; p<0.002); +46ms (F2, (1,137) =8.73; p<0.004)), but no such costs were found when objects and backgrounds were both in grey (-0.4ms (F1, (1,59,) =0.01; p<0.974) and -7ms (F2, (1,137) = 0.26; p<0.609)) (see figure 31 a, b).

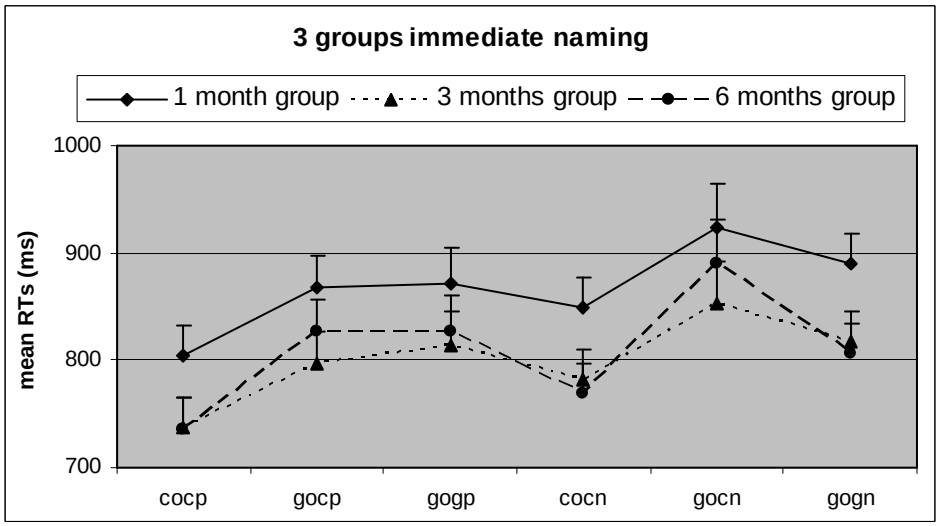
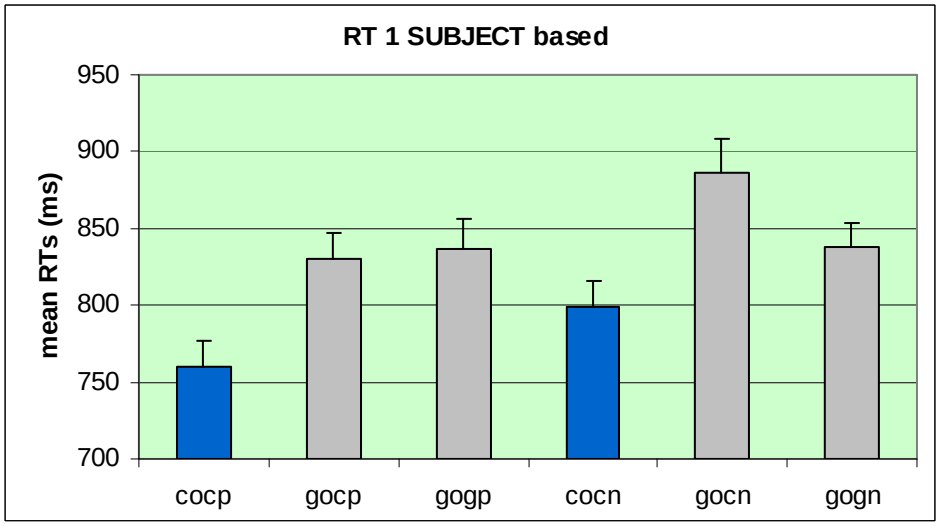
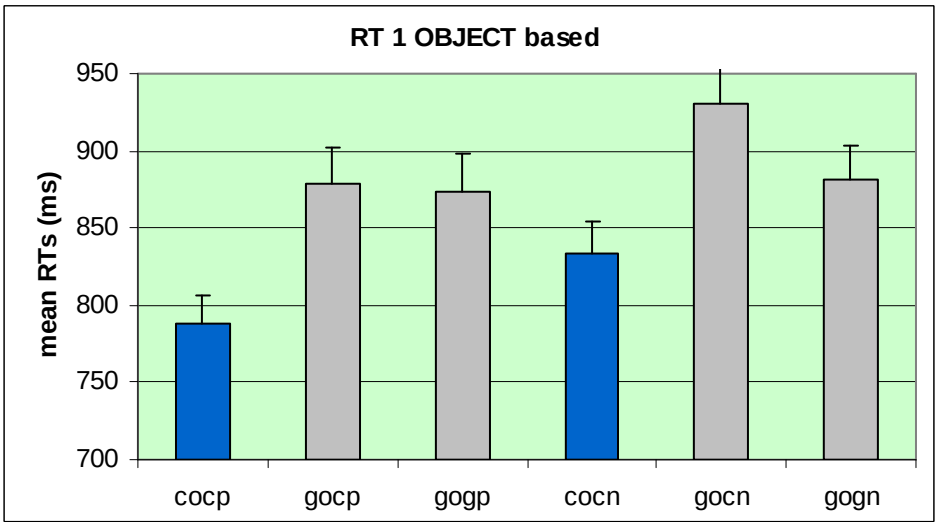


Figure 30. Experiment 2. Mean naming reaction times in ms for the 3 subject groups in the immediate naming task, The Legend: **c** = coloured, **g** = grey-scaled, **o** = object, **n** = noise background, **p** = plain background. **cocp** = coloured object in front of a plain background; **gocp** = grey-scaled object in front of a plain background; **gogp** = grey-scaled object in front of a grey-scaled plain background; **cocn** = coloured object in front of a coloured fractal noise; **gocn** = grey-scaled object in front of a coloured fractal noise; **gogn** = grey-scaled object in front of a grey-scaled fractal noise.



Figures 31 a, b. Experiment 1. Mean naming reaction times in ms for the 60 participants in the immediate naming task, results are shown a) subject based and b) item based. The two picture conditions that are presenting the object in colour are shown as dark columns (**cocp** and **cocn)**.

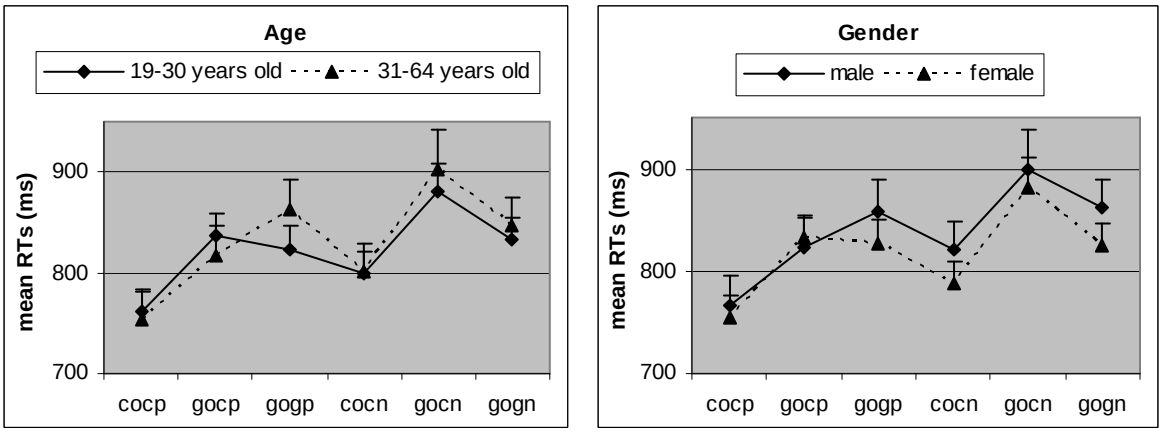


Figures 31 a, b. Experiment 1. Mean naming reaction times in ms for the 60 participants in the immediate naming task, results are shown a) subject based and b) item based. The two picture conditions that are presenting the object in colour are shown as dark columns (**cocp** and **cocn)**.

To further examine the effect of Object colour independent of incongruity effects, a further analysis was carried out using Object colour (colour vs. grey) and Background condition (plain vs. noise) as Factors and by excluding data for the incongruent object-background variations (gocp and gocn). Results show a main effect of Object colour where pictures in colour were named on average 58ms faster than their grey counterparts ($F(1,59) = 25.01$; $p<0.0001$) and an effect of Background condition with objects embedded in noise backgrounds named on average 20ms slower than in plain backgrounds ($F(1,59) = 6.00$; $p<0.017$). There was also an Object colour x Background condition interaction ($F(1,59) = 4.18$; $p<0.045$) showing that object colour effects were stronger in the plain background conditions.

To analyse whether the observed colour effects were related to any age or gender factors, subjects were divided into to two age groups: 19-30 years old and 31-64 years old, and grouped by gender. Two separate analyses were carried out with Picture design (six levels) as a within-subjects Factor and age (19-30 years old vs. 31-64 years old) or gender (male vs. female) as between-subjects Factor. Results show that for both analyses there was a

significant effect of Object colour with (F_{age}(3.9,228) = 15.19; p<0.0001) and (F_{gender} (3.9,228) = 13.09; p<0.0001), and no Picture design x Age interaction ((F_{age}(3.9,228) = 0.852; p<0.492) or Picture design x Gender interaction ((F_{gender}(3.9,228) = 0.527; p<0.714) (see figures 32 a, b). These results clearly show that the observed colour effects in this experiment are robust as they are independent of Factors such as age (19-64 years) or gender.



Figures 32 a, b. Experiment 2. Figure a) shows mean naming reaction times in ms for the 60 participants in the immediate naming task according to age (19-30 years old N= 38 vs. 31-64 years old N= 22); figure b) shows mean naming reaction times in ms for the 60 participants in the immediate naming task according to gender (male N= 21 vs. female N= 39).

To explore whether colour effects were related to category effects or to the colour diagnosticity of the objects, item-based ANOVAs were carried out using first Picture design (6 conditions) and the two categories living (n=72) and non-living items (n=68) as Factors, and second, using the three categories fruits & vegetables (n=39), animals (n=28), and manmade objects (n=68) as Factors. In a further step, results were analysed using Picture design (6 conditions) and Diagnosticity values (2 conditions: high (n= 87) versus low (n= 53)) as Factors. The analysis for the two categories showed a main effect of Picture design with coloured objects named more quickly than grey ones (F(4.5,615) =19.41; p<0.0001) and a main effect of Category in that living things were named more slowly across all picture designs compared with non-living things (+87ms, F(1, 136) = 4.59; p<0.034). There was no Picture design x Category interaction (F(4.5, 615) = 1.45; p<0.203), indicating that the effects

for colour did not differ between these two categories. The analysis for the three categories showed again a main effect of Picture design with coloured objects named more quickly than grey ones ($F(4.5,588.6) = 17.66$; $p<0.0001$), and a main effect of Category in that animals and manmade objects were named equally fast and significantly faster than fruits & vegetables. However, in contrast to the comparison of the two categories living and non-living things, the Picture design x Category interaction was significant ($F(9.0, 588.6) = 2.59$; $p<0.006$). There was an effect for object colour showing that animals benefited the least and fruits & vegetables the most from colour (see figures 33 and 34 a-c).

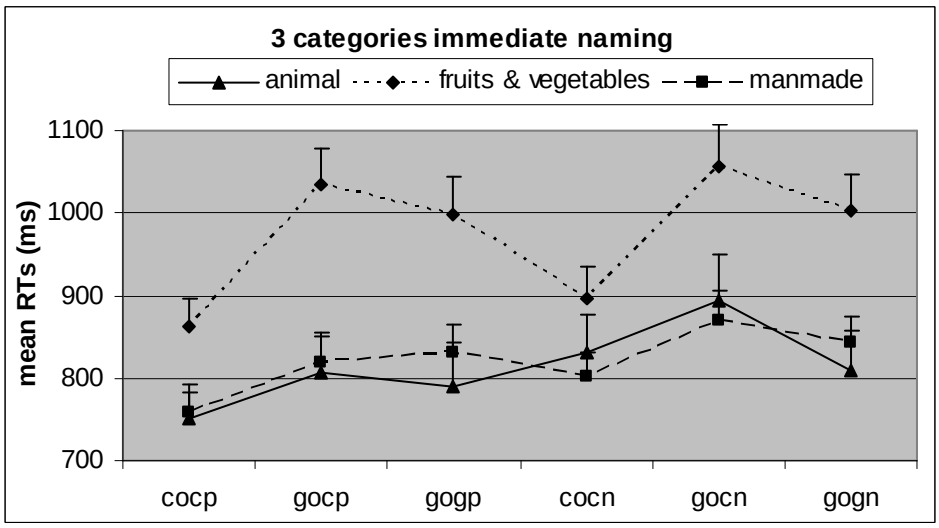
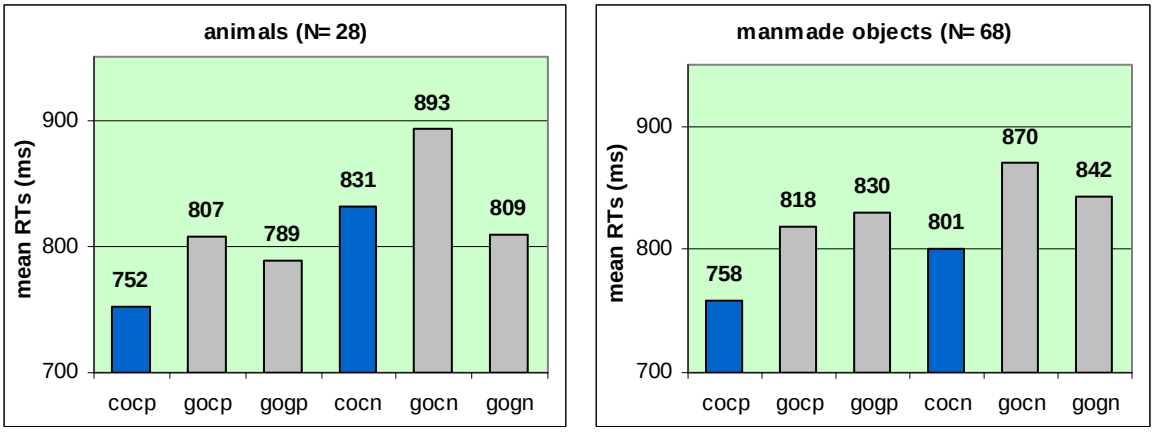
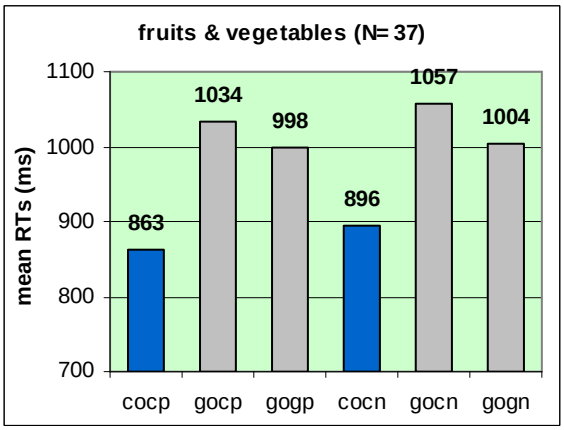


Figure 33, Experiment 2 shows mean naming reaction times in ms for the 60 participants in the immediate naming task for the 3 categories animals, fruits & vegetables, and manmade objects.



Figures 34 a - c, Experiment 2 show mean naming reaction times in ms for the 60 participants in the immediate naming task for the 3 categories animals, manmade and objects fruits & vegetables, the number in brackets in the header represents the number of category members that were named correctly in all the 6 picture designs.



Figures 34 a - c, Experiment 2 show mean naming reaction times in ms for the 60 participants in the immediate naming task for the 3 categories animals, manmade and objects fruits & vegetables, the number in brackets in the header represents the number of category members that were named correctly in all the 6 picture designs.

The analysis of Colour diagnosticity showed a main effect of Picture design (F (4.5, 616.4) = 17.18; p<0.0001) and an effect of Colour diagnosticity in that high colour diagnostic objects were named slower than low colour diagnostic objects (+109ms F(1, 136) = 6.85; p<0.010). There was no Colour diagnosticity x Picture design interaction (F(4.5,616.4) = 1.32; p<0.254) indicating that the observed colour effects did not depend on colour diagnosticity values. The separate analysis of the manmade category where 19 objects had high and 49 low colour diagnostic values, showed again a significant main effect of Picture design with coloured objects named more quickly than grey ones (F (4.1, 270.7) = 5.26; p<0.0001), but no Picture design x Diagnosticity interaction (F (4.1, 270.7) = 0.77; p<0.546), showing again that colour effects did not depend on colour diagnosticity values.

Analysis of the abstract forms

We were interested to evaluate whether objects that do not possess any association with colour would show any colour effects on naming. For that reason, we introduced 10 abstract forms (cylinder, trapezoid, sphere, hemi-sphere, pyramid, square, cube, pentagonal-prism, cone and rhomboid). All 10 of them were named during immediate naming and five of them were repeated in the priming task. However, subjects did not produce enough correct

responses to allow a further statistical analysis of the 10 abstract forms, as there were only 198 correctly named trials out of 600 possible responses and only three of the 10 forms were named correctly across all six picture designs. The low name frequency and low familiarity with the objects made naming difficult and often failing. Many subjects reported that they had not problems identifying the forms but that they could not remember their names, as they had not named them since leaving school.

Accuracy

To establish whether object colour influences picture identification, lexical access or misnaming the object, accuracy data were analysed as follows. First, responses were screened for correct naming and error types. The 60 English-speaking participants involved in the immediate naming task, performed at close to ceiling with 95.06 % correct naming and with error rates below 0.2% in each error category. The most frequent, of the albeit small number, of errors were failures to identify the picture (1.87% of all responses). Because of the low error rates, no further analyses were carried out.

In conclusion, results of the immediate naming task were very similar to those of experiment 1 where all 60 participants were part of the control group. Results showed again a strong effect of object colour where pictures in colour were named on average 58ms faster than when they were grey. The colour effect was significant whether objects were easy to segment from a plain background or had to be segmented from a noise, suggesting that the advantage of an object possessing the attribute of colour outweighed the difficulty of segmenting the object from a noisy background. Results also showed an effect for object segmentation in that objects embedded in noise backgrounds were named on average 20ms slower than objects embedded in plain backgrounds. Pictures with an incongruity between object and background colour were named the slowest despite having a segmentation benefit due to enhanced colour

contrast at the borders between object and background. These findings show again that the interference of object colour knowledge has a stronger effect on naming latencies than any segmentation advantage by colour. It was further found that the object colour effect was unrelated to category when comparing living- with non-living things. However, category effects appeared when comparing the three main categories fruits & vegetables, animals, and manmade objects showing that animals benefited the least and fruits & vegetables the most from colour in our set. The analyses whether colour effects are dependent on the colour diagnosticity of an object, showed again a negative effect. Results across the whole set and across a subset that included the category of manmade objects, where 19 objects had high and 49 low colour diagnostic values, showed that colour effects were not affected by colour diagnosticity values. Group analyses conducted on all 60 participants further showed that the observed object colour effects were robust across subjects as they were independent of group (1-month, 3-months, or 6-months group) and unrelated to age or gender.

4.3.3: Repeated naming task - priming

4.3.3.1: Analysis

Repetition priming was measured by a between-item calculation where first minus second latency of repeated items are compared. Only trials were included where pictures were named correctly on both occasions. Naming latencies with more than 2.5 standard deviations from the mean of the participant or the item were classified as outliers and excluded. Mean reaction times were calculated for each subject and picture condition as a *subject-based analysis* ($F1$), and for each object and picture condition as *item-based analysis* ($F2$). There were three different subject groups with 20 participants in each group: 1-month group, 3-months group, and 6-months group. The three different subject groups were first analysed as a group analysis to (a) see whether there are any differences in the priming behaviour between the groups, and

(b) to measure whether there is any decay in priming magnitudes related to colour. In a second analysis, all the three subject groups were analysed separately.

4.3.3.2: Results

A repeated measures ANOVA was conducted using Group (1-month group, 3-months group, and 6-months group) and Time (RT1 and RT2), and Picture design (6 conditions) as Factors. Results revealed a strong effect of Time ($F_{group}(1,57) = 54.14$; $p<0.0001$) with, on average, 72.61ms faster naming latencies for pictures that were repeated from study to test (*priming*), and a strong effect for Picture design ($F_{group}(5,285) = 9.5$; $p<0.0001$) with coloured pictures named faster than grey ones. There was no difference in the priming times between the three Groups: Time x Group interaction ($F_{group}(2,57) = 0.30$; $p<0.738$), and Picture design x Time x Group interaction ($F_{group}(4.1, 235,8) = 1.24$; $p<0.271$), and Picture design x Time interaction ($F_{group}(4.1, 235,8) = 0.39$; $p<0.855$), indicating that colour did not affect priming times and that colour effects did not decay over time (see figures 35 and 36).

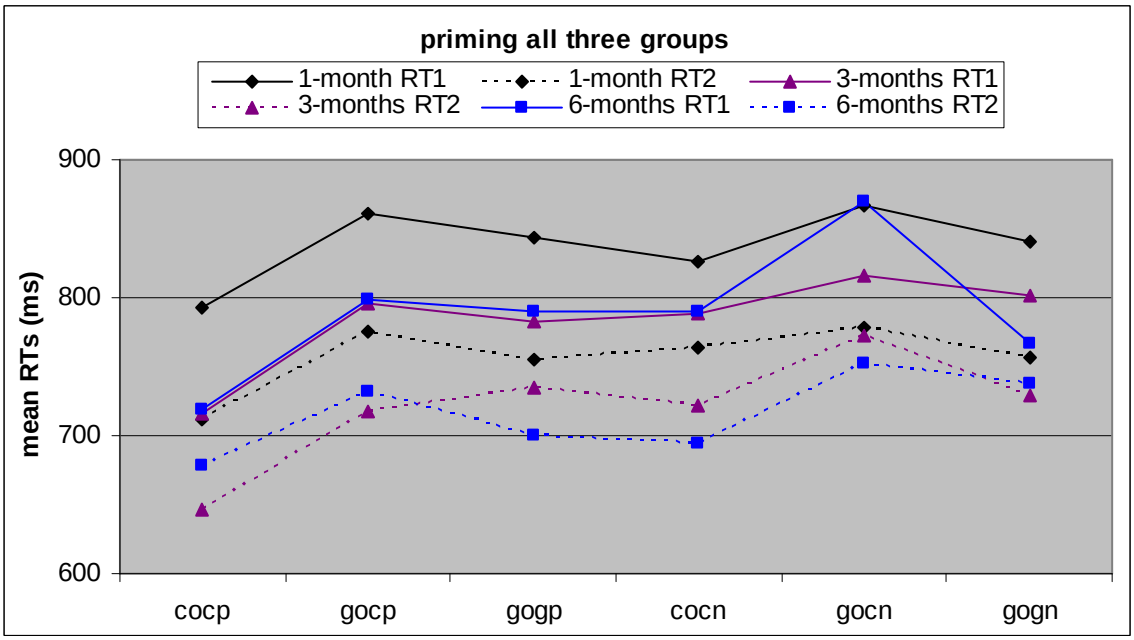


Figure 35 shows the mean naming reaction times in ms for the 3 groups (1-month group, 3-months group, and 6-months group) in the repeated naming task of Experiment 2 per picture design.

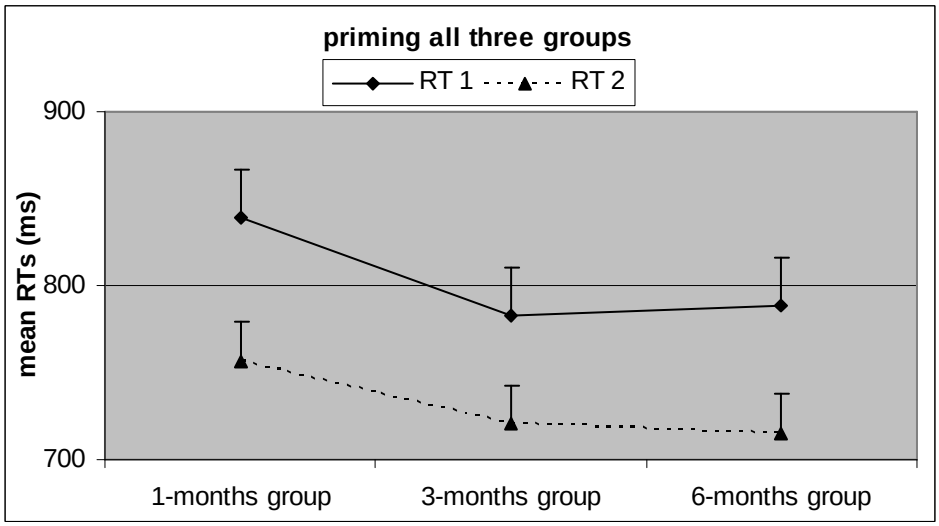
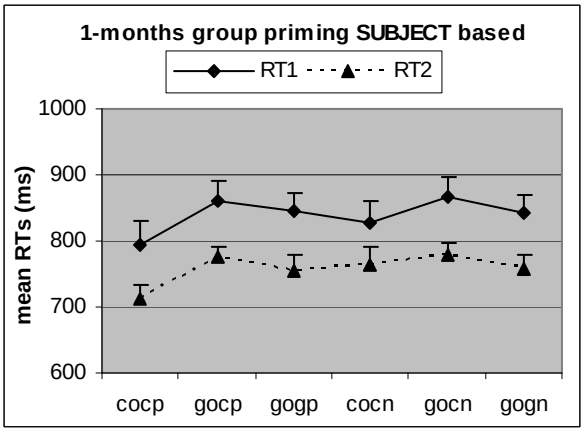
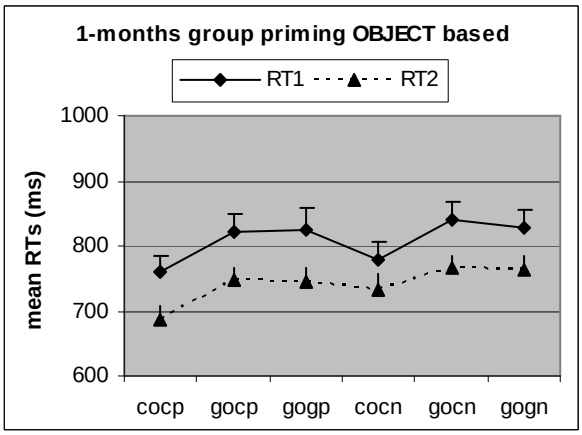
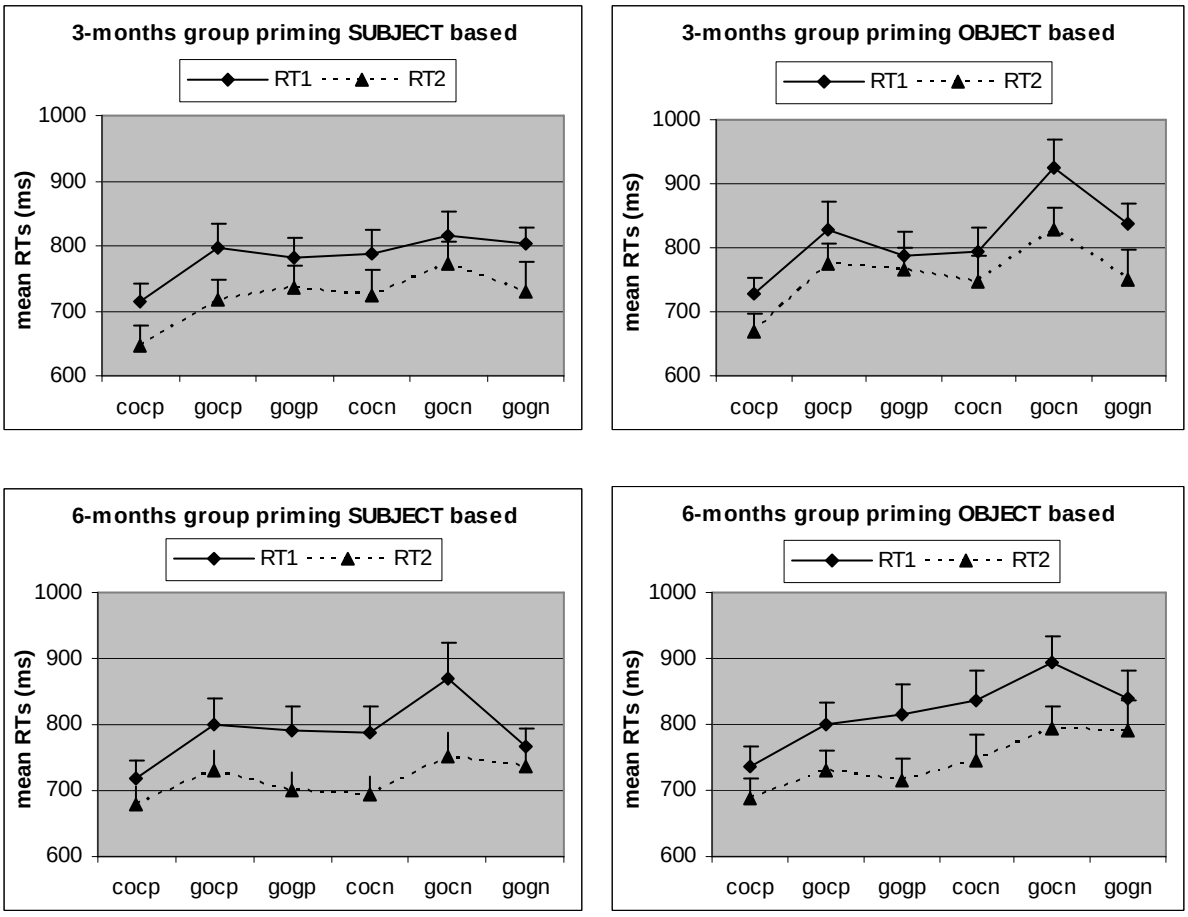


Figure 36 shows the mean naming reaction times in ms for the 3 groups (1-month group, 3-months group, and 6-months group) in the repeated naming task of Experiment 2 as a group comparison.

Subject and item-based ANOVAs using Picture design and Time as Factors confirmed that for each Group there was a strong priming effect for the repeatedly named pictures (-81.94ms, $F1_{1\text{-}month}(1,19) = 36.15$; $p<0.0001$); -69.04ms $F2_{1\text{-}month}(1,62) = 35.06$; $p<0.0001$), (-62.53ms, $F1_{3\text{-}months}(1,19) = 17.97$; $p<0.0001$); -60.51ms $F2_{3\text{-}months}(1,66) = 20.35$; $p<0.0001$), and (-73.36ms, $F1_{6\text{-}months}(1,19) = 10.26$; $p<0.003$); -76.15ms $F2_{6\text{-}months}(1,65) = 33.11$; $p<0.0001$). There was no Picture design x Time interaction ($F1_{1\text{-}month}(5,95) = 0.26$; $p<0.932$); $F2_{1\text{-}month}(5,310) = 0.33$; $p<0.889$), ($F1_{3\text{-}months}(5,95) = 0.55$; $p<0.733$); $F2_{3\text{-}months}(4,269.8) = 0.978$; $p<0.421$), and ($F1_{6\text{-}months}(5,95) = 1.50$; $p<0.195$); $F2_{6\text{-}months}(4.3,280.1) = 0.67$; $p<0.619$) indicating again that colour did not affect priming times (see figures 37 a-f).







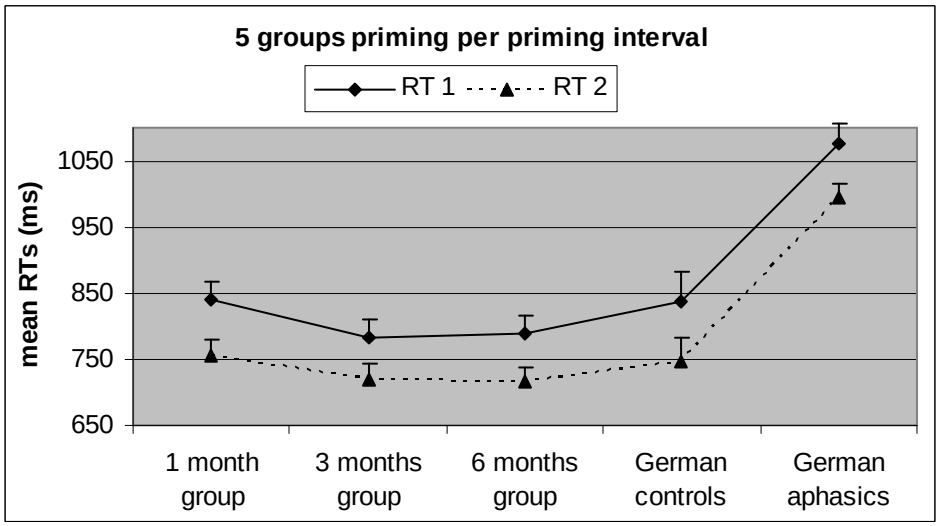
Figures 37 a-f show the mean naming reaction times in ms per picture design in the repeated naming task of Experiment 2 subject based and object based for the 3 groups (1-months group, 3-months group, and 6-months group).

The role of colour, object category, and colour diagnosticity in priming

To measure how colour affects priming times and whether these effects are influenced by object category or by colour diagnosticity, separate item-based ANOVAs were carried out for each group with (1) the two Times (RT1 and RT2), six Picture designs, and the three Categories as Factors, and (2) Time, Picture design and Colour diagnosticity (high versus low) as Factors. There was no effect for Category ($F_{1month}(2,58) = 1.71$; $p<0.190$), ($F_{3months}(2,62) = 1.92$; $p<0.155$), and ($F_{6months}(2,61) = 0.32$; $p<0.722$) or Colour diagnosticity ($F_{1month}(1,61) = 0.68$; $p<0.412$), ($F_{3months}(1,65) = 0.88$; $p<0.349$), and ($F_{6months}(1,64) = 0.10$; $p<0.746$), and none of the interactions were significant. These results show that priming was equally effective regardless of the object category, the picture design or the diagnosticity of the colour of the item.

Group analysis of five subject groups

A further group analysis was carried to evaluate whether the observed priming effects in experiment 2 would be similar to those observed in the repeated naming task of experiment 1 where the priming interval was on average 12 days. A repeated measures ANOVA was conducted using Group (English-speaking participants: 1-month group, 3-months group, 6-months group, and German-speaking participants: healthy subject group, and aphasic subject group) and Time (RT1 and RT2), and Picture design (6 conditions) as Factors. Results revealed a strong effect for Time ($F_{group}(1,89) = 65.39$; $p<0.0001$) with on average 78.03ms faster naming latencies for pictures that were repeated from study to test, and a strong effect for Picture design ($F_{group}(5,445) = 11.5$; $p<0.0001$) with coloured pictures named faster than the grey ones. There was no difference in the priming times between the five Groups: Time x Group interaction ($F_{group}(4,89) = 0.22$; $p<0.921$), and no Picture design x Time x Group interaction ($F_{group}(20,445) = 0.82$; $p<0.686$), and no Picture design x Time interaction ($F_{group}(5,445) = 0.85$; $p<0.51$). These results show that priming times were unaffected by the following factors: (a) by picture design, whether objects were shown in colour or grey, or in a congruent or incongruent object and background colour condition; (b) by age, whether the mean age was 30.5 years (60 English-speaking participants) or 59.6 years (34 German-speaking participants); (d) by language, whether the language the pictures were named in was English or German; and (c) by anomia, whether subjects were anomic or non-anomic. Most importantly however, results clearly show that priming magnitudes remained stable and did not decay over a time (12 days to 6 months) (see figures 38 a, b).



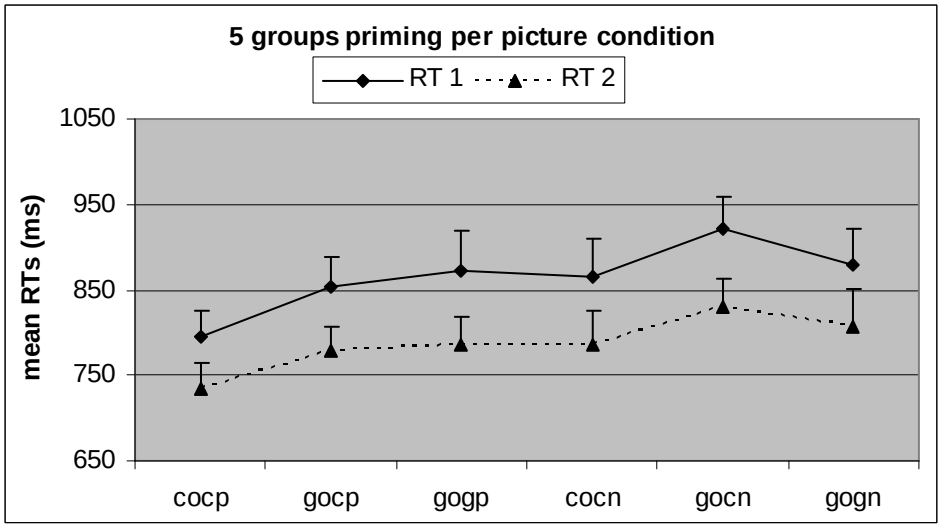


Figure 38 a shows the mean naming reaction times in ms in the repeated naming task for the 5 different subject groups that took part in the repeated naming tasks of experiments 1 and 2. The 1-month group renamed the pictures after 1 month, the 3-months group after 3 months, the 6-months group after 6 months, and the German control participants and the German aphasic subjects renamed the pictures after 12 days. **Figure 38 b** shows the priming times as group analysis of all 5 groups per picture condition.

To exclude the possibility that the observed priming effects are simply a result of test adaptation, mean RTs of all correctly named items at study (92.83 % correct) where compared with mean RTs of all correctly named *new* items at test (91.07 % correct). Results show that the new pictures presented at test were named *slower* than the new pictures named at study by on average 33.2ms. This might have been caused either by fatigue effects, as twice as many items had to be named at test, or because the item selection of the new stimuli at test was more difficult to name, or as a combination of both Factors.

In conclusion, the results of the repeated naming task showed strong priming effects with, on average, 78.03ms faster naming latencies for pictures that were repeated from study to test with no decay of priming magnitudes over time, and no differences among five different subject groups. Results also showed a strong effect for object colour with coloured pictures named faster than grey ones. In addition, priming was equally effective regardless of the object category, the picture design or the diagnosticity of the colour of the item and independent of between subject factors such as age, gender, health, or language.

4.4: Discussion

Results of the immediate naming task were similar to those observed in the immediate naming task of experiment1: the 60 English-speaking participants showed a strong effect for object colour with coloured pictures named on average 58ms faster than the grey ones independent of object category or the diagnosticity of the colour of the item. Performance between the three subgroups (1-month group, 3-months group, and 6-months group) showed no significant difference when analysed separately and colour effects were unaffected by age, or gender.

The results of the repeated naming task were also straightforward: (1) there was again a highly significant effect for object colour with coloured pictures named faster than grey ones independent of object category or the colour diagnosticity of the item and independent whether objects where easy or difficult to segment. (2) There was no difference in the colour effects between study and test showing that colour facilitated the naming process equally well during encoding and recall. (3) Naming the pictures for a second time resulted in strong priming effects with on average 78.03ms faster naming for pictures that were repeated from study to test. (4) Priming magnitudes were the same across the six picture designs showing that pictures were primed in the same manner regardless of differences in surface details

(object and background colour), segmentation demand (plain or noisy background), congruity of object and background colour, object category and colour diagnosticity of the object. (5) Priming magnitudes remained stable over time with no decline across the four different delays: 12 days, 30 days, 90 days, and 180 days. (6) Priming effects for colour did not decay over time. (7) Group analyses revealed no difference in priming behaviour across the three subject groups of experiment 2, and no difference across groups when analysing all five subject groups including the two German subject groups from the repeated naming task of experiment 1. This clearly shows that priming was also unaffected by subject factors such as age, gender, health (aphasic / non-aphasic), or the language the pictures were named in (English or German).

How do our results relate to findings of other studies and to models of visual priming? Our findings fit with computational models on visual priming (Ullman, 1995; Friston, 2005; Grill-Spector et al., 2006) that repetitive experience with a stimulus facilitates operations of analogies, associative activation and generation of prediction if the perceptual representation of the stimulus matches the representation in memory. It is assumed that the generation of predictions, as top-down process, facilitates the recognition process by reducing the number of possible candidates of object representations that need to be considered thereby speeding up the recognition process. These models are supported by findings from neuroimaging studies that found decreased activity for brain regions involved in object recognition after stimuli were processed for a second time (e.g., Wiggs & Martin, 1998; Grill-Spector et al. 1999; 2006; James et al., 2000; Simons et al., 2001; Vuilleumier et al., 2002; Horner & Henson, 2008).

Three neuroimaging studies that specifically investigated neuronal activity during repeated *naming* of pictures found priming associated changes in the posterior regions bilaterally and

changes in the left frontal brain (van Turennout et al., 2000; 2003; Meister et al., 2005). It was suggested that the decreased activity in the posterior parts of the brain reflect a sparser and more efficient object representation due to perceptual learning, whereas decreased activity in the left anterior regions reflect experience-induced reorganization of brain circuitry mediating lexical retrieval. Our results do not allow to directly distinguish between these two learning processes that were observed in these fMRI studies. However, if the priming effects found in our study were mediated mainly at the level of lexical retrieval, than we should have observed much lower priming magnitudes for the aphasic than for the non-aphasic subject groups, but this was not the case as priming was the same across all the groups. We should have also found differences in priming times related to the semantic- and lexical selection demands of the pictures (e.g., higher processing demands for pictures with grey than with coloured objects), but that was again not the case as all six different picture versions primed the same way. Because our priming results were unaffected by such conceptual factors, results would fit with the assumption that priming during repeated picture naming is an implicit process (i.e. occurs without intention) which is mainly mediated at the perceptual levels of object recognition (Brown et al., 1991; Roediger & McDermott, 1993; Park & Gabrieli, 1995; Roediger & Geraci, 2005). Research has shown that priming at perceptual levels can last over long periods (e.g., Nickerson, 1968; Cave, 1997; Maylor, 1998; Mitchell, 2006) while priming at higher conceptual levels is prone to a faster decay (Roediger & McDermott, 1993; Brown et al., 1996; Roediger & Geraci, 2005). Our results contribute to findings on long lasting priming effects in perceptual priming tasks as they demonstrate that priming during repeated picture naming remained stable over a period of six months.

How do our results relate to other studies that measured priming effects over more than one retention period? Other experiments on repetition priming in picture naming have shown that priming magnitudes may drop rapidly after very short delays (i.e. immediate recall) but that facilitation loss is slower over longer retention periods (Mitchell & Brown, 1988; Mitchell at

al., 1990; Brown et al., 1996; van Turennout, 2000; 2003; Francis & Saenz, 2007). This is in line with the early theory by Ebbinghaus (1885) that forgetting generally occurs rapidly at first but slows over time. Thus, the longer an item is retained in memory, the less likely it is to be lost in the next unit of time. Long lasting priming effects in picture naming that do not decline between retention intervals as found in our study, have been reported by other people when using *achromatic* picture stimuli. For instance, no decline in priming magnitudes were found between 1hour, 6 hours, and 3 days (van Turennout ,2003), between 1 day and 6 weeks (Meister et al., 2005), and between 1,4, and 6 weeks (Mitchell & Brown,1988). The findings by Cave (1997) were not that straightforward as subject produced more variation in naming latencies and priming times across the different delays. Accordingly, Cave (1997) found a decline between 6 weeks (-72ms) and 48 weeks (-28ms), but stable priming times between the intervals of 8,10,12,16, 24, and 32 weeks (on average -50ms). To our knowledge, the only study that measured priming times over different retention periods (1hour and 48 hours delays) with *coloured* picture material is the study by Cave et al. (1996). Likewise, in our study, Cave and her colleagues showed that priming for colour did not decay over time. However, they used artificially coloured line drawings of artefacts and may have measured new association learning rather than measuring priming effects on realistic picture material as it was used in our study. Their results are therefore difficult to compare with our study. Studies on priming of recognition of scenes have shown that colour enhances *accuracy* of recognition during recall (Homa & Viera, 1988; Gegenfurtner & Rieger, 2000; Suzuki & Takahashi, 1997; Wichmann et al, 2002; Spence et al., 2006). Unfortunately, none of these studies compared the *processing time* of chromatic with achromatic picture versions of the scenes between study and test. One could assume that the recognition advantage by colour at test originated from a richer scene (and object) representation that has been stored in memory when the scenes were seen for the first time. If objects in colour provide a richer representation in memory than priming should not only result in enhanced accuracy but in

enhanced priming magnitudes as well. However, we did not find a superiority of coloured objects over grey ones for priming magnitudes in our results. The reason for this may lie in the different task demands: priming in recognition tasks may involve more conscious recollection strategies than naming task do. In fact, recent (Brady et al, 2008) and older work (Standing, 1973) could show that visual long-term memory has a massive storage capacity for object details including colour when subjects are instructed to explicitly memorize what they have seen. Brady et al. (2008) could show that observers were capable to make same / different judgements that were between 87% - 92 % correct after they had memorized a large set of stimuli once during a 3 seconds presentation time per picture. The stimulus set consisted of pictures of 2500 real world objects presented in their original colours and placed in front of a white background. At recognition, participants were confronted with a mixed set of old items and new items that differed either by category, by exemplar or just by state (e.g., opened or closed dresser). The high accuracy rate of the same / different judgements when dealing with such a large set indicated that observers did not store only the gist information of the objects but encoded and retained many specific details about each of the objects (see also Homa & Viera, 1988 about what is stored in scene recognition, and Fagot & Cook, 2006 about memory-based exemplar and featural learning strategies in Monkeys).

In contrast, results in our study derived from an implicit priming task where subjects were left naïve about the real purpose of the study and where they were not encouraged to explicitly memorize the pictures they had to name. The observed effects for object colour in our study suggest that object colour leads to a coding advantage at study and to a coding advantage at test. This coding advantage feeds through the system and speeds up subsequent levels of the naming process both at study and at test. At a second encounter with the stimulus, the overall processing time is reduced but there is no decrease or increase of the colour effect when compared with achromatic picture representations. Any time differences between the six

picture versions that occurred at study due to picture details remain the same when the pictures are named again at test. How do our results fit with current models of priming? Because priming times in our study were unaffected by perceptual differences of the pictures, our results may best fit with the 'facilitation model' which states that in the beginning neurons fire robustly to both first and repeated presentation of the stimulus, but that the neuronal activity stops sooner when the stimulus is repeated. Because repetition of the stimulus improves prediction, synaptic changes accelerate, leading to shorter processing time (James et al., 2000; Grill-Spector et al. 2003; Henson & Rugg, 2003; James & Gauthier; 2003; Friston, 2005). This means that the observed priming magnitudes in our experiment are a result of synaptic potentiation when the pictures are named for a second time and this priming mechanism occurred for each of the picture version in the same way.

Results also showed that priming behaviour was unrelated to age differences across the subject groups. This is in line with several other studies who found that statistically, picture-naming priming is unaffected by age although numeric trends mostly favour the younger (Benton, 1967; Mitchell, 1989; Mitchell et al., 1990; Johnson et al., 1996; Fleischman et al., 2005; Ally et al., 2008).

4.5: Conclusion

Experiment 2 was designed to investigate whether there is decay in priming times with respect to colour during repeated picture naming by comparing different delays. The main effect of the results showed strong priming effects for pictures that were repeated from study to test with, on average, 78.03ms faster naming. Similar to the results in experiment 1, it was found that object colour facilitated the naming process equally well during encoding (at

study) and recall (at test). In addition, priming magnitudes were the same across the six picture designs, showing that pictures were primed in the same manner regardless of differences in surface details (object and background colour), segmentation demand (plain or noisy background), congruity of object and background colour, object category and colour diagnosticity of the object. This means that there was no advantage in priming magnitudes for colour whether it appeared in the object or in the background of the renamed picture. These observations replicated the results found with the two German subject groups in the repeated naming task of experiment 1, where we had used a shorter delay (12 days) between study and test. The results of experiment 2 further showed that priming magnitudes remained stable over time with no decline across the three different delays: 30 days, 90 days, and 180 days and no differences among the three subject groups. Most importantly, however, results showed that there was no decay in priming effects for colour over time. This latter observation is in line with the theory that priming during repeated picture naming occurs implicitly at the *perceptual* levels of object recognition (e.g., Roediger & McDermott, 1993) and can remain stable over time (e.g., Mitchell, 2006). No evidence was found that priming was also mediated at higher levels of the naming process as suggested by studies using fMRI (van Turennout et al., 2000; 2003; Meister et al., 2005), because priming magnitudes were the same for aphasic and non-aphasic subjects as revealed in the group analysis across all five subject groups that included the two German subject groups from experiment 1. Finally, because priming times in our study were unaffected by perceptual differences of the pictures and by inter-subjects variables (health, gender, age, spoken language), results also fit with a neuronal model of visual priming, namely the ‘facilitation model’, stating the neuronal activity has the same pattern during encoding and recall, but that stimulus repetition improves prediction and thereby leading to shorter processing time when the stimulus is repeated (e.g., James et al., 2000; Grill-Spector et al. 2003). To our knowledge, this is the first study to show

that colour effects on priming during repeated picture naming can last without any decay over a period of 12 to 180 days.

Chapter 5: Experiment 3 - Colour effects on rapid object detection

5.1: Introduction

Data from the two previous experiments on object naming clearly demonstrated that object colour speeds up the naming process compared with when objects are shown in greyscale. Results showed that the reaction time advantages that accrue for coloured objects were strongly influenced by high-level processing stages including conceptual object knowledge and lexical selection, making it difficult to separate the influence of colour on earlier low-level visual processing stages such as object segmentation. We therefore decided to use an ultra-rapid object detection task with a subset of our stimuli to separate earlier from later visual processing stages and to measure how colour might affect object segmentation *before* semantic object processing occurs.

Evolutionary theories assume that colour vision in humans evolved in order to facilitate objects vision and to give objects meaning (Skorupski & Chittka, 2008). Colour vision allows for objects to be distinguished in fluctuating light conditions, e.g. detecting the fruit amongst foliage falling in sunlight or shadow, and to successfully discriminate a real edge from a simple shadow boundary (Gordon & Abramov, 1998). This means that colour adds a further dimension to the visual system where spectral reflectance is independent of luminance (Goffaux et al., 2005; Bowmaker & Hunt, 2006; Bowmaker, 2008). However, the brain is not just a passive recipient of sensory information and memory influences the interpretation of sensory information. Computational models therefore assume that figure-ground differentiation is based on experience, in that top-down information can influence and modulate lower visual processing stages. This means that object segmentation, detection, categorization and identification are interactive processes involving feedback loops that run from early visual processing stages to the prefrontal areas of the brain and back again to form

predictions about an object's identity (Borenstein & Ullman, 2002; Friston, 2005; Ullman, 2006; Kveraga et al., 2007). The computational model of Borenstein & Ullman (2002) and Ullman (2006) states that incoming images are compared with template-like fragments, stored in memory from previous experience of the world, where each subregion of the template is computed as either figure or ground. The information in this fragment-based representation then entails both the information about the object category *and* the figure-ground segmentation of the image. In fact, there is empirical evidence that segmentation and categorization of scenes and objects are strongly linked together in that object categorization influences segmentation (Peterson & Gibson, 1993, 1994; Peterson & Kim 2001; Peterson & Lampignano, 2003). Furthermore, studies using magnetoencephalography (MEG), event-related potentials (ERP) (Liu et al., 2002; Halgren et al., 2003) and behavioural paradigms show that *detection*, *segmentation*, and *basic level categorization* of objects occur at the same time and that they may use the same perceptual information (Evans & Treisman, 2005; Grill-Spector & Kanwisher, 2005; Ullman, 2006; Bowers & Jones, 2007; Mack et al., 2008). In contrast, results from studies using ERPs (Curran et al., 2002) and functional magnetic resonance imaging (Grill-Spector, 2003; Grill-Spector et al., 2004) indicate that *identification* of a given category may be based on the same processing mechanisms, but occurs later in time, as additional time for processing is needed to perform an identification task compared with simple object detection (+ 65ms in the study by Grill-Spector et al., 2004). Hence, using an ultra rapid object detection task may enable us to measure colour effects on object segmentation *before* higher-level identification processing influences overall reaction times.

That colour facilitates segmentation has been shown in several studies across different paradigms. For instance, positive effects due to colour were found on pattern recognition (Gur & Akri, 1992; Li & Lennie, 1997; Syrkin & Gur 1997), on defining object contours (Rivest & Cavanagh, 1996; Kentridge et al., 2004; Kingdom et al., 2004; Kingdom & Kasrai, 2006) and

on object recognition (Chaparro et al., 1993; Møller & Hurlbert, 1996; Bloj et al., 1999; Gegenfurtner & Rieger, 2000; Edwards et al., 2003; Fine et al., 2003; Shevell & Kingdom, 2008; in faces :Yip & Sinha, 2002; Edwards et al., 2003; Russel & Sinha, 2007).

However, rapid object detection paradigms that tested colour effects have yielded mixed results, which are highly task dependent. For instance, Fei-Fei et al. (2005) found null effects for colour when using a go/no-go animal detection task in briefly presented scenes (27 ms) placed peripherally on a screen. Whereas Delorme et al. (2000) found that humans detected animals about 2% more accurately and food items 10-15ms faster (both effects were significant) in briefly flashed photographs (20ms for humans and 32ms for monkeys) of food and animal targets when they were in colour compared with when they were grey. Contrary to people, accuracy and processing speed for monkeys were only slightly better with colour for familiar, but not for untrained, items. Furthermore, most colour advantages were found for items with longer reaction times but not for the faster ones. The authors concluded therefore that colour might have boosted only the ambiguous photographs by supporting segmentation, for instance, in close-up views of a rose vs. a salad, but that colour in general is not a crucial aspect in object detection and that any benefit by colour occurs at a later stage of processing. Yao & Einhäuser (2008) came to a similar conclusion when using a task where observers were asked to detect and then report the presence of animal images in greyscale and colour stimuli. Their paradigm consisted of a two-target rapid serial visual presentation where each trial consisted of forty images that were presented for 50 ms each with the first half (20 images) presented in greyscale and the second half in colour or *vice versa*. The target picture with the animal appeared first between frames 6-15, and for a second time between frames 26-35. Although seven out of their ten subjects detected the coloured animals more accurately in T1 (when seen *first*), and only two out of ten in T2, results were not considered to be in favour for colour during initial detection. It was further observed that subjects showed a

strong preference for reporting coloured targets when targets were of different species, but that they chiefly reported the second target when animals were of same species. Because of these differences, it was concluded that colour had little effect on detection, but was used in later stages of processing for recollection. However, their results might have been flawed because the authors neglected negative priming effects that could have occurred when the target pictures were repeated within the trial and changed in their colour appearance. It has been shown by Gegenfurtner & Rieger (2000) that changing the colour of the same target picture between study and test (T1 and T2) reduces recognition accuracy and this already occurs at stimulus presentation times of 32ms.

In contrast to the observations by Delorme et al. (2000), Fei-Fei et al. (2005), and Yao & Einhäuser (2008) are conflicting findings that colour improves recognition in rapid detection tasks. For instance, Wichmann et al. (2006) found a significant increase in accuracy for coloured stimuli of 3% in a go/no-go animal detection task when scenes were presented briefly (50 ms) and placed centrally on a screen. In some of their earlier experiments, the accuracy rate was 5%-10% higher for coloured stimuli of different scenes, compared with greyscaled scenes, when various stimulus exposure times between 50ms and 1000ms were used in a rapid recognition task (Wichmann et al. (2002). Furthermore, Gegenfurtner & Rieger (2000) found a colour advantage in the encoding and recognition of scenes with exposure times as short as 16ms. This is consistent with the findings of Edwards et al. (2003) in an attempted replication of the results of Delorme et al. (2000) in an electrophysiological investigation in the monkey. They presented chromatic and achromatic photographs that contained human or monkey heads, animals, everyday objects, or abstract figures for a duration of between 28ms and 167ms for detection. They found that information about colour was processed at the same time as shape in the monkey's IT cortex. This is opposite to the findings by Delorme et al. (2000) who also examined monkeys and stated that coarse

achromatic information that is mainly transmitted by the near colour-blind magnocellular pathway (M-pathway) is sufficient to allow ultra-rapid categorization. Edwards et al. (2003) found no evidence for such a first wave of achromatic processing, as most colour-sensitive cells responded earliest to the response onset of the coloured stimuli and that the majority of the tested neurons (70%) in the inferior temporal lobe (IT) evoked significantly reduced responses with the achromatic images compared with coloured ones. More evidence for a facilitating role of colour at rapid stimulus presentation times comes from studies on naming objects and scenes. Laws & Hunter (2006) showed better accuracy for coloured objects than for their grey scaled versions at 20ms presentation time, and Oliva & Schyns (2000) found better naming for correctly than for incorrectly coloured scenes at 30ms exposure duration.

Taken together, several behavioural studies have provided evidence that colour helps to segment objects and scenes and thereby facilitating object recognition. However, whether colour alters performance during rapid object detection and whether colour is related to object categorization remains controversial. This experiment aims to measure segmentation effects of colour at an early visual processing stage by using an ultra-rapid object detection paradigm and by contrasting the categories of living with non-living things to evaluate whether there is a category effect at such a short stimulus exposure time. Studies by Fei-Fei and colleagues (Fei-Fei et al., 2005; 2007) suggest that the visual system might be biased towards natural objects (living things) during object detection at ultra-rapid stimulus presentation times.

5.2: Method

Experiment 3 was constructed to measure time differences on object segmentation *before* semantic processing can take place by varying (a) object colour, (b) background colour, and (c) background context in a *fast object detection paradigm*. The test stimuli used in this

experiment were again from the newly created picture set. Experiment 3 was conducted at Durham University and used subjects who had not participated in any of the previous experiments. Participants were undergraduate students and staff from the Psychology Department. The dependent variable in this fast object detection task was reaction time.

5.2.1: Participants

Fifteen participants took part in experiment 3, twelve of whom were psychology students, and three were staff members. One of the students had to be excluded from the analysis because of unusually long reaction times and an excessive error rate. Of the remaining 14 participants, nine were female and five were male with a mean age of 24.8 years (between 18-36 years old), 13 were right-and one was left-handed see Appendix 8. The study was conducted under the ethical regulations of Durham University and all subjects gave consent to take part in the experiment. Six of the students were undergraduates and were given course credits for their participation. The other nine participants volunteered to take part in the experiment. All subjects had normal or corrected to normal vision and no colour vision deficits.

5.2.2: Stimuli

For the rapid object detection task in experiment 3, we selected 40 different objects from the original set and created four images that contained only backgrounds. The images of the 40 different objects contained only one single object. Half of the objects were from the manmade category with low colour diagnosticity, the other half were fruits (6), vegetables (7), and animals (7) and had high colour diagnosticity (see Appendix 3). All objects were presented in eight different picture versions, an additional two to those used in experiment one. These two additional picture variations contained the object in its original colour, but the backgrounds were transformed into grey. The backgrounds for the four new background images were

photographed under exactly the same conditions and equipped with the same horizon line as the rest of the set. The four backgrounds were a coloured plain background, a grey-scaled plain background, a coloured fractal noise, and a grey-scaled fractal noise. The eight different object picture designs and the four different background conditions are shown in the colour plate in Appendix 2 and explained down below.

Pictures with objects

1. cocp = **coloured object** in front of a **coloured plain background**
2. cogp = **coloured object** in front of a **grey-scaled plain background**
3. gocp = **grey-scaled object** in front of a **coloured plain background**
4. gogp = **grey-scaled object** in front of a **grey-scaled plain background**
5. cocn = **coloured object** in front of a **coloured fractal noise**
6. cogn = **coloured object** in front of a **grey-scaled fractal noise**
7. gocn = **grey-scaled object** in front of a **coloured fractal noise**
8. gogn = **grey-scaled object** in front of a **grey-scaled fractal noise**

Pictures with backgrounds only

9. cp = **coloured plain background**
10. gp = **grey-scaled plain background**
11. cn = **coloured fractal noise**
12. gn = **grey-scaled fractal noise**

Legend: c = coloured, **g** = grey-scaled, **o** = object, **n** = noise background, **p** = plain background

The total set for experiment 3 consisted of 640 images and a block of 28 practice items that were not analyzed. Half of the 640 images contained an object (40 objects x 8 different versions = 320), the other half was made of the four different background versions that did not contain any object. The 640 images were divided into eight blocks of 80 pictures each randomized for picture design with the constraint that each object version appeared only once.

5.2.3: Procedure

All subjects were tested individually. They were seated in a dimly lit room in front of a monitor and viewed the images from a distance of 50 cm. Stimuli were displayed using a Cambridge Research Systems Visage Visual Stimulus Generator on an EIZO FlexScan F56 17 inch computer monitor. The size of the pictures was 1048 x 699 pixels presented with a resolution of a height of 12.5cm and a width of 19.5cm against a dark-grey background. Each image was displayed for 20ms and was followed by a blank screen. Following the subject's response there was an interval of 600-1200ms before the onset of the next image.

The task was a go/no-go categorization task where subjects had to answer the question "is there an object in the image?" using a manual response. Participants were instructed to maintain the index finger of their dominant hand throughout the series on the button and to release the button as quickly as possible whenever they had detected the presence of an object in the scene. At the start of the experiment, each participant was given a series of 28 practice trials. The experiment proper consisted of eight series of 80 images, of which half were targets and half were non-targets in randomised order.

5.3: Results

5.3.1: Design

Experiment 3 was designed as an ultra rapid detection task in which 3 factors were varied in order to address the question of (a) whether colour has any influence on object segmentation and (b) if so, what role colour plays in the object segmentation process by systematically varying object and background colour and background context. Response latencies were the dependent variable.

5.3.2: Analysis

First, all responses where analysed for correct responses or false alarms in detecting the objects. Trials with pictures that contained only backgrounds were not further analyzed. Only trials with correct detection responses were included in the reaction time analyses. Mean reaction times were calculated for each subject and picture design as a *subject-based analysis* ($F1$), and for each object and picture design as *item-based analysis* ($F2$). Detection latencies more than 1.5 standard deviations from the mean of the participant or object respectively were classified as outliers and excluded. Greenhouse-Geisser correction was used when data violated the assumption of sphericity. Treatment means were compared using *LSD* (*Least Significant Difference*) Tests.

Reaction times

First, data were analysed subject-based ($F1$) and object-based ($F2$) using repeated measures ANOVAs with Picture design (eight levels) as within-subjects ($F1$) or within-items ($F2$) Factor. Results showed a highly significant effect for picture design with objects in front of a plain background detected faster than objects embedded in a noise ($F1(7,91) = 10.40$; $p<0.0001$); $F2(4.3,170.6) = 8.01$; $p<0.0001$). Pairwise comparisons further revealed that

objects in pictures that contained colour (either object or background in colour or both object and background in colour) were detected faster than objects in pictures that were overall grey (gogp, gogn). For the achromatic object and the *plain* achromatic background differences with the coloured plain background were (+6.9ms ($F1(1,13) = 5.03$; $p<0.043$); +1.1ms ($F2(1,39) = 0.52$; $p<0.821$)), and with the grey plain background and the coloured object (+8.9ms ($F1(1,13) = 5.22$; $p<0.040$); +7.0ms ($F2(1,39) = 2.52$; $p<0.120$)), and with the coloured plain background and the coloured object (+11.1ms ($F1(1,13) = 5.0$; $p<0.043$); +9.2ms ($F2(1,39) = 4.82$; $p<0.34$)). For the achromatic object and the *noise* achromatic background differences with the coloured noise background were (+11.5ms ($F1(1,13) = 3.68$; $p<0.077$); +11.6 ($F2(1,39) = 8.21$; $p<0.007$)), and with the grey plain background and the coloured object (+14.4ms ($F1$ $(1,13) = 8.09$; $p<0.014$); +19.0ms ($F2(1,39) = 13.93$; $p<0.001$))and with the coloured plain background and the coloured object (+12.8ms ($F1(1,13) = 8.03$; $p<0.014$); +10.8ms ($F2(1,39) = 3.96$; $p<0.054$)) (see figures 39 and 40.

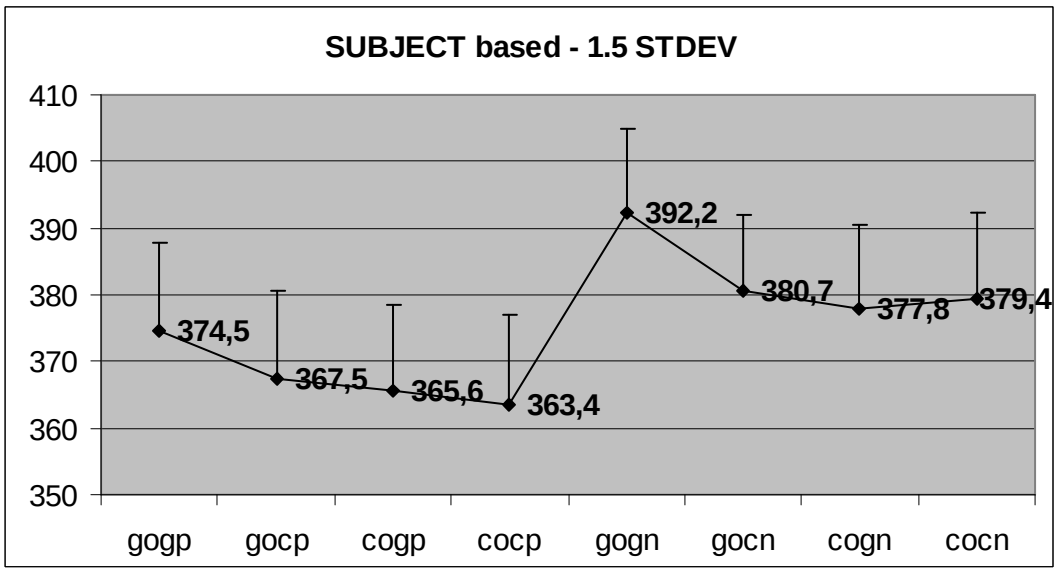


Figure 39. Mean reaction times in ms for the rapid object detection task in experiment 3 subject based. Legend: **c** = coloured, **g** = greyscaled, **o** = object, **n** = noise background, **p** = plain background, **gogp** = greyscaled object in front of a greyscaled plain background; **gocp** = greyscaled object in front of a plain background; **cogp** = coloured object in front of a greyscaled plain background, **cocp** = coloured object in front of a plain background; **gogn** = greyscaled object in front of a greyscaled noise, **gocn** = greyscaled object in front of a coloured noise; **cogn** = coloured object in front of a greyscaled noise, and **cocn** = coloured object in front of a coloured noise.

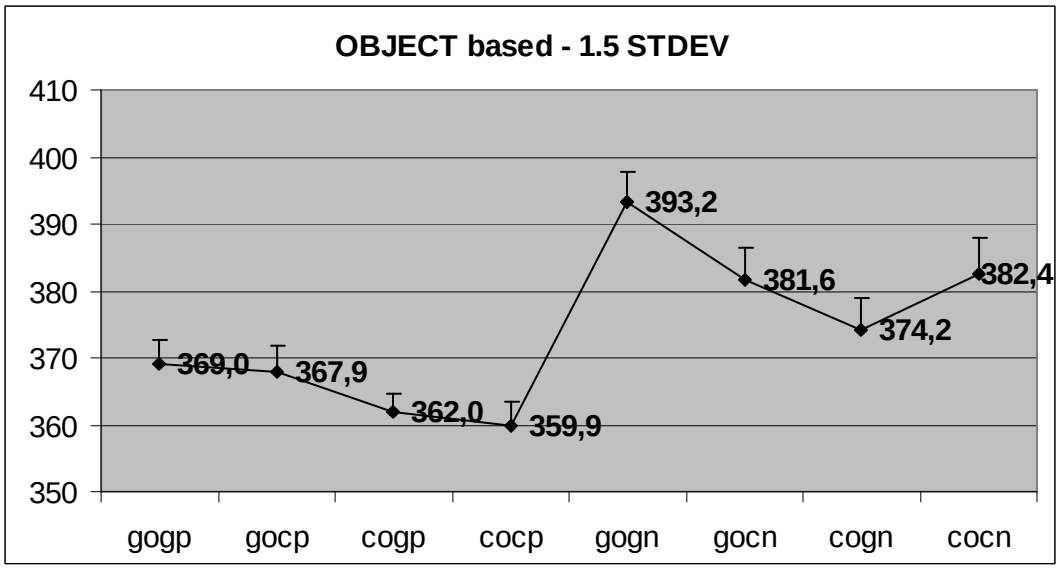
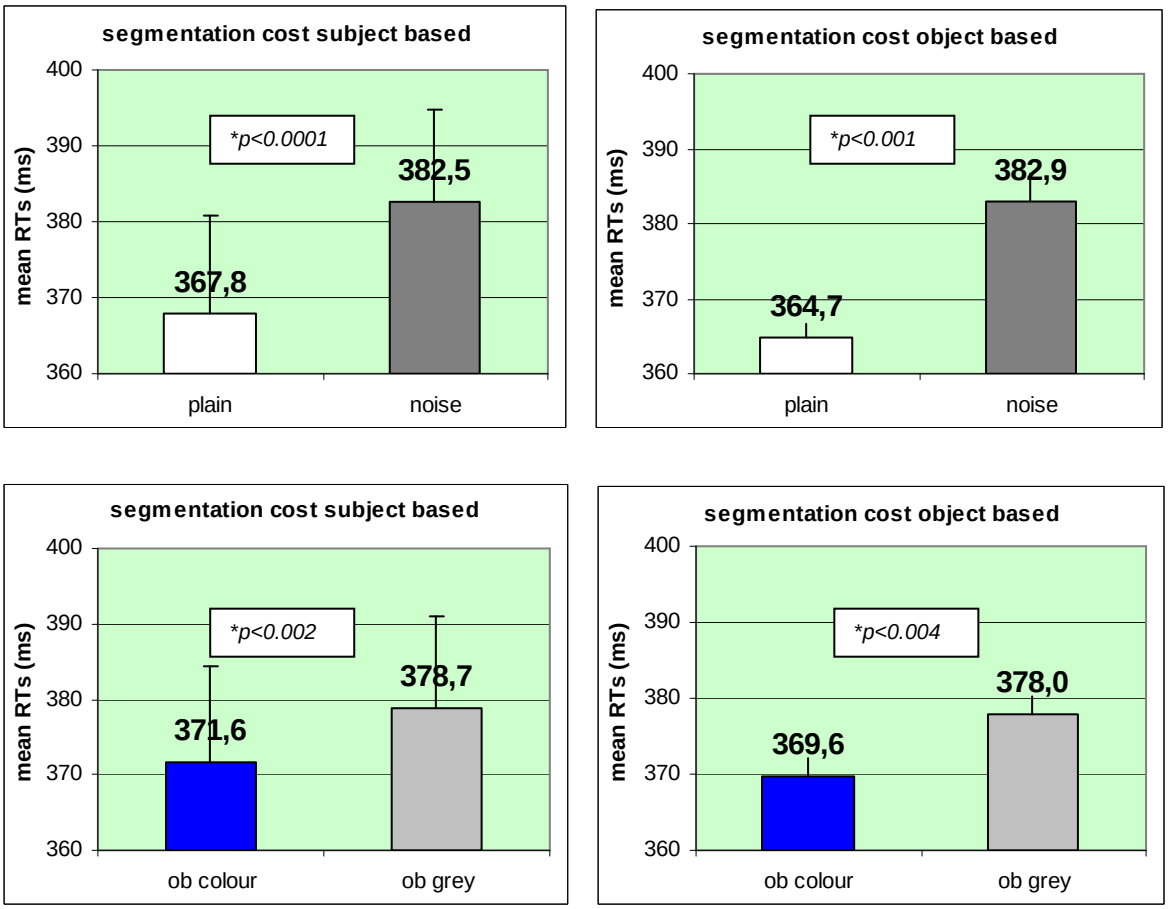


Figure 40. Mean reaction times in ms for the rapid object detection task in experiment 3 object based. Legend: **c** = coloured, **g** = greyscaled, **o** = object, **n** = noise background, **p** = plain background, **gogp** = greyscaled object in front of a greyscaled plain background; **gocp** = greyscaled object in front of a plain background; **cogp** = coloured object in front of a greyscaled plain background, **cocp** = coloured object in front of a plain background; **gogn** = greyscaled object in front of a greyscaled noise, **gocn** = greyscaled object in front of a coloured noise; **cogn** = coloured object in front of a greyscaled noise, and **cocn** = coloured object in front of a coloured noise.

To further analyse the segmentation costs in respect to colour, a 2 x 2 x 2 subject-based ($F1$) ANOVA and a 2 x 2 x 2 object-based ($F2$) ANOVA were carried out using Object colour (colour vs. grey), Background condition (plain vs. noise), and Background colour (colour vs. grey) as Factors. Results showed a significant effect for Object colour with objects in colour detected on average faster than objects in grey (-7.2ms ($F1(1,13) = 15.50$; $p<0.002$); -8.3ms ($F2(1,39) = 9.20$; $p<0.004$)) (see figure 41 c, d). The effect for Background condition was also significant with objects detected faster from plain than from noisy backgrounds (-14.7ms ($F1(1,13) = 38.19$; $p<0.0001$); -18.7ms ($F2(1,39) = 16.0$; $p<0.001$)) (see figure 41 a, b). The effect for Background colour was only significant in the subject-based analysis with objects detected faster from coloured than from grey backgrounds (-4.7ms ($F1(1,13) = 6.15$; $p<0.028$); -1.7ms ($F2(1,39) = 0.62$; $p<0.434$) (see figure 41 e, f). There was no Background condition x Object colour interaction ($F1(1,13) = 0.09$; $p<0.768$; $F2(1,39) = 0.12$; $p<0.722$), and no Background condition x Background colour interaction ($F1(1,13) = 0.07$; $p<0.936$;

*F*2(1,39) = 0.42; *p*<0.993). However, the Object colour x Background colour interaction showed positive trends (*F*1(1,13) = 3.56; *p*<0.082; *F*2(1,39) = 3.40; *p*<0.72) suggesting that objects in pictures with colour contrast were detected faster than objects in pictures where both object and background were grey. The Background condition x Object colour x Background colour interaction was only significant in the object-based (*F*2(1,39) = 4.47; *p*<0.041) but not in the subject-based analysis (*F*1(1,13) = 1.21; *p*<0.291). The results indicate that segmentation cost were lowest for objects in front of plain backgrounds. Object colour and colour contrast (i.e. picture designs that provided a colour contrast between the object and the background with either object or background in colour or both object and background in colour) also seemed to speed up the segmentation process. By far the highest segmentation costs seem to occur when objects and backgrounds were both grey.



Figures 41 a-f. Mean reaction times in ms for the rapid object detection task in experiment 3. Legend: **plain** = plain background, **noise** = noise background; **ob colour** = object in colour; **ob grey** = object in grey; **bg colour** = background in colour; **bg grey** = background in grey.

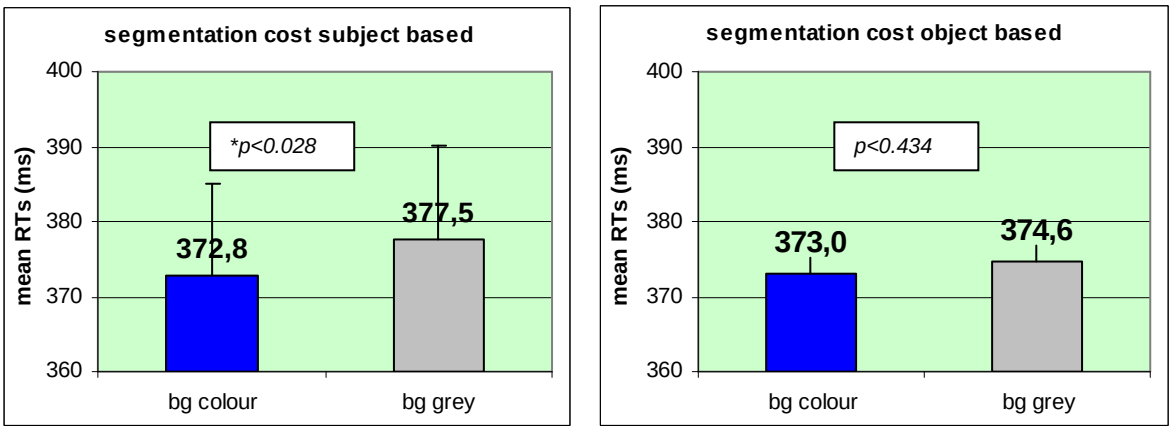


Figure 41 a-f. Mean reaction times in ms for the rapid object detection task in experiment 3. Legend: **plain** = plain background, **noise** = noise background; **ob colour** = object in colour; **ob grey** = object in grey; **bg colour** = background in colour; **bg grey** = background in grey.

To analyse whether any category effects influenced object detection latencies, we first conducted an item based ANOVA with Picture design (eight levels) as within-items Factors and Category (20 living vs. 20 non-living items) as between-items Factor. In a second step, a 2 x 2 x 2 x 2 item based ANOVA was carried out with Object colour (colour vs. grey), Background condition (plain vs. noise), Background colour (colour vs. grey), and Category (living vs. non-living items) as Factors. The results for the first ANOVA revealed again a highly significant effect for picture design ($F2(4.3,166.4) = 8.51$; $p<0.0001$) with objects in front of plain backgrounds detected faster than objects embedded in a noise. The effect for Category was also significant showing that living items were detected on average 11.1ms faster than non-living items ($F2(1,38) = 9.65$; $p<0.004$) (see figure 42). This category effect was the opposite of what we have found in the naming tasks of experiments 1 and 2 where living items were *named* much slower compared with non-living items. Opposite category effects for basic-level categorisation and naming tasks are in line with theories stating that living items have a processing speed advantage in basic-level categorisation task such as in object detection, however, when the selection demand between the objects increases such as it is required for naming, living items are processed slower (Humphreys et al., 1999; Gale et al., 2003; Låg, 2005). It is nevertheless astonishing that a category effect arose at such a short

stimulus presentation time of 20ms. This rapid object detection task was constructed to mainly measure segmentation effects and included an *implicit* categorisation task. Subjects were not instructed to pay any attention to object origin or object detail and it was possible to perform the task by using low-level cues only, category effects were therefore not expected.

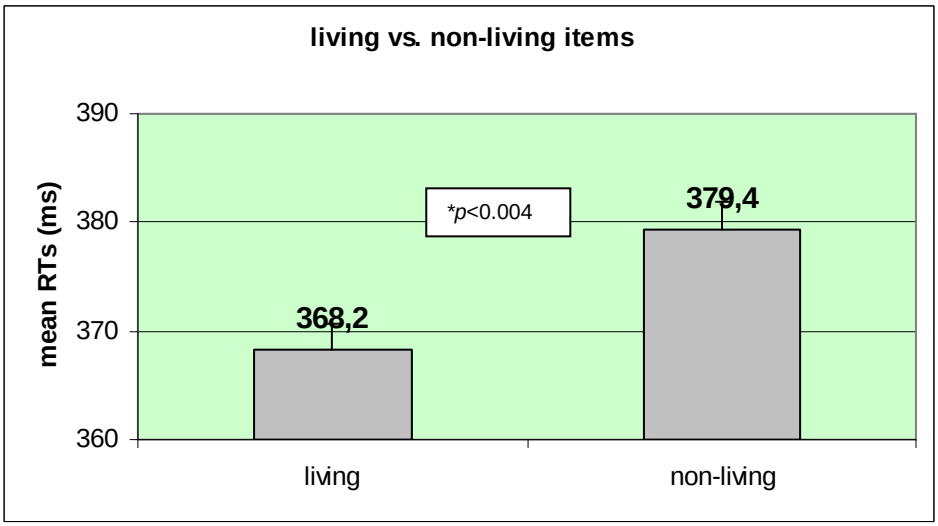


Figure 42. Mean reaction times in ms for the rapid object detection task in experiment 3 for living and non-living items.

The second ANOVA showed again a main effect for Background condition with objects detected faster from plain than from noisy backgrounds (-18.2ms ($F2(1,38) = 17.27$; $p<0.0001$) and a main effect for Object colour with objects in colour detected faster than the grey ones (-8.3ms ($F2(1,38) = 9.55$; $p<0.04$). Contrary to the subject-based analysis, the main effect for Background colour was not significant (+1.7ms ($F2(1,38) = 0.068$; $p<0.440$). The Object colour effect was independent of Background condition ($F2(1,38) = 0.134$; $p<0.716$), and independent of Category: no Object colour x Category interaction ($F2(1,38) = 2.49$; $p<0.123$) and no Object colour x Background condition x Category interaction ($F2(1,38) = 2.92$; $p<0.96$). These latter effects were the same as found in the naming tasks of experiments 1 and 2 where the advantage of object colour was unrelated to whether objects belonged to the category of living or non-living things. There was no difference between the categories

related to Background colour ($F2(1,38) = 0.005$; $p<0.946$), but a significant Category x Background condition interaction ($F2(1,38) = 4.09$; $p<0.050$) with no difference between the two categories when the backgrounds were plain, but a processing speed advantage for living items of 19.98ms when the background was noisy. The Category x Background condition x Background colour interaction was also significant ($F2(1,38) = 7.72$; $p<0.008$) with living items detected faster (-7.92ms) but non-living items slower (+4.55ms) from a coloured than from a grey noisy background. For the plain background conditions, these effects were exactly the other way round +4.88ms for the living items and -8.17ms for the non-living items when the background was in colour. There was a positive trend for the Object colour x Background colour interaction ($F2(1,38) = 3.69$; $p<0.062$), which was also observed in the previous subject-based and object-based 3-way ANOVAs ($F1(1,13) = 3.56$; $p<0.082$); $F2(1,39) = 3.40$; $p<0.72$)) and a Category x Object colour x Background colour interaction ($F2(1,38) = 4.26$; $p<0.046$) showing that pictures with enhanced contrast between object and background (i.e. were object and background colour differed) were detected faster and this was especially valid for the category of non-living items. The Background condition x Object colour x Background colour interaction was also significant ($F2(1,38) = 4.46$; $p<0.041$) showing that colour contrast between object and background had a stronger effect in the noise condition (see figure 43).

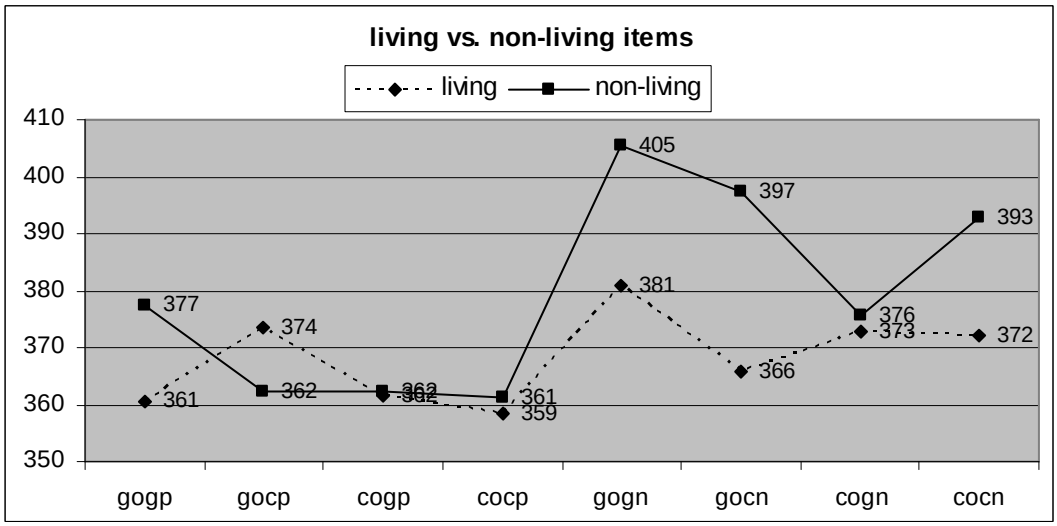


Figure 43. Mean reaction times in ms for the rapid object detection task in experiment 3 for living and non-living items per picture design.

Taken together, results show that objects embedded in a noisy background condition are detected slower with additional segmentation costs of on average +18ms than objects from a plain background condition. Results also indicate that colour may speed up the segmentation process by on average -8ms. This main effect for object colour was significant in the 3-way ANOVAS subject-based ($p<0.002$) and object-based ($p<0.004$), and in the 4-way ANOVA object-based ($p<0.04$). However, results were less conclusive when reaction times were analysed per category as between-item Factor (20 living vs. 20 non-living objects). As can be seen in figure 43, mean reaction times for pictures with the object in colour were not generally faster than for those where the object is grey when the two categories were computed as between-item Factors, which was also shown in the non-significant Object colour x Category interaction ($p<0.123$). Nevertheless, a closer look at individual mean detection times per subject (14) and per object type (40) and picture design, reveal that only 2 out of 14 subjects (14.28%) in the plain background conditions, and 1 out of 14 subjects (7.14%) in the noise background conditions responded fastest to pictures that were *overall grey*. The same was valid for the individual object scores: only 5 out of 40 objects (12.5%) in the plain condition and 2 out of 40 objects (5%) in the noise condition were detected faster in

pictures that were overall achromatic. Whereas, 67.85% (plain) and 78.57% (noise) of the subjects responded faster when the object was in colour than when it was grey, and 60% (plain) and 61.25% (noise) were the percentages object based. Similar numbers were found for the effect of colour contrast: 64.28% (plain) and 71.43% (noise) of the subjects responded faster when the picture contained a contrast between object and background colour (i.e. when object and background colour differed) than when the pictures were overall grey (i.e. low in contrast), and 53.75% (plain) and 71.25% (noise) were the percentages object based see tables 3 and 4. The percentages about the colour contrast are reflected in the positive trends for the Object colour x Background colour interactions indicating that objects in pictures with enhanced *colour contrast* may facilitate segmentation and thereby speeding up the detection process. This is in direct contrast to the findings in the naming tasks where such pictures were named slowest because the incongruity between object and background colour slowed down the lexical selection process. Although our results may not provide a clear picture of how colour affects rapid detection in respect to *object category*, results do indicate a difference between the two categories in respect to *background colour* and *background condition*. It showed that living items are detected much faster than non-living items when the background is a noise, and this is even more so when the noise is in colour.

Reaction times ultra-rapid detection task experiment 3 per subject								
Subject	**gogp**	**gocp**	***co*gp**	***co*cp**	**gogn**	**gocn**	***co*gn**	***co*cn**
1	321,0	296,4	311,6	314,7	353,9	314,0	315,9	331,5
2	322,4	322,9	311,1	315,5	326,7	354,3	339,4	324,0
3	325,2	315,8	331,7	314,2	343,7	352,5	339,1	335,1
4	328,6	331,3	329,8	345,4	368,8	359,4	348,2	346,8
5	346,8	340,6	336,4	344,6	371,5	355,0	340,9	353,3
6	347,3	350,9	357,9	349,9	353,9	361,1	352,1	345,1
7	348,7	342,8	335,9	330,4	376,6	338,9	336,6	343,7
8	367,4	368,3	340,4	337,8	397,2	377,2	369,6	373,1
9	378,0	375,0	375,5	364,0	379,9	399,9	388,0	413,2
10	402,9	396,9	403,4	391,4	412,8	407,6	421,4	402,7
11	420,6	384,5	374,1	363,4	410,6	407,7	418,9	413,4
12	422,7	430,6	424,0	422,3	445,3	412,8	416,8	417,7
13	424,4	414,9	411,0	396,4	451,4	407,1	421,0	423,6
14	486,9	474,4	476,2	497,4	498,6	482,6	480,7	488,7

Table 3. Mean reaction times in ms per subject for the rapid object detection task in experiment 3. Legend: **gogp** = greyscaled object in front of a greyscaled plain background; **gocp** = greyscaled object in front of a plain background; **cogp** = coloured object in front of a greyscaled plain background, **cocp** = coloured object in front of a plain background; **gogn** = greyscaled object in front of a greyscaled noise, **gocn** = greyscaled object in front of a coloured noise; **cogn** = coloured object in front of a greyscaled noise, and **cocn** = coloured object in front of a coloured noise.

Reaction times ultra-rapid detection task experiment 3 per object

Object	Cat.	**gogp**	**gocp**	***cogp***	***cocp***	**gogn**	**gocn**	***cogn***	***cocn***
chicken	1	334,6	308,2	329,2	385,4	381,3	360,7	367,9	393,8
cucumber	1	338,9	346,2	349,0	360,8	414,8	395,3	424,7	377,4
snake	1	340,9	348,6	368,5	356,8	382,8	335,2	332,0	373,7
horse	1	345,1	359,4	363,0	378,9	393,0	355,8	403,6	395,8
onion	1	347,4	375,0	342,6	322,4	404,8	348,6	318,8	372,6
alligator	1	347,4	382,8	362,2	358,1	427,6	387,8	429,7	390,6
pepper	1	351,6	381,5	389,3	342,4	419,5	380,2	350,3	358,0
strawberry	1	354,2	397,1	339,8	324,2	402,3	361,8	371,4	384,6
coconut	1	355,5	376,3	381,0	338,9	410,5	356,8	391,9	355,5
pear	1	358,1	404,9	378,1	364,6	354,2	337,7	359,4	329,5
orange	1	360,6	385,0	357,0	370,3	363,3	376,6	352,9	365,4
crab	1	364,2	349,0	347,4	347,7	398,4	387,8	406,2	384,9
potato	1	365,4	403,1	354,2	352,2	343,7	375,0	345,1	354,2
pig	1	369,8	375,0	340,9	346,6	335,2	375,0	338,9	414,8
sweet corn	1	373,6	417,6	399,1	373,4	346,4	375,0	362,0	359,4
celery	1	373,6	395,8	386,7	362,0	376,4	367,8	364,6	343,8
aubergine	1	375,0	367,2	358,2	367,2	354,6	352,9	402,3	394,9
banana	1	378,9	384,6	372,8	352,3	339,8	333,8	345,1	338,9
apple	1	388,0	332,8	359,4	393,8	375,0	367,8	368,5	383,5
squirrel	1	390,6	379,8	353,4	372,4	397,1	385,8	418,0	368,5
sock	2	323,9	369,8	360,6	367,8	408,9	420,7	453,1	501,6
screwdriver	2	350,3	404,7	371,4	334,1	394,9	390,6	390,6	364,1
shoe	2	356,8	329,5	373,6	332,4	375,0	355,5	362,2	409,4
Lego	2	359,4	363,3	386,7	368,5	411,1	434,9	418,3	395,4
firelighter	2	359,4	363,0	380,7	370,2	424,3	414,1	345,1	434,9
teapot	2	360,6	332,9	350,9	346,2	409,1	393,5	390,6	378,3
wool	2	363,0	340,9	377,6	348,6	397,1	419,0	369,0	351,6
candle	2	365,9	407,7	365,4	373,6	394,5	377,6	353,4	382,8

pencil	2	367,2	349,0	367,9	346,4	427,1	415,4	381,9	450,3
mug	2	373,7	354,2	337,7	333,3	384,9	401,0	365,0	391,9
pincers	2	376,3	358,1	360,8	334,1	379,7	365,9	339,5	359,4
clothes peg	2	384,1	364,6	356,8	375,0	468,8	442,7	414,1	467,0
umbrella	2	384,1	346,4	364,6	325,3	428,1	462,2	369,3	407,6
vase	2	389,2	375,0	319,0	402,3	406,3	346,2	404,8	371,4
book	2	389,4	342,5	343,8	362,0	399,7	394,5	359,4	353,4
ruler	2	393,8	369,8	381,5	369,0	412,8	391,8	351,0	350,3
toy car	2	394,5	340,4	355,5	413,4	401,6	380,2	369,3	354,6
hot water bottle	2	396,3	365,9	346,6	393,5	381,0	397,1	369,8	391,9
sponge	2	421,9	358,0	367,2	343,7	375,0	334,6	360,7	369,8
toothbrush	2	438,8	410,2	380,7	385,4	429,0	410,9	347,7	371,4
mean naming									
RTs exp. 2		**gogp**	**gocp**	***co*gp**	***co*cp**	**gogn**	**gocn**	***co*gn**	***co*cn**
living		767.4	810.0	-	**700,2**	**773.4**	826.9	-	798.0
non-living		763.0	736.2	-	**710,2**	**773.7**	796.6	-	736.3

Table 4. Mean reaction times in ms per object for the rapid object detection task in experiment 3. Legend: **Cat.** = object category, **1**= living, **2** = non-living item; **gogp** = greyscaled object in front of a greyscaled plain background; **gocp** = greyscaled object in front of a plain background; **cogp** = coloured object in front of a greyscaled plain background, **cocp** = coloured object in front of a plain background; **gogn** = greyscaled object in front of a greyscaled noise, **gocn** = greyscaled object in front of a coloured noise; **cogn** = coloured object in front of a greyscaled noise, and **cocn** = coloured object in front of a coloured noise. The mean *naming* reaction times per category for these objects were taken from experiment 2.

5.4: Discussion

The results of the object detection task suggest that *object colour* may play a role in ultra-rapid object detection, probably by facilitating object segmentation. However, although the main effect for object colour was statistically highly significant, it did not show consistency when looking at individual subject scores or mean detection times per object type and picture design (see table 3 on page 205 and table 4 on page 206). These observations are similar to those made by Delorme et al. (2000), who found a large amount of variability between their ten subjects in accuracy scores and reaction times in respect to colour. A closer look at their

tables with the individual subject scores in the food and animal task (p. 2194) shows that ten out of ten subjects responded faster with food items and six out of ten with animals when the pictures where in colour than when they were grey, although that not all of these colour advantages reached significance. It further showed that subjects with slower reaction times profited more from colour than subjects with very fast reaction times. This led the authors to the assumption that colour is only a relevant feature for subjects that need longer to respond. Furthermore, they came to a similar conclusion when examining individual object scores, claiming that only pictures that might be ambiguous for segmentation would benefit from colour, as pictures that were detected fast did not show much benefit from colour whereas the slower detected pictures did. This was clearly different in our study. As can be seen in the tables 3 and 4, colour effects were not related to whether an object was detected faster or slower. In addition, subjects showed similar patterns in respect to colour whether their individual reaction times where faster or slower (i.e. above or below 350ms). The variability between subject's performance and individual object processing times in respect to colour observed by Delorme et al. and in our study, may rather indicate that there is more than one strategy to perform an ultra-rapid object detection task, than to indicate whether colour per se matters or not.

The average time gain by object colour was 8ms in our ultra-rapid object detection task, which shows that object colour does not play the same strong role as found in the previous two naming tasks where the colour advantage was much higher in proportion to the overall processing time. On the other hand, results showed a consistent tendency for *colour contrast*, with pictures that provided an enhanced colour contrast (i.e. where object and background colour differed) detected faster than pictures that were overall grey and therefore low in contrast. This suggests that enhanced colour contrast may ease segmentation and thereby facilitate object detection. This finding would be in line with studies that found that colour has

a positive effect on defining object contours. For instance, it was found that in tasks with longer stimulus exposure times, colour helps the linking of contours (McIlhaga & Mullen, 1996), contour shape processing (Georghiu & Kingdom, 2007), and that the *combination* of colour and luminance facilitates the recognition of object boundaries in natural scenes (Rivest & Cavanagh, 1996; Fine et al., 2003; Kingdom, 2003; Kingdom et al., 2004; Kingdom & Kasrai, 2006; Shevell & Kingdom, 2008). Colour also plays a role in pattern recognition (Gur & Akri, 1992; Li & Lennie, 1997; Syrkin & Gur 1997), in defining landmarks within faces (Yip & Sinha, 2002; Edwards et al., 2003; Russel & Sinha, 2007), and in object recognition (Chaparro et al., 1993; Møller & Hurlbert, 1996; Bloj et al., 1999). Furthermore, it has been shown that colour can be a useful cue for subjects with visual form agnosia. For instance, experiments with the patient D.F., who cannot identify objects and scenes on the basis of their shapes due to a profound visual form agnosia, have shown that she could use global and local colour information to define boundaries and contours of objects and scenes (Milner & Heywood, 1989; Milner et al., 1991; Humphrey et al., 1994; Steeves et al., 2004).

How do our findings relate to other studies on object segmentation that used ultra rapid object detection? Our results are in line with other studies showing that colour enhances recognition accuracy of scenes already at 16ms (Gegenfurtner & Rieger, 2000) and 50ms presentation duration (Wichmann et al. 2002, 2006). Results also fit with parts of the study by Delorme et al. (2000), who found that colour speeded up the detection of *food* items by 10-15ms in human observers when pictures were flashed for 20ms, which was the same stimulus presentation time as used in our study. However, they are at odds with their findings that colour increased the accuracy of the detected animals about 2%, but did not decrease the processing speed. In addition, no colour effects were found when testing monkeys with the same stimuli at 32ms stimulus presentation time for stimuli that were untrained. To our knowledge, the only other study that measured *processing time* in respect to colour instead of

focussing on accuracy data only is the study by Edwards et al. (2003). They tried to replicate the findings of Delorme et al. (2000) by using single-cell recording in IT (inferotemporal cortex) in an adult monkey. The presentation times of their stimuli that were shown either in an appropriate colour, in an achromatic version, or wrongly coloured, varied between 14ms and 56ms. The single-cell recordings showed that the colour signals dominated the earlier part of the responses with colour discrimination peaking before that of shape by 10-20ms. These results clearly showed that colour was processed at the very early stages of ultra-rapid object detection and not at a later stage as suggested by Delorme et al. (2000).

The positive effects for colour found with our paradigm are also at odds with the "null effects" for colour found by Fei-Fei et al. (2005). However, our results may be difficult to compare because their task differed in too many aspects from the task used in our experiment. They measured colour effects in the near absence of attention by presenting stimuli peripherally on a screen at 6 deg, where poor colour vision would be expected given the low cone density. They found that when much of attention is engaged elsewhere, subjects can perform a rapid natural scene categorization task without colour information as accuracy rates did not differ whether the scenes where shown in colour or not. Unfortunately, the authors reported only the accuracy scores but did not provide any data about the processing times and whether those differed between the chromatic and achromatic scenes. In contrast to their test settings, in our ultra-rapid object detection task stimuli were placed centrally (in the focus of attention), in a larger size (with a resolution of a height of 12.5cm and a width of 19.5cm) and categorization was assessed *implicitly*, as subjects were just requested to decide whether there is an *object* in the scene or not. Classification of living vs. non-living things was measured by reaction times and implicitly because subjects were not told which types of objects and categories would be involved in the task. All stimuli of the different categories were randomly mixed and their appearance could not be predicted. Living things were of

domestic (3) or wild animals (4), fruits (6) or vegetables (7), and non-living things objects were of tools (5), clothes (4), toys (2), or household items (9). All of the objects were placed in isolation against a plain background or a fractal noise, which did not provide any size or contextual information. In the task by Fei-Fei et al. (2005), subjects were extensively trained on ultra-rapid detection before the test and had to detect either animals or cars. These objects were shown in context, which could have helped their detection. Thus, subjects could have employed strategies and could have focused on low-level cues other than colour.

In fact, it has been shown that context can affect object recognition at very early stages of visual processing. A model proposed by Bar (2004) and his group (Bar et al., 2006) implies that a rapid coarse processing of a scene that is computed by the magnocellular dorsal visual pathway, could activate the most likely possible object in a contextual frame. If contextual interference would already happen at 20ms presentation time, we would have found increased reaction times for the stimuli that contained an incongruity between object colour and background colour as observed in the naming tasks. However, our results show that latencies were not affected by incongruity (wrong assumption of object greyness) but that they were affected by object category! These striking findings suggest that top-down semantic activation for category occurs already at 20ms stimulus exposure time, but that contextual interference occurs later. Edwards et al. (2003) found responses to incongruent colour (context) already at 14ms presentation time during single cell recording in an adult monkey. However, it seems that this effect needs presentation times longer than 20ms in human observers to take place. Other studies have shown that contextual effects (e.g., incongruent colour or inconsistent background information) can influence subject's performance as early as at 26ms (Joubert et al., 2008), 30ms (Oliva & Torralba, 2006), 42ms (Castelhano & Henderson, 2008), and 50ms presentation time (Wichmann et al., 2002). Interestingly, Joubert et al. (2008) found that at 26ms presentation time observers already responded to objects that were cut out from their

original context and pasted in into another background, which gave them an unrealistic appearance despite the author's effortful, but fruitless attempts to "smoothen" the edges and to blend the objects in. Although the objects popped out and consequently should have been easier to segment, reaction times were down by 10-20ms compared with when the objects were shown in their original context. It seems that the brain already uses a kind of "reality" filter for the perceptual features that are part of the boundaries between the objects and the backgrounds and detects them as being unreal and thereby delaying the segmentation process. In contrast, objects in our study were cut out from their original backgrounds, manipulated in colour (greyscaled and equated in luminance) and than pasted in again. This manipulation resulted in an enhanced colour contrast at the boundaries between the objects and the backgrounds by maintaining most of the natural information of the scene including shadows and surface reflections. Another explanation for the fact that our reaction times did not increase by the violation of context congruency (wrong assumption of object greyness) at 20ms presentation time is that the violation might have been processed only *after* the manual response was done at a later stage as required for object detection such as at the level of object recognition. In contrast, the violation in the study by Joubert et al. (2008) might have been processed at the perceptual level of object segmentation and thereby affecting overall reaction times.

Research indicates that the brain prefers computing natural scenes over manmade settings as it computes "synthetic" or unrealistic looking stimuli differently than naturalistic objects and scenes (e.g., Shevell & Kingdom, 2008). This has been demonstrated using fMRI in humans where natural scenes activated the inferior temporal cortex, while falsely coloured did not (Zeki & Marini 1998), and in other studies using behavioural paradigms. For instance, Braun (2003) observed that natural scenes require less attention for processing than artificial ones, and Oliva & Torralba (2006) found that recognition accuracy dropped when presenting unrealistically rather than realistically coloured scenes at 30ms exposure time. In addition,

Fei-Fei and his colleagues found that when the information is scarce such as at very short stimulus exposure durations, subjects show a strong preference to perceive ambiguous scenes as outdoor rather than as an indoor scene (2007) and detect natural scenes faster than "synthetic" looking ones (Fei-Fei et al., 2005, see also Li et al., 2002). They also found a stronger correlation between the recognition of living things and overall scene context compared with non-living objects. In addition, Joubert et al. (2008) showed that at very short exposure times, subjects produced more go responses with natural scenes than with manmade scenes indicating that the visual system might compute the former ones with less effort.

Our results point to a similar direction as living things were detected faster than non-living things when presented in front of a fractal noise that simulated a natural background condition and this was even more so when the noise was in colour. The category effects further show that when object segmentation was easy, as with the plain background conditions, differences between the two categories were small. This indicates that factors such as visual complexity and image familiarity were about equally distributed between the two categories. This is also demonstrated in the average *naming* reaction times, which were about the same for the two categories when the object was easy (cocn = coloured object in front of coloured plain background) and when it was difficult to segment (gogn grey object in front of a greyscaled noise) during object naming (see table 4). In contrast, during rapid object detection when object segmentation becomes more demanding as in the noise conditions, category effects are stronger showing that living things are detected much faster than non-living things. The only noise condition where living things and non-living things were detected at a similar speed was the picture condition where a coloured object had to be segmented from a greyscaled noise. This picture condition contains a strong colour contrast at the border between object and background, which might have provided a similar ease for both categories for detection to take place. The category effects were not related to *object colour* but to *colour contrast*,

showing that living things benefited little from colour contrast between the object and background, whereas non-living things were detected on average 8ms faster from plain backgrounds and on average 11.6ms faster from noisy backgrounds when the picture contained a colour contrast than when it was all grey. These findings show that whatever it is that makes the brain distinguish between living and non-living objects at such a short stimulus presentation time is not related to colour semantics.

However, it must be highlighted that the observed category effects found in our study derived from a small number of different members (objects) *per category* (20 living and 20 non-living items), which might also explain why colour effects by category were different than when analysing colour effects across the whole stimulus set. In fact, other studies that have measured category effects during ultra-rapid detection have used similar participant numbers as in our study, but included much more different members per object category into their sets (e.g., 44 natural vs. 44 manmade by Fei-Fei et al., 2007; and 700 natural vs. 700 manmade by Wichmann et al., 2006). It would be interesting to run our experiment again with a larger item number per object category and to include different exemplars of a category member (e.g., different horses, teapots, and apples) as it was done in other studies to verify the observed category effects.

It is nevertheless astonishing that we found indications for category effects at such a short stimulus exposure time. The task in our study was a very basic object detection paradigm where subjects had to decide whether a picture contained an object or not with objects in the target pictures always appearing in the centre of the image. Comparing the non-object distracters that were of a plain or a fractal noise background with pictures that contain an object placed against those backgrounds could have been achieved by focussing on a central blob that differed from the background and by using only coarser or low-level image statistics. It was not required for the task to *recognize* or define the category or identity of the

objects. For that reason, it was not even necessary to pay attention to any outline contour of the object or to specific object surface details. That we nevertheless observed category and colour effects with our paradigm at 20ms stimulus exposure time, fits with data from magnetoencephalography (MEG), event-related potentials (ERP) (Liu et al., 2002; Halgren et al., 2003), and behavioural results, suggesting that object *detection*, *segmentation*, and *basic level categorization* occur at the same time and may use the same perceptual information (Grill-Spector & Kanwisher, 2005; Bowers & Jones, 2007; Mack et al., 2008). However, the factors that may drive categorization allowing the brain to discriminate between living and non-living things during ultra-rapid detection cannot be distinguished with our test paradigm. That we found advantages for object colour and a positive trend for colour contrast effects at such short stimulus presentation time is in line with psychophysical evidence suggesting that the perception of surface colour and three-dimensional shape are fundamentally linked and that chromatic features of a scene can influence other perceptual features and processes such as shape, texture, and object segmentation (Shevell & Kingdom, 2008). What can be inferred from our results is that colour might be involved in rapid object detection, in that it can ease segmentation and thereby speeding up the object detection. However, results also indicate that there is more than one strategy to detect an object in a scene and that colour and colour contrast may not be the most important factors.

5.5: Conclusion

Experiment 3 was designed as an ultra-rapid object detection task using a subset of the stimuli of the previous naming tasks with the aim to separate earlier from later visual processing stages and to measure how colour might affect object segmentation *before* semantic object processing occurs. The stimulus set contained twenty category members of living items that were contrasted with twenty category members of non-living items and each of these items where shown in eight different picture designs that were manipulated in colour. Results show

that pictures that contained an object in colour or that provided a colour contrast between object and background where detected faster than pictures that were grey. This indicates that colour might be involved in the segmentation process where it helps to speed up the object detection process. However, these colour effects were not consistent across subjects and objects suggesting that there is more than one strategy to detect an object in a scene and that colour and colour contrast may not be the most important factors. In contrast to other studies that found that colour might only be helpful at later stages of the ultra-rapid object detection process, namely for subjects that are slow to respond or for objects that are difficult to segment (e.g., Delorme et al., 2000), our results show that colour advantages occurred independently of such factors. Subjects use of colour cues was unrelated to their overall detection latencies and objects profited from colour independent of their overall detection times. Similar to observations in other studies (e.g., Fei-Fei et al., 2005; 2007), we found that the visual system might be biased towards natural objects (living things) when information is sparse as during ultra-rapid object detection . This was demonstrated with significant category effects showing that living items were detected much faster by on average 20ms than non-living items when the difficulty of the object segmentation increased. However, like in the previous naming experiments, category effects were not related to object colour. It was further found that at 20ms stimulus exposure time, incongruity between object and background colour (i.e. when object and background colour differed) did not interfere with higher-level object colour knowledge as observed in the naming paradigms. On the contrary, it showed a positive trend indicating that the enhanced colour contrast was processed at the perceptual level only thereby possibly easing the segmentation process. The observed bias towards natural objects (living things) in difficult-to-segment picture conditions at 20ms stimulus exposure time suggest that the brain already uses top-down activation to categorize the objects during ultra-rapid detection. These latter findings are in line with theories stating that object segmentation, detection, and *basic level* categorization occur at the same time and

that they may use the same perceptual information (e.g., Liu et al., 2002; Halgren et al., 2003; Grill-Spector & Kanwisher, 2005).

Chapter 6: General discussion

The aim of this thesis was to establish the role of colour during object naming by incorporating a cross-linguistic design, and by testing healthy people and aphasic patients with anomia. Experiments 1 and 2 were designed to address how colour contributes to image *segmentation* and object *identification* in the process of naming common real objects, and how colour affects *priming* measures when objects are named a second time after a delay. The third experiment was constructed to measure time differences in object segmentation *before* semantic processing can take place by using an ultra-rapid object detection paradigm. In order to properly address these questions, we created a new picture set that allows better control of variables such as surface colour, object viewpoint, background condition and context, effects of light including shadowing, than is offered by most stimuli available from other sources.

It is known that confrontation naming of objects involves a widespread anatomical network in the brain ranging from visual cortices to the frontal brain areas where information flow is supported by feedback loops between the areas involved in the computation (e.g., Damasio et al., 2004). Results of studies of the influence of colour on object recognition suggest that colour might be a variable that affects not only a single level of processing during the naming process, but might be felt throughout the system. The combination of the results found in the three experiments presented in this thesis does indeed indicate that colour can affect naming at different levels of processing. It was found that *object colour* speeded up the naming process in experiments 1 and 2 by an average of 79ms, since pictures with the object in colour were named faster than achromatic objects and this advantage of colour was independent of any segmentation costs or benefits. Thus, the picture version where the coloured object had to be segmented from coloured noise was named much faster than any grey object presented against a plain background condition, although the latter ones were much easier to segment.

Thus, the colour effect that speeded up the naming process could not have occurred at the perceptual level of object segmentation only, but must have involved other levels of object recognition, including object colour knowledge, to speed up the semantic selection process. This argument is supported by the findings in experiment 3, where object colour speeded up ultra-rapid object detection by an average of 8ms, most likely as a result of easing the object segmentation process. Thus, object colour effects were much smaller when pictures were presented for brief durations and did not require processing at the semantic level of object recognition than when participants could inspect the pictures for naming in their own time. The average segmentation advantage of 8ms for object colour in our study is similar to that found by Delorme et al., (2000) who used exactly the same stimulus exposure of 20ms for detection. They found time advantages for colour between 10 and 15ms but mainly in the category of food items and not as much in the category of animals, whereas in our results object colour effects were unrelated to object category. The category effects found in our experiments will be discussed further below.

Results in the ultra-rapid object detection task further revealed that not only object colour but also *colour contrast* facilitated object segmentation. This was shown by a positive trend for pictures where objects and their backgrounds differed in colouration, that is, when grey objects were presented against coloured backgrounds or coloured objects were presented against grey backgrounds. Colour contrast has also been shown to ease segmentation during rapid recognition of scenes (Wichmann et al., 2002), probably by increasing the saliency between the border of the object and the background. The positive colour contrast effects found during our ultra-rapid object detection task are particular interesting as they caused different effects from those observed during object naming where such pictures increased overall processing times. Such prolonged processing times for naming was especially found with the picture version where a grey object appeared in front of coloured noise. The wrong

assumption of object greyness (e.g., a greyscale carrot is generally not expected in front of a noisy coloured background), led to a conflict between the perceived object colour at the perceptual level of object recognition and the knowledge about object colour stored in memory and thereby prolonged overall naming reaction times. Thus, despite the picture providing a segmentation advantage at the perceptual level of object recognition, object colour knowledge at the semantic level of object recognition slowed down overall reaction times. This showed that a later process (interference by conceptual colour knowledge) can reduce effects of apparently earlier stages (facilitation by colour contrast), if the later process is the more influential determinant of overall reaction time. These divergent findings between the two tasks also indicates that at 20ms stimulus exposure time, incongruity between object and background colour (i.e. when object and background colour differed) did not interfere with higher-level object colour knowledge as observed in the naming paradigms. These findings clearly show that colour can influence naming at different levels of processing and that these effects occur independently of each other and may start at different times.

6.1. *Colour effects according to object category or colour diagnosticity of the objects*

In all of the three experiments reported here, colour effects were not related to object category or colour diagnosticity of the objects, when the distinction was made between living and non-living things. However, in the naming tasks category effects emerged when categories were divided into fruits & vegetables vs. animals vs. manmade objects showing that for the category of fruits & vegetables, reaction times were longer and identification error rates higher than for the category of animals or manmade objects. Fruits & vegetables also benefited more from object colour than the two latter categories. Longer reaction times for fruits & vegetables during object naming have been observed in several other studies. It is assumed that fruits & vegetables are often structurally similar which leads to higher

competition amongst semantically related neighbours, which in turn increases the semantic and lexical selection process (e.g., Rossion & Pourtois, 2004).

6.2. *Naming and detecting living versus non-living things*

Although living things were named on average 80ms slower than non-living things in the naming tasks, the opposite effect was found in the ultra-rapid object detection paradigm where living things were detected on average 20ms faster when the segmentation demand increased. The observed bias towards natural objects (living things) in difficult-to-segment picture conditions at 20ms stimulus exposure time suggest that the brain already uses top-down activation to categorize the objects during ultra-rapid detection. Other researchers (Fei-Fei et al., 2005; 2007; Li et al., 2002; Joubert et al., 2008) have also observed similar findings. Such a preference for the detection of natural objects would make sense as it enables the brain to drive attention quickly towards a new stimulus and to make a behavioural response. This mechanism may have its roots in evolution where the environment consisted of mainly natural objects and scenes. Our findings that the brain already uses top-down activation to categorize the objects during detection at very short stimulus exposure times, also fit with theories stating that object segmentation, detection, and *basic level* categorization occur at the same time and that they may use the same perceptual information (e.g., Liu et al., 2002; Halgren et al., 2003; Grill-Spector & Kanwisher, 2005).

6.3. *Colour effects on repeated object naming (priming)*

The repeated naming tasks of experiments 1 and 2 showed strong priming effects for pictures that were repeated from study to test with an average of 78ms faster naming. These results were independent of perceptual differences of the pictures (object and background colour, background condition), semantic differences of the pictures (congruity of object and background colour, object category, and colour diagnosticity of the object) and by inter-

subjects variables (health, gender, age, and spoken language). Most importantly however, we could demonstrate for the first time that colour effects on priming during repeated picture *naming* can last without any decay over a period of 12 to 180 days. Furthermore, we provide evidence that priming *magnitudes* are not related to object colour, as all different six picture conditions were primed in the same way. To our knowledge, the only other research that measured the effects of colour on priming with a time interval longer than immediate recall was the study by Cave et al., (1996). They found a decline for accuracy but not for priming times when subjects had to *recognize* artificially coloured line drawings after 1 hour and 48 hours delay. In contrast, Vernon & Lloyd-Jones, (2003) found a marginal priming effect in favour of black-and-white line drawings over coloured line drawings during immediate recall in a repeated naming task, but using only 10 stimuli per condition. Our results add to the findings of Cave et al., (1996) and Vernon & Lloyd-Jones, (2003) by providing evidence that object colour does not enhance priming magnitudes and does not prime less than achromatic pictures by using a higher number of participants (N = 94) and far better stimulus quality (photographic depictions of real common objects) and quantity (N = 140). Our results showed that object colour improved object segmentation and semantic selection during encoding *and* recall compared with achromatic picture stimuli, but that *overall* processing time decreased when the object was named a second time. Because the overall decrease of processing time was the same for pictures with and without colour information, it can be inferred that the attribute of colour did not affect priming times. Our findings also provide evidence that subjects not only encode and store an *achromatic gist* of the picture during object naming, as suggested by edge-based accounts (e.g., Biederman, 1987), or abstract core information of the picture as suggested by Anderson, (1985, p 107). Instead, our results indicate that '*analogous'* information is encoded, stored, and retrieved during repeated picture naming which includes detailed information about both colour and shape (see also Homa & Viera, 1988).

Another important finding of our research is that aphasic subjects with anomia showed the same priming potential as the healthy controls. Because priming magnitudes were the same for people with aphasia who suffer from brain damage resulting in anomia as for healthy subjects without word finding problems, our findings suggest that priming during repeated picture naming is mainly perceptual in nature. Since subjects were left naïve about the real purpose of the experiment and not instructed to explicitly pay attention to any surface details during the naming task, priming occurred implicitly at the perceptual level of object recognition (e.g., Park & Gabrieli, 1995; Roediger & Geraci, 2005). Because priming magnitudes in our study were robust over time and across different delays and unaffected by perceptual and semantic differences between the pictures, results would fit best with the 'facilitation model' of visual object priming. This model states that the neuronal activity has the same pattern during encoding and recall, but that stimulus repetition improves prediction, which leads to shorter processing time when the stimulus is repeated (e.g., James et al., 2000; Grill-Spector et al. 2003).

Results of the naming tasks in experiment 1 provide evidence that aphasic subjects with anomia produce more accurate and faster naming with coloured than with achromatic picture material. This is in line and further confirms observations from two early studies by Bisiach (1966) and Benton et al., (1972) who examined colour effects and stimulus characteristics during confrontation naming in aphasic populations. Our results exceed these early findings by involving a much larger number of participants (N = 29) and by using a much larger number and better-controlled stimuli. In addition, our results further confirm observations by other researchers that aphasic subjects suffer from other than language related deficits because subjects in our study profited most from object colour information when the demand of naming the pictures increased. Aphasic subjects took significantly longer to retrieve the

correct names than healthy controls when object colour was missing in pictures with higher segmentation demands (gogn), higher semantic differentiation demands (fruits & vegetables), and when pictures contained an incongruity between background and object colour (gocp, gocn). Thus, object colour information seems to be particular helpful for subjects with impaired strategies for lexical retrieval and in situations where parallel possessing is required as they may possess fewer attentional- (Murray, 1999) and working memory resources (Miyake et al., 1995) than healthy controls.

6.4. *Conclusion*

In conclusion, our research provides evidence that object colour facilitates object naming and ultra-rapid detection. It was found that the positive effects by colour occur at different levels of processing which can be active in parallel and independent of each other and which can start at different times. First, colour leads to segmentation advantages by being part of the shape-forming process (i.e. by defining contour) and by enhancing the saliency between object and background at a perceptual level of object recognition. Second, in naming, colour facilitates semantic differentiation at a conceptual level of object colour knowledge, which in turn speeds up the identification process. Third, faster identification due to colour eases the lexical selection process and speeds up overall naming times. These colour effects were found as a pattern that is valid for healthy subjects across different age groups, across two different languages, and in aphasic subjects with anomia. Our results implicate that using coloured picture material may ease naming not only in healthy subjects but in particularly in brain damaged individuals who suffer from anomia. Furthermore, colour may be also helpful in ultra-rapid object detection.

References

- Alario, F.X., Ferrand, L., Laganaro, M., New, B., Frauenfelder, U.H., Segui, J. (2004) Predictors of picture naming speed. *Behavior Research Methods Instruments & Computers, Vol. 36, No. 1, pp 140-155*

- Ally, B.A., Waring, J.D., Beth, E.H., McKeever, J.D., Milberg, W.P., Budson, A.E., (2008) Aging memory for pictures: Using high-density event related potentials to understand the effect of aging on the picture superiority effect. *Neuropsychologia, Vol. 46, pp 679-689*

- Asch, S.E., Ceraso, J., Heimer, W. (1960) Perceptual conditions of associations. *Psychological Monographs: General and Applied, Vol. 74, pp 1-48*

- Baddeley, A. (2004) *Your memory – A users guide.* London: Carlton Books

- Bar, M. (2004) Visual objects in context. *Nature Reviews Neuroscience, Vol. 5, pp 617*

- Bar, M., Biederman, I. (1998) Subliminal visual priming. *Psychological Science, Vol. 9, pp 464-469*

- Bar, M., Kassam, K.S., Ghuman, A.S., Boshyan, J., Schmidt, A.M., Dale, A.M., (2006) Top-down facilitation of visual recognition. *Proceedings of the National Academy of Sciences, USA, Vol. 103, pp 449-454*

- Barrow, I.M., Holbert, D., Rastatter, M. P. (2000) Effect of color on developmental picture-vocabulary naming of 4-, 6-, and 8- years-old children. *American Journal of Speech-Language Pathology, Vol. 9, pp 310-318*

- Barry, C., Hirsch, K.W., Johnston, R.A., Williams, C.L. (2001) Age of acquisition, word frequency, and the locus of repetition of picture naming. *Journal of Memory and Language, Vol. 44, No. 3, pp 350-375*

- Barry, C., Morrison, C.M., Ellis, A.W., (1997) Naming the Snoodgrass and Vanderwart pictures: Effects of age of acquisition, frequency, and name agreement. *Quarterly Journal of Experimental Psychology, Vol.50A, pp 560-585*

- Bartram, D.J. (1974) The role of visual and semantic codes in object naming. *Cognitive Psychology,Vol. 6, pp 325-356*

- Benton, A.L. (1967) Problems of test construction in the field of aphasia. *Cortex, Vol.3, pp 32-58*

- Benton, A.L., Smith, K.C., Lang, M. (1972) Stimulus characteristics and object naming in aphasics patients. *Journal of Communication Disorders, Vol.5, pp 19-24*

- Berry, C.J., Shanks, D.R., Henson, R.N.A. (2008) A unitary signal-detection model of implicit and explicit memory. *TRENDS in Cognitive Sciences, Vol. 12, No.10, pp 367-373*

- Biederman, I. (1972) Perceiving real-world scenes. *Science, Vol. 177, pp 77-80*

- Biederman, I. (1987) Recognition-by-components: A theory of human image understanding. *Psychological Review, Vol. 94, pp 115-147*

- Biederman, I., Cooper, E. (1991). Evidence for complete translational and reflectional invariance in visual object priming. *Perception, Vol. 20, pp* 58*5-593*

- Biederman I, Cooper, E. (1991b) `Priming contour-deleted images: Evidence for intermediate representations in visual object recognition. *Cognitive Psychology, Vol. 23, pp 393-419*

- Biederman, I., Cooper, E. (1992). Size invariance in visual object priming. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 18, pp 121-133*

- Biederman, I., Ju, G. (1988) Surface versus edge-based determinants of visual recognition. *Cognitive Psychology, Vol .20, pp 38-64*

- Bisiach, E. (1966) Perceptual Factors in the Pathogenesis of Anomia. *Cortex, Vol. 2, pp 90-95*

- Bisiach, E. (1976). Characteristics of visual stimuli and naming performance in aphasic adults: Comments on the paper by Corlew and Nation. *Cortex, Vol. 12, No. 1, pp 74-75*

- Bloj, M.G., Kersten, D., Hurlbert, A.C. (1999) Perception of three-dimensional shape influences colour perception through mutual illumination. *Nature, Vol. 402, No. 23/30 pp 877-879*

- Borenstein, E., Ullman, S. (2002) *Class – specific top – down segmentation.* Paper presented at the European Conference on Computer Vision, Glasgow, Scotland.

- Bowes, J.S., Jones, K.W. (2008) Detecting objects is easier than categorizing them. *The Quarterly Journal of Experimental Psychology, Vol. 61, No. 4, pp 552-557*

- Bowmaker, J. K. (2008) Evolution of vertebrate visual pigments. *Vision Research, Vol. 48, pp 2022-2041*

- Bowmaker, J. K. & Hunt, D. M. (2006) Evolution of vertebrate visual pigments. *Current Biology, Vol. 16, No. 13, R484*

- Boyce, S.J., Pollatsek, A., Rayner, K. (1989) Effect of background information on object identification. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 15, No. 3, pp 556-566*

- Brady, T.F., Konkle, T., Alvarez, G.A., Oliva, A. (2008) Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academic Sciences, USA, Vol. 105, pp 14325-14329*

- Braun, J. (2003) Natural scenes upset the visual applecart. *TRENDS in Cognitive Sciences Vol.7 No.1, pp 7-9*

- Breitmeyer, B.G., Ogmen, H., Chen, J., (2004) Unconscious priming by color and form: Different processes and levels. *Conscious and Cognition, Vol. 13, pp 138-157*

- Breitmeyer, B.G, Ro, T., Singhal, N.S., (2004) Unconscious color priming occurs at stimulus – not percept – dependent levels of processing. *Psychological Science, Vol. 15, No. 3, pp 198-202*

- Brodie, E.E., Wallace, A.M., Sharat, B. (1991) Effect of surface characteristics and style of production on naming and verification of pictorial stimuli. *American Journal of Psychology, Vol. 104, No. 4, pp 517-545*

- Brookshire, R.H. (1971) Effects of task difficulty on naming performance by aphasic subjects. *Journal of Communication Disorders, Vol. 3, pp 289-301*

- Brookshire, R.H. (1972) Effects of trial time and inter-trial interval on naming by aphasic subjects. *Journal of Speech and Hearing Research, Vol. 15, pp 551-558*

- Brown, A.S., Jones, T.C., Mitchell, D.B. (1996) Single and multiple test repetition priming in implicit memory. *Memory, Vol. 4, No. 2, pp 159-174*

- Brown, A.S., Neblett, D.R., Jones, T.C., Mitchell, D.B. (1991) Transfer of processing in repetition priming: Some inappropriate findings. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 17, 514-515*

- Bruce, V., Young, A. (1998) *In the Eye of the Beholder, The Science of Face Perception.* Oxford: Oxford University Press

- Canny, J. (1986) A computational approach to edge detection. *IEEE Transactions on Pattern Analysis and machine Intelligence, Vol. 8, pp 670-698*

- Carroll, M., Byrne, B., Kirsner, K. (1985) Autobiographical memory and perceptual learning: A developmental study using picture recognition, naming latency, and perceptual identification. *Memory & Cognition, Vol. 13, pp 273-279*

- Carr, T.H., McCauley, C., Sperber, R.D., Parmelee, C.M. (1982) Words, pictures, and priming: On semantic activation, conscious identification, and the automaticity of information processing. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 8, No. 6, pp 757-777*

- Carson, C., Belongie, S., Greenspan, H., Malik, J. (2002) Blobworld: image segmentation using expectation-maximization and its expectation to image querying. *IEEE Transaction and Pattern Analysis & Machine Intelligence, Vol. 24, pp 1026-1038*

- Castelhano, M.S., Henderson, J.M. (2008) The Influence of Color on the Perception of Scene Gist. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 34, No. 3, pp 660-675*

- Cavanagh, P. (1987) Reconstructing the third dimension: interactions between color, texture, motion, binocular disparity and shape. *Computer Vision Graphics Image Processing, Vol.37, pp 171-195*

- Cavanagh, P., Adelson, E., Heard, P. (1992) Vision with equiluminant contrast: 2. A large scale technique and observations. *Perception, Vol.21, pp 219-226*

- Cave, C. (1997) Very long-lasting priming in picture naming. *Psychological Science, Vol. 8, No. 4, pp 322-325*

- Cave, C., Bost, P.R., Cobb, R.E. (1996) Effects of color and pattern on implicit and explicit picture memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 22, No. 3, pp 639-653*

- Chainay, H., Humphreys, G.W., (2001) The real-object advantage in agnosia: Evidence for a role of surface and depth information in object recognition. *Cognitive Neuropsychology, Vol. 18, No. 2, pp 175-191*

- Chainay, H., Rosenthal, V. (1996) Naming and picture recognition in probable Alzheimer's disease: Effects of color, generic category, familiarity, visual complexity, and shape similarity. *Brain and Cognition, Vol. 30, pp 403-405*

- Changizi, M. A., Zhang, Q., Shimojo, S. (2006) Bare skin, blood and the evolution of primate colour vision. *Biology Letters, Vol. 2, pp 217-221*

- Chaparro, A., Stromeyer, C.F., Huang, E.P., Kronauer, R.E., Rhea, T, Eskew, J. (1993) Colour is what the eye sees best. *Nature, Vol. 361, pp 348-350*

- Chaumon, M., Drouet, V., Tallon-Baudry, C. (2008) Unconscious associative memory affects visual processing before 100 ms. *Journal of Vision, Vol. 8, No.3:10, pp 1-10*

- Cole, G.C., Kuhn, G., Heywood, C.A., Kentridge, R.W. (2009) The prioritization of feature singletons in the change detection paradigm. *Experimental Psychology, Vol. 56, No.2, pp 134-146*

- Collins, A.F., Ellis, A.W. (1992) Phonological priming of lexical retrieval in speech production. *British Journal of Psychology, Vol. 83, No. 3, pp 375-388*

- Cornelissen, K., Laine, M., Tarkiainen, A., Tiina Järvensivu, T., Martin, N., Salmelin, R. (2003) Adult brain plasticity elicited by anomia treatment. *Journal of Cognitive Neuroscience, Vol. 15, No. 3, pp 444-461*

- Croner, L.J., Albright, T.D. (1997) Image segmentation enhances discrimination of motion in visual noise. *Vision Research, Vol. 37, No. 11, pp 1415-1427*

- Cuetos, F., Ellis, A. W., Alvarez, B. (1999). Naming times for the Snodgrass and Vanderwart pictures in Spanish. *Behavior Research Methods, Instruments & Computers,Vol. 31, pp 650-658*

- Curran, T., Tanaka, J.W., Weiskopf, D.W. (2002) An electrophysiological comparison of visual categorization and recognition memory. *Cognitive, Affective, & Behavioral Neuroscience, Vol. 2, No. 1, pp 1-18*

- Damasio, S.R., McKee, J., Damasio, H. (1979) Determinants of performance in colour anomia. *Brain and Language, Vol.7, pp 74-85*

- Damasio, H., Tranel, D. Grabowski, T., Adolphs, R., Damasio, A. (2004) Neural systems behind word and concept retrieval. *Cognition, Vol. 92, pp 179-229*

- Davenport J.L., Potter, M.C., (2004) Scene consistency in object and background perception. *Psychological Science Vol., 15, pp 559-564*

- Davidoff, J.B. (1991) *Cognition through colour.* Cambridge, MA: MIT Press

- Davidoff, J.B. (2001) in Humphreys, G.W., Forde, E.M.E. (2001) Hierarchies, similarity, and interactivity in object recognition: "Category-specific" neuropsychological deficits. *Behavioral and Brain Sciences, Vol. 24, pp 453-509*

- Davidoff, J.B., De Bleser, R. (1993) Optic aphasia: a review of past studies and reappraisal. *Aphasiology, Vol. 7, No. 2, pp 135-154*

- Davidoff, J.B., Ostergaard, A. L. (1988). The role of colour in categorical judgments. *Quarterly Journal of Experimental Psychology, Vol.40A, pp* 533-544

- Davidoff, J.B., Walsh, V., Wagemans, J. (1997) Higher-level cortical processing of colour. *Acta Psychologica, Vol. 97, pp 1-6*

- Davies, G.M., Shepperd, J.W., Ellis, H.D. (1978) Remembering faces – Acknowledging our limitations. *Journal of The Forensic Science Society, Vol. 18, No. 1-2, pp 19-24*

- Dell, G.S., O'Seaghdha, P.G. (1991). Mediated and convergent lexical priming in language production: A comment on Levelt et al. (1991). *Psychological Review, Vol. 98, pp 604-61*

- Dell, G.S., O'Seaghdha, P.G. (1992). Stages of lexical access in speech production. *Cognition, Vol. 42, pp 287-314*

- Delorme, A., Richard, G., Fabre-Thorpe, M. (2000) Ultra rapid categorisation of natural scenes does not rely on colour cues in monkeys and humans. *Vision Research, Vol. 40, pp 2187-2200*

- DeRenzi, E., Spinnler, H., Scotti, C., Faglioni, P. (1972) Impairment in associating color to form - concomitant with aphasia. *Brain, Vol. 95, pp 293-304*

- Desimone, R. (1996) Neural mechanisms for visual memory and their role in attention. *Procedures of the National Academic Sciences U. S. A., Vol. 93, pp 13494-13499*

- Devlin, J.T., Russell, R.P., Davis, M.H., Price, C.J., Moss, H.E., M., Fadili, J., Tyler L.K. (2002) Is there an anatomical basis for category-specificity? Semantic memory studies in PET and fMRI. *Neuropsychologia, Vol. 40, pp 54-75*

- De Winter, J., Wagemans, J. (2004) Contour-based object identification and segmentation: Stimuli, norms and data, and software tools. *Behavior Research Methods, Instruments,* & *Computers, Vol. 36, No. 4, pp 604-624*

- Dobbins, I.G., Schnyer, D.M., Verfaelle, M., Schacter, D.L. (2004) Cortical activity reductions during repetition priming can result from rapid response learning. *Nature, Vol. 428, pp 316-319*

- Durso, F.T., Johnson, M.K. (1979) Facilitation in naming and categorizing repeated pictures and words. *Journal of Experimental Psychology: Human Learning and Memory, Vol. 5, pp 449-459*

- Ebbinghaus, H. (1885*) Memory: A contribution to experimental psychology {translated 1913}.* New York: Dover

- Ecker, K.H., Zimmer, H.D., Groh-Bordin, C. (2007) Color and context: An ERP study on intrinsic and extrinsic feature binding in episodic memory. *Memory 6 Cognition, Vol. 35, No. 6, pp 1483-1501*

- Edwards, R., Xiao, D., Keysers, C., Földiak, P., Perrett, D. (2003) Color sensitivity of cells responsive to complex stimuli in the temporal cortex. *Journal of Neurophysiology, Vol. 90, pp 1245-1256*

- Engelkamp, J. Zimmer, H.D., de Vega, M. (2000) Pictures in memory: The role of visual - imaginal information. In Denis, M., Cornoldi, C., Logie, H., de Vega, M., Engelkamp, J. (ed.) *Imagery, language and visuo – spatial thinking.* Hove, UK: Psychology Press

- Evans, K.K., Treisman, A. (2005) Perception of Objects in Natural Scenes: Is It Really Attention Free? *Journal of Experimental Psychology: Human Perception and Performance, Vol. 31, No. 6, 1476-1492*

- Fabre-Thorpe, M. Delorme, A., Marlot, C. Thorpe, S.J. (2001) A limit of processing of ultra-rapid visual categorization of novel natural scenes. *Journal of Cognitive Neuroscience, Vol. 13, No. 2, pp 171-180*

- Fabre-Thorpe, M. Richard, G., Thorpe, S.J. (1998) Rapid categorisation of natural images by rhesus monkeys. *NeuroReport, Vol. 9, No. 2, pp 303-308*

- Fanini, A., Nobre, A.C., Chelazzi, L. (2006) Selecting and ignoring the component features of a visual object: A negative priming paradigm. *Visual Cognition, Vol., 14, No. 4/5/5/7/8, pp 584-618*

- Farah, M.J. (1995) The neural bases of mental imagery. In Gazzaniga, M.S. (ed.) *The Cognitive Neurosciences.* Cambridge MA: MIT Press

- Farah, M.J. (2000) *The Cognitive Neuroscience of Vision.* Oxford, UK: Blackwell Publishers

- Farah, M.J., Aguirre, G.K. (1999) Imaging visual recognition: PET and fMRI studies of the functional anatomy of human vusiau recognition. *TRENDS in Cognitive Sciences, Vol. 3, No. 5, pp 179-186*

- Farnsworth Panel D-15 test and the Lanthony15 Hue desaturated panel D-15 d test (Richmond Products Inc., Albuquerque)

- Fei-Fei, L., Iyer, A., Koch, C., Perona, P. (2007) What do we perceive in a glance of a real-world scene? *Journal of Vision, Vol. 7, No. 1, pp 1-29*

- Fei-Fei, L., VanRullen, R., Koch, C., Perona, P. (2002) Rapid natural scene categorization in the near absence of attention. *Procedures of the National Academic Sciences U. S. A., Vol., 99, No. 14, pp 9596-9601*

- Fei-Fei, L., VanRullen, R., Koch, C., Perona, P. (2005) Why does natural scene recognition require little attention? Exploring attentional requirements for natural and synthetic stimuli. *Visual Cognition, Vol. 12, pp 893-924*

- Fernandez, A.A., Morris, M.R. (2007) Sexual selection and trichromatic color vision in primates: Statistical support for the preexisting-bias hypothesis. *The American Naturalist, Vol. 170, No. 1, pp 10-20*

- Fine, I., Jacobs, R.A. (2002) Comparing perceptual learning across tasks: A review. *Journal of Vision, Vol.* 2, pp 190-203

- Fine, I., MacLeod, D. I.A., Boynton, G.M. (2003) Surface segmentation based on the luminance and colour statistics of natural scenes. *Journal of the Optical Society of America, Vol. 20, No. 7, pp 1283-1291*

- Fleischman, D.A., Gabrieli, J.D.E., Wilson, R.S., Moro, T.T., Bennett, D.A. (2005) Repetition priming and recognition memory in younger and older persons: Temporal stability and performance. *Neuropsychology, Vol. 19, No. 6, 750-759*

- Folk, C. L., Remington, R.W., Johnston, J.C. (1992) Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 18, pp 1030-1044*

- Forde, E.M.E., Humphreys, G.W. (1999) Category-specific recognition impairments: A review of important case studies and influential theories. *Aphasiology, Vol. 13, No. 3pp 169-193*

- Francis, W.S., Sáenz, S.P. (2007) Repetition priming endurance in picture naming and translation: Contribution of component process. *Memory & Cognition, Vol. 35, No. 3, 481-493*

- Frattali, C. (2005) What's in a name? Commentary on Szekely et al. (2005), timed action and object naming. *Cortex, Vol. 41, pp 3-5*

- Friston, K. (2005) A theory of cortical responses. *Philosophic Transactions of the Royal Society London B Biological Sciences, Vol., 360, pp 815-836*

- Funt, B., Cardei, V. (2000) Computational uses of color. In Steven Davis (ed.) *Color Perception.* Oxford: Oxford University Press

- Furmanski, C.S., Engel, S.A. (2000) Perceptual learning in object recognition: object specificity and size invariance. *Vision Research, Vol. 40, pp 473-484*

- Gaffan, D., Heywood, C.A. (1993) A spurious category-specific visual agnosia for living things in normal human and nonhuman primates. *Journal of Cognitive Neuroscience Vol. 5, pp 18-28*

- Gainotti, G. (2000) What the locus of the brain tell us about the nature of the cognitive defect underlying category-specific disorders: A review. *Cortex, Vol. 36, pp 539-550*

- Gale, T.M., Laws, R.K., Foley, K. (2006) Crowded and sparse domains in object recognition; Consequences for categorization and naming. *Brain & Cognition, Vol. 60, pp 139-145*

- Gale, T.M., Laws, R.K., Frank, R.J., Leeson, V.C. (2003) Basic-levelv visual similarity and category specificity. *Brain & Cognition, Vol. 53, pp 229-231*

- Gauthier, I., James, T.W., Curby, K.M, (2003) The influence of conceptual knowledge on visual discrimination. *Cognitive Neuropsychology, Vol. 20, No. 3/4/5/6, pp 507-523*

- Gegenfurter, K.R., Rieger, J. (2000) Sensory and cognitive contributions of color to the recognition of natural scenes. *Current Biology, Vol. 10, No. 13, pp 805-808*

- Gelb, A., Granit, R. (1923) Die Bedeutung von 'Figur' und 'Grund' für die Farbenschwelle. Zeitschrift für Psychologie, *Vol. 93, pp 83-118*

- Gerlach, C., Aaside. C.T., Humphreys, G.W., Gade, A., Paulson, O.B, Law, I. (2001) Brain activity related to integrative processes in visual object recognition: bottom – up integration and the modulatory influence of stored knowledge. *Neuropsychologia Vol. 40, pp 1254-1267*

- Gerlach, C., Law, I., Gade, A., Paulson, O.B. (1999) Perceptual differentiation and category effects in normal object recognition. *Brain, Vol. 122, pp 2159-2170*

- Gerlach, C., Law, I., Gade, A., Paulson, O.B. (2006) Shape configuration and category-specificity. *Neuropsychologia, Vol. 44, pp 1247-1260*

- Gheorghiu, E., Kingdom, F.A.A. (2007) Chromatic tuning of contour shape mechanisms revealed through the shape-frequency and shape-amplitude after-effects. *Vision Research, Vol. 47, pp 1935-49*

- Gibson, B.S., Amelio, J. (2000) Inhibition of return and attentional control settings. *Perception and Psychophysics, Vol. 62, pp 496-50*

- Gibson E. J. (1969) *Principles of Perceptual Learning and Development* New York: Appleton-Century- Crofts

- Glaser, W.R. (1992) Picture naming. *Cognition, Vol. 42, pp 61-105*

- Glaser, W.R., Glaser, M.O., (1989) Context effects in Stroop-like word and picture processing. *Journal of Experimental Psychology: General, Vol. 118, pp 13-42*

- Goffaux, V., Corentin, J., Mouraux, A., Oliva, A., Schyns, P., Rossion, B. (2005) Diagnostic colours contribute to the early stages of scene categorization: Behavioural and neurophysological evidence. *Visual Cognition, Vol. 12, No. 6, pp 798-892*

- Gollan, T.H., Montoya, R.I., Fenema-Notestine, C., Morris, S.K. (2005*)* Bilingualism affects picture naming but not picture classification. *Memory & Cognition, Vol. 33, No. 7, pp 1220-1234*

- Goodglass, H., Barton, M., Kaplan, E. (1968) The relationship between sensory modality and object-naming in aphasia. *Journal of Speech and Hearing Research, Vol. 11, pp 488-496*

- Goolsby, B., Suzuki, S. (2001) Understanding priming of color-singleton search: Roles of attention at encoding and „ retrieval“. *Perception and Psychophysics, Vol. 63, No. 6, pp 929-944*

- Gordon, J., Abramov, I. (1998) In Backhaus, W., Kliegl, R., Werner, J.S. (ed.) *Color vision – Perspective from different disciplines.* Berlin: Walter de Gruyter

- Graf, M., Schneider, W.X. (2001) in Humphreys, G.W., Forde, E.M.E. (2001) Hierarchies, similarity, and interactivity in object recognition: “Category-specific” neuropsychological deficits. *Behavioral and Brain Sciences, Vol. 24, pp 453-509*

- Grill-Spector, K. et al. (1999) Differential processing of objects under various viewing conditions in the human lateral occipital complex. *Neuron, Vol. 24, pp 187-203*

- Grill-Spector, K. (2003) The neural basis of object perception*. Current Opinion in Neurobiology, Vol. 13, pp 159-166*

- Grill-Spector, K. (2004) The functional organization of the ventral visual pathway and its relationship to object recognition. In Kanwisher, N. & Duncan, J. (ed.) *Functional Neuroimaging of Visual Cognition- Attention and Performance XX.* Oxford: Oxford University Press

- Grill-Spector, K., Henson, R., Martin, A. (2006) Repetition and the brain: neural models of stimulus-specific effects. *TRENDS in Cognitive Sciences, Vol. 10, No.1, pp 14-23*

- Grill-Spector, K., Kanwisher, N. (2005) As soon as you know it is there, you know what it is. *Psychological Science, Vol. 16, No. 2, pp 152-160*

- Grill-Spector, K., Knouf, N., Kanwisher, N. (2004) The fusiform face area subserves face perception, not generic within – category identification. *Nature Neuroscience, Vol.7, pp 555-562*

- Grossberg, S., Mingolla, E. (1985) Neural dynamics of perceptual grouping: texture, boundaries and emergent segmentation. *Perception and Psychophysics, Vol. 38, pp 141-171*

- Gur, M., Akri, V. (1992) Isoluminant stimuli may not expose the full contribution of colour to visual functioning: Spatial contrast sensitivity measurements indicate interaction between colour and luminance processing. *Vision Research, Vol. 32, No. 7, pp 1253-1262*

- Haarmann, H.J., Just, M.A., and Carpenter, P.A. (1997) Aphasic sentence comprehension as a resource deficit: A computational approach. *Brain & Language, Vol. 59, pp 76-120*

- Halgren, E., Mendola, J., Chong, C.D., Dale, A.M. (2003) Cortical activation to illusory shape as measured with magnetoencephalography. *NeuroImage, Vol. 18, pp 1001-1009*

- Hanna, A., Remington, R. (1996) The representation of color and form in long-term memory. *Memory and Cognition, Vol. 24, No. 3, pp 322-330*

- Hansen, T., Giesel, M., Gegenfurtner, K.R. (2008) Chromatic discrimination of natural objects. *Journal of Vision, Vol. 8, No.1, pp 1-19*

- Hansen, T., Olkkonen, M.,Walter, S., Gegenfurtner, K. R. (2006). Memory modulates color appearance. *Nature Neuroscience, Vol. 9, pp 1367-1368*

- Haushofer, J., Kanwisher, N. (2007) In the eye of the beholder: Visual experience and categories in the human brain. *Neuron, Vol. 53, No. 6, pp 773-775*

- Hayward W., Williams, P. (2000) Viewpoint dependence and object discriminability. *Psychological Science, Vol. 11, No. 1, pp 7-12*

- van der Heijden, A.H.C., Kurvink, A.G., de Lange, L., de Leeuv, F., van der Geest, J.N. (1996) Attending to color with proper fixation. *Perception and Psychophysics, Vol. 58, No. 8 pp 1224-1237*

- Henderson, J.M., Hollingworth, A. (2003) Eye movements, visual memory, and scene representation. In Peterson, M.A. & Rhodes, G. (ed.), *Analytic and holistic process in the perception of faces, objects, and scenes.* (pp 356-383). New York: Oxford University Press.

- Henson, R.N. and Rugg, M.D. (2003) Neural response suppression, haemodynamic repetition effects, and behavioural priming. *Neuropsychologia, Vol. 41, pp 263-270*

- Heywood, C., Cowey, A., (1998) With color in mind. *Nature Neuroscience, Vol.1, No.3, pp 171-173*

- Heywood, C., Kentridge, R., Cowey, A., (2001) In De Gelder, B., Haan, E.H.F., Heywood, C.A. (ed.) *Out of Mind.* Oxford: Oxford University Press

- Heywood, C., Cowey, A., Newcombe, F. (1991) Chromatic discrimination in a cortically blind observer. *European Journal of Neuroscience, Vol. 3, pp 802-812*

- Hillis. A.E., Caramazza, A. (1995). Converging evidence for the interaction of semantic and sublexical phonological information in accessing lexical representations for spoken output. *Cognitive Neuropsychology, Vol. 12, pp 187-227*

- Holbrook, J.B., Backer Cave, C. (2003) The effects of study-task relevance on perceptual repetition priming. *Memory & Cognition, Vol. 31, No. 3, pp 380-392*

- Homa, D., Viera, C. (1988) The representation of color and form in long – term memory. *Memory & Cognition, Vol. 24, pp 322-330*

- Horner, A.J., Henson, R.N. (2008) Priming, response learning and repetition suppression. *Neuropsychologia, Vol. 46, pp 1979-1991*

- Howard, D., Nickels, L., Coltheart, M., Cole-Virtue, J. (2006) Cumulative semantic inhibition in picture naming: experimental and computational studies. *Cognition, Vol. 100, pp 464-482*

- Howard, D., Patterson K. (1992) *The Pyramid and Palm Trees Test* .Suffolk: Thames Valley Test Company

- Huber, W., Poeck, K., Weniger, D., & Willmes, K. (1983) *Aachener Aphasie Test.* Göttingen: Hogrefe

- Humphrey, G.K., Goodale, M.A., Jakobson, L.S., Servos, P. (1994) The role of surface information in object recognition: studies of a visual form agnosic and normal subjects. *Perception, Vol. 23, pp 1457-1481*

- Humphreys, G.W., Forde, E.M.E. (2001) Hierarchies, similarity, and interactivity in object recognition: "Category-specific" neuropsychological deficits. *Behavioral and Brain Sciences, Vol. 24, pp 453-509*

- Humphreys, G.W., Lamote, C., Lloyd – Jones, T.J. (1995) An interactive activation – competition approach to object processing: Effects of structural similarity, name frequency and task in normality and pathology. *Memory, Vol. 3, pp 535-586*

- Humphreys, G.W., Price, J., Riddoch, M.J. (1999) From objects to names: A cognitive neuroscience approach. *Psychological Research, Vol. 62, pp 118-130*

- Humphreys, G.W., Riddoch, M.J. (1987) *To see but not to see: A case study of visual agnosia.* London: Lawrence Erlbaum Associates

- Humphreys, G.W., Riddoch, M.J. & Quinlan, P.T. (1988) Cascade processes in picture identification. *Cognitive Neuropsychology, Vol. 5, pp 67-103*

- Ilmberger, J., Eisner, W., Schmid, U., Reulen, H-J. (2001), Performance in picture naming and word comprehension: Evidence for common neuronal substrates from intraoperative language mapping. *Brain and Language Vol.76, pp 111*–118

- James, T.W., Humprey, G.K., Gati, J.S., Menon, R.S., Goodale, M.A. (2000) The effects of visual object priming on brain activation before and after recognition. *Current Biology, Vol. 10, pp 1017-1024*

- James, T.W. and Gauthier, I. (2006) Repetition-induced changes in BOLD response reflect accumulation of neural activity. *Human Brain Mapping, Vol. 27, No. 1, pp 37-46*

- Jiang, X., Bradley, E., Rini, R.A., Zeffiro, T., VanMeter, J., and Riesenhuber, M. (2007) Categorization training results in shape- and category- selective human neural plasticity. *Neuron 53, No. 6, pp 891-903.*

- Johnson, C.J. (1995) Effects of colour on children's naming of pictures. *Perceptual and Motor Skills, Vol. 80, pp 1091-1101*

- Johnson, C.J., Paivo, A., Clark, J.M. (1996) Cognitive components of picture naming. *Psychological Bulletin, Vol. 120, No. 1, pp 113-139*

- Jolicoeur, P., Gluck, M.A., Kosslyn, S.M. (1984) Pictures and names: Making the connection. *Cognitive Psychology, Vol. 16, pp 243-275*

- Joubert, O.R., Fize, D., Rousselet, G.A., Fabre-Thorpe, M. (2008) Early interference of context congruence on object processing in rapid visual categorization of natural scenes. *Journal of Vision, Vol. 8, No. 13:11, pp 1-18*

- Joseph, J.E. (1997) Color processing in object verification. *Acta Psychologica, Vol. 97, pp 95-127*

- Joseph, J.E., Proffitt, D.R. (1996) Semantic versus perceptual influences of color in object recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 22, No. 23, pp 407-429*

- Kan, I. P., Thompson-Schill, S. L. (2004) Effect of name agreement on prefrontal activity during overt and covert picture naming. *Cognitive, Affective, & Behavioral Neuroscience, Vol., 4, No. 1, pp 43-57*

- Kanwisher, N. (2000) Domain specificity in face perception. *Nature Neuroscience Vol. 3, No. 8,* pp 759-763

- Karni, A., Bertini, G. (1997) Learning perceptual skills: behavioral probes into adult cortical plasticity. *Current Opinion in Neurobiology,* Vol. 7, pp 530-535

- Kellenbach, M.L., Brett, M., Patterson, K. (2001) Large, colourful, or noisy? Attribute – and modality – specific activation during retrieval of perceptual attribute knowledge. *Cognitive, Affective, & Behavioural Neuroscience, Vol. 1, No. 3, pp 207-221*

- Kemp, R., Pike, G., White, P., Musselman, A. (1996) Perception and recognition of normal and negative faces: the role of shape from shading and pigmentation cues. *Perception, Vol. 25, pp 37-52*

- Kentridge, R.W., Cole, G.G., Heywood, C.A. (2004) The primacy of chromatic edge processing in normal and cerebrally achromatic subjects. *Progress in Brain Research, Vol. 144, pp 161-169*

- Kingdom, F.A.A. (2003) Colour brings relief to human vision. *Nature Neuroscience, Vol*. 6, *pp 641-44*

- Kingdom, F.A.A., Beauce, K., Hunter, L. (2004) Colour vision brings clarity to shadows. *Perception, Vol. 33, pp 907-914*

- Kingdom, F.A.A., Kasrai, R. (2006) Colour unmasks dark targets in complex displays. *Vision Research, Vol. 46, pp 814-822*

- Koch, C. & Ullman, S. (1985) Shifts in visual selective attention. Towards the underlying neural circuitry. *Human Neurobiology, Vol.4, pp 219-227*

- Kristjánsson, Á., Vuilleumier, P., Malhotra, P., Husain, M., Driver, J. (2005) Priming of color and position during visual search in unilateral spatial neglect. *Journal of Cognitive Neuroscience, Vol. 17, No. 6, pp 859-873*

- Kremin, H., Akhutina, T., Basso, A., Davidoff, J., De Wilde, M., Kitzing, P., Lorenz, A., Perrier, D., van der Sandt-Koenderman, M., Vendrell, J., Weniger, D. (2003) A cross-linguistic data bank for oral picture naming in Dutch, English, German, French, Italian, Russian, Spanish, and Swedish (PEDOI). *Brain and Cognition, Vol. 53, pp 243–246*

- Kveraga, K., Ghuman, Bar, M. (2007) Top-down predictions in the cognitive brain. *Brain and Cognition, Vol. 65, pp 145-168*

- Lachman, R. Lachman, J.L. (1980) Picture naming: Retrieval and activation of long-term memory. In L.W Poon, J.L. Fozard, L.S Cermak, D. Arenberg, L.W Thompson (ed.) *New directions in memory and aging.* (pp 313-343) Hillsdale: New York, Erlbaum

- Låg, T. (2005) Category-specific effects in object identification: what is 'normal'?. *Cortex, Vol. 41, pp 833-841*

- Laiacona, M., Luzzatti, C., Zonca, G., Guarnaschelli, C., Capitani, E. (2001) Lexical and semantic factors influencing picture naming in aphasia. *Brain and Cognition, Vol. 46, pp 184-187*

- Laine, M., Martin, N. (2006) *Anomia: theoretical and clinical aspects.* Hove and New York: Psychology Press

- Lantz, D.L., Steffire, V. (1964) Language and cognition revisited. *Journal of Abnormal and Social Psychology, Vol. 69, 472-481*

- LaPointe, L., Stierwald, J.A.G., Hancock, A.B., Heald, G.R., Golf, R. (2006) Semantic distraction effects on picture identification in aphasia. *Brain and Language, Vol. 99, pp 122-123*

- Laws, K.R., (1999) Gender affects latencies for naming living and nonliving things. *Cortex, Vol. 35, pp 729-733*

- Laws, K.R., (2000) Category-specific naming errors in normal subjects: the influence of evolution and experience. *Brain and Language, Vol. 75, pp 123-133*

- Laws, K.R., (2005a) Forum on 'methodological critique of category specificity 'Illusions of normality' A methodological critique of category-specific naming . *Cortex, Vol. 41, pp 842-851*

- Laws, K.R., (2005b) Forum on 'methodological critique of category specificity' Categories, controls and ceilings. *Cortex, Vol. 41, pp 869-872*

- Laws, K.R., Adlington, R.L., T.M. Gale, Moreno-Martinez, F.J., Sartori, G. (2007) A meta-analytic review of category naming in Alzheimer's disease. *Neuropsychologia, Vol. 45, pp 2674-2682*

- Laws, K.R., T.M. Gale (2002) Category-specific naming and the 'visual' characteristics of line drawn stimuli. *Cortex, Vol. 38, pp 7-21*

- Laws, K.R., Hunter, M.Z. (2006) The impact of colour, spatial resolution, and presentation speed on category naming. *Brain and Cognition, Vol. 62, pp 89-97*

- Laws, K.R., Neve, C. A. (1999) 'Normal' category-specific advantage for naming living things. *Neuropsychologia, Vol. 37, pp 1263-1269*

- Leder, H. (1996) Line drawings of faces reduce configural processing. *Perception, Vol. 25, pp 355-366*

- Lee, K.J., Perrett, D. (1997) Presentation – time measures of the effects of manipulations in colour space on discrimination of famous faces. *Perception, Vol. 26, pp 733-752*

- Leopold, D.A., Logothetis, N. (1995) Activity changes in early visual cortex reflect monkey's percept during binocular rivalry. *Nature, Vol. 379, pp 549-552*

- Levelt, W.J.M. (1989) *Speaking: From intention to articulation.* Cambridge, MA: MIT Press

- Levelt, W.J.M. (1992) Assessing words in speech production: stages, processes and representations. *Cognition, Vol. 42, pp 1-22*

- Levelt, W.J.M., Schriefers, H., Vorberg, D., Meyer, A.S., Pechmann, T., Havinga, J. (1991) The time course of lexical access in speech production: A study of picture naming. *Psychological Review, Vol. 98, pp 122-142*

- Lewis, M.B. (2006) Chasing psycholinguistic effects: A cautionary tale. *Visual Cognition, Vol. 13, No. 7/8, pp 1012-1026*

- Li, A., Lenny, P. (1997) Mechanisms underlying the segmentation of coloured textures. *Vision Research, Vol. 93, pp 7421-7426*

- Li, F.F., VanRullen, R., Koch, C., Perona, P. (2002) Rapid natural scene categorization in the near absence of attention. *Proceedings of the National Academy of Sciences, USA, Vol. 99, No. 14, pp 9596-9601*

- Li, L., Miller, E.K., Desimone, R. (1993) The representation of stimulus familiarity in anterior inferior temporal cortex. *Journal of Neurophysiology, Vol. 69, pp 1918-1929*

- Ling, Y., Hurlbert, A. (2004) Color and size interactions in a real 3D object similarity task. *Journal of Vision, Vol. 4, pp 721-734*

- Liu, J., Harris, A., Kanwisher, N. (2002) Stages of processing in face perception: An MEG study. *Nature Neuroscience, Vol. 5, pp 910-916*

- Livingstone, M. S., Hubel, D. (1988) Segregation of form, color, movement and depth: Anatomy, physiology and perception. *Science, Vol. 240, pp 740-749*

- Lloyd-Jones, T.J. (2005) The role of color in the implicit memory performance of healthy older adults and individuals with Alzheimer disease. *Neuropsychology, Vol. 19, No.1 pp 44-53*

- Lloyd-Jones, T.J., Humphreys, G.W. (1997) Perceptual differentiation as a source of category effects in object processing : evidence from naming and object decision. *Memory and Cognition, Vol. 25, pp18-35*

- Lloyd-Jones, T.J., Nakabayashi, K. (2009) Independent effects of colour on object identification and memory. *Quarterly Journal of Experimental Psychology, Vol.62, No. 2, pp 310-322*

- Lloyd-Jones, T.J., Nettlemill, M. (2007) Sources of error in picture naming under time pressure. *Memory & Cognition, Vol. 35, No. 4, pp 816-836*

- Loftus, G.R. (1985) Picture perception: Effects of luminance on available information and information-extraction rate. *Journal of Experimental Psychology: General, Vol. 114, pp 342-346*

- Loftus, G.R., Hanna, A., Lester, L. (1988) Conceptual masking: How one picture steals attention from another picture. *Cognitive Psychology, Vol. 20, pp 237-282*

- Loftus, G.R., Hogden, J. (1988) Picture perception: Information extraction and phenomenological appearance. In G.H Bower (ed.) *The psychology of learning and motivation* New York: Academic Express

- Loftus, G.R., McLean, J. (1999) A front end to a theory of picture recognition. *Psychonomic Bulletin & Review, Vol. 6, pp 394-411*

- Logan, G.D., Taylor, S.E., Etherton, J.L. (1996) Attention in the Acquisition and Expression of Automaticity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 22, No. 3, pp 620-638*

- Lueschow, A., Miller, E.K., Desimone, R. (1994) Inferior temporal mechanisms for invariant object recognition. *Cerebral Cortex, Vol. 4, No. 5, pp 523-531*

- Luria, A.R. (1947) *Travmaticheskaja afazija.* Izd. AMN SSR, Moskva (Russian)

- Luria, A.R. (1962) *Vysshije korkovyje funktsii cheloveka.* Izd. MGU, Moskva (Russian)

- Macario, J.F. (1991) Young children's use of color classification: Foods and canonically colored objects. *Cognitive Development, Vol. 6, pp 17-46*

- Mack, M.L., Gauthier, I., Sadr, J., Palmeri, T.J. (2008) Object detection and basic-level categorization: Sometimes you know it is there before you know what it is. *Psychonomic Bulletin & Review, Vol. 15, No. 1, pp 28-35*

- Maljkovic, V., Nakayama, K. (1994) Priming of pop – out: I. Role of features. *Memory & Cognition, Vol. 22, No. 6, pp 657-672*

- Mapelli, D., Behrmann, and M. (1997) The role of color in object recognition: evidence from visual agnosia. *Neurocase, Vol. 3, pp 237-247*

- Marks, W. (1991) Effects of encoding the perceptual features of pictures on memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 17, No. 3, pp 566-577*

- Marr, D. (1982) *Vision.* San Francisco CA: Freeman

- Marr, D., Nishihara, H.K. (1978) Representation and recognition of the spatial organization of three dimensional shapes. *Proceedings of the Royal Society of London, Series B, 200, pp 269-294*

- Marshall, R.C. (1976) Word retrieval of aphasic adults. *Journal of Speech and Hearing Disorders, Vol. 41, No. 4, pp 444 – 451*

- Marsolek, C.J. (2008) What antipriming reveals about priming. *TRENDS in Cognitive Sciences Vol. 12, No. 5, pp 176-181*

- Maunsell, J.H.R., Ghose, G.M., Assad, J.A., MsAdams, C.J., Boudreau, C.E., Noerager, B.D. (1999) Visual response latencies of magnocellular and parvocellular LGN neurons in macaque monkeys. *Visual Neuroscience, Vol. 16, pp 1-14*

- Mausfeld, R. (1998) Colour perception: From Grassmann codes to a dual code for object and illumination colors. In Backhaus, W., Kliegl, R., Werner, J.S. (ed.) *Color vision – Perspective from different disciplines.* Berlin: Walter de Gruyter

- Mausfeld, R., Heyer, B. (ed.) (2003) *Colour perception: mind and the physical world.* Oxford: Oxford University Press

- Maylor, E. (1998) Retrieving names in old age: Short- and (very) long-term effects of repetition. *Memory & Cognition, Vol. 26, No. 2, pp, 309-319*

- McCarthy, R. A. and L. D. Kartsounis (2000) Wobbly words: Refractory anomia with preserved semantics . *Neurocase, Vol. 6, No.6, pp 487-497*

- McCauley, C., Parmelee, C.M., Sperber, R.D., Carr, T.H. (1980) Early extraction of meaning from pictures and its relation to conscious identification. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 6, No. 2, pp 265-276*

- McDonald, J.S., Tadmor, Y. (2006) The perceived contrast of texture patches embedded in natural scenes. *Vision Research, Vol. 46, pp 3098-3104*

- McIlhagga, W.H., Mullen, K.T. (1996) Contour integration with colour and luminance contrast. *Vision Research, Vol. 36, pp 1265-79*

- McKelvie, S.J., Sano, E.K., Stout, D. (2001) Effects of colored separate and interactive pictures on cued recall. *The Journal of General Psychology, Vol. 121, No.3, pp 241-251*

- McNeil, M.R. (1997) Resource allocation theory: clinical implications. Paper presented at the annual meeting of the Academy of Neurologic Communication Disorders and Sciences, Boston MA.

- McRae, K., de Sa, V.R., Seidenberg, M.S. (1997) On the nature and scope of featural representations of word meaning. *Journal of Experimental Psychology: General, Vol. 126, pp 99-130*

- Mecklenbräuker, S., Hupach, A., Wippich, W. (2001) What colour is in the car? Implicit memory for colour information in children. *The Quarterly Journal of Experimental Psychology, Vol. 54a, No. 4, pp 1069-1086*

- Meister, I.G., Weidemann, J., Foltys, H., Brand, H., Willmes, K., Krings, T., Thron, A., Töpper, R., Boroojerdi B. (2005) The neural correlate of very-long-term picture priming. *European Journal of Neuroscience, Vol. 21, pp 1101-1106*

- Meyer, A.S., Sleiderink, A.M., Levelt, W.J.M. (1998) Viewing and naming objects: eye movements during noun phrase production. *Cognition, Vol. 66, pp B25-B33*

- Mills, R., Knox, A.W., Juola, J.F., Salmon, S.J. (1979) Cognitive loci of impairments in picture naming by aphasic subjects. *Journal of speech and Hearing Research, Vol. 22, pp 73-87*

- Milner, A.D., Heywood, C.A. (1989). A disorder of lightness discrimination in a case of visual form agnosia. *Cortex, Vol. 25, pp 489-494*

- Milner, A.D., Perrett, D.I., Johnston, R.S., Benson, P.J., Jordan, T.R., Heeley, D.W., Bettucci, D., Mortara, F., Mutani, R., Terassi, E., Davidson, D.L. (1991). Perception and action in ‘‘visual form agnosia’’. *Brain, Vol. 114, pp 405-428*

- Mitchell, D. B. (1989) How many memory systems? Evidence from aging. *Journal of Experimental Psychology: Learning, Memory, & Cognition, Vol.15, pp 31-49*

- Mitchell, D.B. (2006) Nonconsciuos priming after 17 years. *Psychological Science, Vol. 17, No. 11, pp 925-929*

- Mitchell, D.B., Brown, A.S. (1988) Persistent repetition priming in picture naming and its dissociation from recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 14, No. 2, pp 213-222*

- Mitchell, D.B., Brown, A.S., Murphy, D.R. (1990) Dissociations between procedural and episodic memory: Effects of time and aging. *Psychology and Aging, Vol. 5, pp 264-276*

- Mitchell, D.B. (1993) Implicit and explicit memory for pictures: Multiple views across the lifespan. In P. Graf & M. E. J. Masson (eds.) *Implicit memory: New directions in cognition, development, and neuropsychology* (pp. 171-190). Hillsdale, NJ: Erlbaum

- Mitchum, C.C., Ritgert, B.A., Sandson, J., Sloan Bernd, R. (1990), The use of response analysis in confrontation naming. *Aphasiology, Vol. 4, No. 3, pp 261-280*

- Miyake, A., Carpenter, P.A., Just, M.A. (1995) Reduced resources and specific impairments in normal and aphasic sentence comprehension. *Cognitive Neuropsychology, Vol. 12, pp 651-679*

- Møller, P., Hurlbert, A.C. (1996) Psychophysical evidence for fast region-based segmentation process in motion and colour. *Proceedings of the National Academic Sciences, USA, Vol. 93, pp 13494-13499*

- Mohr, E. (2004) *Colour facilitates naming in post acute aphasic subjects.* Master dissertation, University of Newcastle upon Tyne

- Montanes, P., Goldblum, M. C., Boller, F. (1995) The naming impairment of living and nonliving items in Alzheimer's disease. *Journal of the International Neuropsychological Society, Vol. 1, pp 39–48*

- Moore, C.J., Price, C.J. (1999) Three distinct regions for word and picture naming in the ventral visual pathway. *NeuroImage, Vol. 10, pp 181-192*

- Moore, C., Price, C.J. (1997) Category-specific object naming differences: A functional imaging study. *27th Annual Meeting of the Society for Neuroscience, No. 414, pp 5*

- Morrison, C. M., Ellis, A. W., Quinlan, P. T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. *Memory & Cognition, Vol. 20, pp 705-714*

- Morton, J. (1979) Word recognition. In: Morton J., Marshall. J.C. (ed.) *Psycholinguistics.* London: Elek

- Moscovitch, M., Vriezen, E., Goshen-Gottstein, Y. (1993) Implicit tests of memory in patients with focal lesions or degenerative brain disorders. In: Boller F., Grafman J. (ed.) *Handbook of Neuropsychology Vol. 8.* Amsterdam: Elsevier Publishers

- Moscovitch, M., Winocur, G., McLachlan, D. (1986) Memory as assessed by recognition and reading time in normal and memory-impaired people with Alzheimer's disease and other neurological disorders. *Journal of Experimental Psychology: General, Vol. 115, pp 331-347*

- Muller, J.R., Metha, A.B., Krauskopf, J., Lennie, P. (1999) Rapid adaptation in visual cortex to the structure of images. *Science Vol. 285, pp 1405-1408*

- Mummery, C.J., Patterson, K., Hodges, J.R., Price, C.J. (1998) Functional neuroanatomy of the semantic system: Divisible by what? *Journal of Cognitive Neuroscience, Vol. 10, No. 6, pp 766-777*

- Murphy, G.L. (1991) Parts in object concepts: Experiments with artificial categories. *Memory & Cognition, Vol. 19, 423-438*

- Murray, L. L. (1999) Attention and aphasia: theory, research and clinical implications. *Aphasiology, Vol. 13, No.2, pp 91-111*

- Murray, J.E., Jolicoeur, P., Mullen, P.A., Ingleton, M. (1993) Orientation invariant transfer of training in the identification of rotated natural objects. *Memory & Cognition, Vol. 21, 604-610*

- Murtha, S., Chertkow, H., Beauregard, M., Evans, A. (1999) The neural substrate of picture naming. *Journal of Cognitive Neuroscience, Vol. 11, No. 4, pp 399-423*

- Musen, G., O'Neil, J.E. (1997) Implicit memory for nonverbal associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 23, No. 5, pp 1192-1202*

- Naor-Raz, G., Tarr, M.J. (2003) Is color an intrinsic property of object representation? *Perception, Vol. 32, pp 667-680*

- Nicholson, K.G., Humphrey, G.K. (2001) Surface cues reduce the latency to name rotated images of objects. *Perception, Vol. 30, pp 1057-1081*

- Nicholson, K.G., Humphrey, G.K. (2003) The effect of colour congruency on shape discriminations of novel objects. *Perception, Vol. 32, pp 339-353*

- Nickerson, R.S. (1968) A note on long – term memory for pictorial material. *Psychonomic Science, Vol. 11, No. 2, pp 58*
- Nowak, L.G., Munk, M.H.J., Girard, P., Bullier, J. (1995) Visual latencies in areas V1 and V2 of the macaque monkey. *Visual Neuroscience, Vol. 12, pp 371-384*

- Ojemann, G.A. (1991) Cortical organization of language. *Journal of Neuroscience, Vol. 11, pp 2281-2287*

- Oliva, A., Schyns, P. (2000) Diagnostic colors mediate scene recognition. *Cognitive Psychology, Vol. 41, pp 176-210*

- Oliva, A., Torralba, A. (2001) Modelling the shape of the scene: A holistic representation of the spatial envelope. *International Journal of Computer Vision, Vol. 42, pp 145-175*

- Oliva, A., Torralba, A. (2006) Building the gist of a scene: the role of global image features in recognition. *Progress in Brain Research, Vol. 155, pp 23-36*

- Oliva, A., Torralba, A. (2007) The role of context in object recognition. *TRENDS in Cognitive Sciences, Vol. 11, No. 12, pp 520-527*

- Oliva, A., Torralba, A., Castelhano, M.S., Henderson, J.M. (2003) Top – down control of visual attention in object detection. *Proceeding of the IEEE International Conference Image Processing, 1, pp 253-256*

- Ostergaard, A.L., Davidoff, J.B. (1985) Some effects of color on naming and recognition of objects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 11, No. 3, pp 579-587*

- Palmer, S., Rosch, E., Chase, P. (1981). Canonical perspective and the perception of objects. In J. Long & A. Baddeley (Eds.), *Attention and Performance* (Vol. 9, pp. 135- 151). Hillsdale, N J: Erlbaum.

- Park, S. M., Gabrieli, J. D. E. (1995). Perceptual and nonperceptual components of implicit memory for pictures. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 21, pp 1583-1594*

- Parker, D.M.,Lishman, J.R., Hughes, J. (1992) Temporal integration of spatially filtered visual images. *Perception, Vol. 21, pp 147-160*

- Pavio A., te Linde, J. (1980) Symbolic comparisons of objects on color attributes. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 6, pp 652-661*

- Perlin, K. (2002) Improving noise. *ACM Transcations & Graphics, Vol. 21, No. 3, pp 681-682*

- Peterson, M.A., Gibson, B.S. (1993) Shape recognition contribution to figure – ground organization in three – dimensional display. *Cognitive Psychology, Vol. 25, pp 383-429*

- Peterson, M.A., Gibson, B.S. (1994) Must shape recognition follow figure – ground organization? An assumption peril. *Psychological Science, Vol. 5, pp 253-259*

- Peterson, M.A., Kim, J.H. (2001) On what is bound in figure and grounds. *Visual Cognition, Vol. 8, pp 329-348*

- Peterson, M.A., Lampignano, D.W. (2003) Implicit memory for novel figure – ground displays includes a history of cross – border competition. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 29, pp 808-822*

- Price, C.J. (2000) The anatomy of language: contributions from functional neuroimaging. *Journal of Anatomy, Vol. 197, pp 335-359*

- Price, C.J., Noppeney, U., Phillips, J. (2003) How is the fusiform gyrus related to category – specificity? *Cognitive Neuropsychology, Vol. 20, No. 3/4/5/6, pp 561-574*

- Price, C.J., Humphreys, W. (1989) The effects of surface detail on object categorization and naming. *The Quarterly Journal of Experimental Psychology, Vol. 41A, No. 4, pp 797-828*

- Price, C.J., Moore, C.J., Humphreys, G.W., Frackowiak, R.S., Friston, K.J. (1996) The neural regions sustaining object recognition and naming. *Proceedings of the Royal Society, B263, pp 1501-7*

- Price, C.J., Moore, C.J., Humphreys, W., Wise, R.S.J. (1997) Segregating semantic from phonological processes during reading. *Journal of Cognitive Neuroscience, No. 9, pp 727-733*

- Proverbio, A.M., Burco, F., del Zotto, M., Zani, A. (2004) Blue piglets? Electrophysiological evidence for the primacy of shape over color in object recognition. *Cognitive Brain Research, Vol. 18, pp 288-300*

- Rapp, B., Goldrick, M. (2000) Discreteness and interactivity in spoken word production. *Psychological Review, Vol. 107, No. 3, pp 460-499*

- Reinitz, M.T., Wright, E., Loftus, G.R. (1989) Effects of semantic priming on visual encoding of pictures. *Journal of Experimental Psychology: General, Vol. 118, No. 3, pp 280-297*

- Reis, A., Faísca, L., Ingvar, M., Petersson, K.M. (2006) Color makes a difference: Two-dimensional object naming in literate and illiterate subjects. *Brain and Cognition, Vol. 60, pp 49-54*

- Riddoch, M.J., Humpreys, G.W. (2001) Object recognition. In: Rapp, B. (ed.) *The handbook of cognitive neuropsychology.* Psychology Press: Hove

- Ringo, J.L. (1996) Stimulus specific adaptation in inferior temporal and medial temporal cortex of the monkey. *Behavioural Brain Research, Vol. 76, pp 191–197*

- Rivest, J., Cavanagh, P. (1996) Localizing contours defined by more than one attribute. *Vision Research, Vol. 36, pp 53-66*

- Roediger, H.L. (2003) Reconsidering implicit memory. In: Bowers, J.S. & Marsolek, C.J. (ed.) *Rethinking Implicit Memory.* University Press: Oxford

- Roediger, H.L., III, Geraci, L. (2005) Implicit memory in cognitive research. In : Wenzel, A. & Rubin, D.C. (ed.) *Cognitive methods and their application to clinical research.* American Psychological Association: Washington D.C.

- Roediger, H.L., McDermott, K.B. (1993) Implicit memory in normal human subjects. In Spinnler & Boller, F. (ed.), *Handbook of Neuropsychology.* Amsterdam: Elsevier

- Rolls, E.T. (2008) Top-down control of visual perception: Attention in natural vision. *Perception Vol. 37, pp 333-354*

- Rossion B., Bodart, J-M., Pourtois, G., Thioux, M., Bol, A., Cosnard, G., Georges, B., Michel, C., De Volder, A. (2000) Functional imaging of visual semantic processing in the human brain. *Cortex, Vol. 36, pp 579-591*

- Rossion B., Pourtois G. (2004) Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception, Vol. 33, pp 217-236*

- Rubin, E. (1921) Visuell wahrgenommene Figuren. Copenhagen: Gyldenalske Boghandel [Reprinted as „ Figure and ground" in Beardslee & Wertheimer (ed.) *Readings in perception* (pp 194-203). Princeton, NJ: Van Nostrand, 1958]

- Russell R., Sinha, P., (2007) Real-world face recognition: The importance of surface reflectance properties. *Perception, Vol. 36, No. 9, pp 1368-1374*

- Salmelin, R., Hari, R., Lounasmaa, O. V., Sams, M. (1994) Dynamics of brain activation during picture naming. *Nature, Vol. 368, pp 463-465*

- Sanocki, T., Bowyer, K.W., Adair, J., Sarkar, S. (1995) Are real edges sufficient for object recognition? *Investigative Opthalmology & Visual Science* [Abstract], *Vol. 36, pp 3890*

- Sanocki, T., Bowyer, K.W., Heath, M.D., Sarkar, S. (1998) Are edges sufficient for object recognition? *Journal of Experimental Psychology: Human Perception and Performance, Vol. 24, No. 1, pp 340-349*

- Sawamura, H., Georgieva, S., Vogels, R., Vanduffel, W., Orban, G.A. (2005) Using functional magnetic resonance imaging to assess adaptation and size invariance of shape processing by humans and monkeys. *Journal of Neuroscience, Vol. 25, pp 4294-4306*

- Schacter, D.L. & Buckner, R.L. (1998) Priming and the brain. *Neuron, Vol. 20, pp 185-195*

- Schmidt, T. (2000) Visual perception without awareness: Priming responses by color. In T. Metzinger (ed.) *Neural correlates of consciousness.* (pp 157- 169). Cambridge, MA: MIT Press

- Schmidt, T. (2002) The finger in flight: Real – time motor control by visually masked color stimuli. *Psychological Science, Vol. 13, pp 112-118*

- Schyns, P., Oliva, A. (1994) From blobs to boundary edges: Evidence for time – and spatial – scale – dependent scene recognition. *Psychological Science, Vol. 5, pp 195-200*

- Segalowitz, S.J. (2007) Knowing before we know: Conscious versus preconscious top-down processing and a neuroscience of intuition. *Brain and Cognition, Vol. 65, pp 143-144*

- Shepard, R.N. (1964) Attention and the metric structure of the stimulus space. *Journal of Mathematical Psychology, Vol. 1, pp 54-87*

- Shevell, K.S., Kingdom, F.A.A. (2008) Colour in complex scenes. *Annual Review of Psychology, Vol. 59, pp 143-166*

- Silva, M.M., Groeger, J.A., Bradshaw, M.F. (2006) Attention – memory interactions in scene perception. *Spatial Vision, Vol. 19, No. 1, pp 9-19*

- Simons, J.S., Graham, K.S., Owen, A.M., Patterson, K. Hodges, J.R. (2001) Perceptual and semantic components of memory for objects and faces: A PET study. *Journal of Cognitive Neuroscience Vol. 13, No. 4, pp 430-443*

- Skorupski, P., Chittka, L. (2008) Towards a cognitive definition of colour vision. Nature Precedings: hdl:10101/npre.2008.1766.1 : Posted 04.04.2008

- Sloman, S.A., Hayman, C.A.G., Ohta, N., Law, J., Tulving, E. (1988) Forgetting in primed fragment completion. *Journal of Experimental Psychology Learning, Memory and Cognition, Vol. 14, 223-239*

- Smid, H.G.O., Jacob, A., Heinze, H.-J. (1997) The organization of multidimensional selection on the basis of color and shape: An event – related brain potential study. *Perception & Psychophysics, Vol. 59, No. 5, pp 693-713*

- Snodgrass, J.G. & Vanderwart M. (1980) A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 6, pp 174-215*

- Snodgrass, J.G. & Yuditsky (1996) Naming times for the Snodgrasss and Vanderwart pictures. *Behaviour Research Methods , Instruments & Computers, Vol. 28, No. 4, pp 516-536*

- Spence, I., Wong, P., Rusan, M., Rastegar, Naghmeh (2006) How color enhances visual memory for natural scenes. *Psychological Science, Vol. 17, No. 1, pp 1-6*

- Sperber, R.D., McCauley, C., Ragan, R.D., Weil, C.M. (1979) Semantic priming effects on picture and word processing. *Memory & Cognition, Vol. 7, No. 5, pp 223-239*

- Squire, L.R., Knowlton, B.J., Musen, G. (1993) The structure and organization of memory. *Annual Review of Psychology, Vol. 44, pp 453-495*

- Srinivas, K. (1996). Contrast and illumination effects on explicit and implicit measures of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 22, pp 1123-1135*

- Standing, L. (1973) Learning 10.000 pictures. *Quarterly Journal of Experimental Psychology, Vol. 25, pp 207-222*

- Standing, L., Conezio, J., Haber, R.N. (1970) Perception and memory for pictures: Single-trial learning of 2500 visual stimuli. *Psychonomic Science, Vol. 19, pp73-74*

- Steeves, J.K.E., Humphrey, G.K., Culham, J.C., Menon, R.S., Milner, A.D., Goodale, M.A. (2004) Behavioural and neuroimaging evidence for a contribution of color and texture information to scene classification in a patient with visual form agnosia. *Journal of Cognitive Neuroscience, Vol. 16, No. 6, pp 955-965*

- Stewart, L., Meyer, B-U., Frith, U., Rothwell, U. (2001) Left posterior BA37 is involved in object recognition: a TMS study. *Neuropsychologia, Vol. 39, pp 1-6*

- Stoerig, P. (1998). Wavelength information processing *versus* color perception: evidence from blind sight and color – blind sight. In Backhaus, W., Kliegl, R., Werner, J.S. (ed.) *Color vision – Perspective from different disciplines.* Berlin: Walter de Gruyter

- Stuart, D.J. (1994) *Picture – word differences in memory comparison involving colour.* Dissertation, The University of Western Ontario (Canada).

- Sugase, Y., Yamane, S., Ueno, S., Kawano, K. (1999) Global and fine information coded by single neurons in the temporal visual cortex. *Nature, Vol. 400, pp 869-873*

- Sumner, P. & Mollon, J.D. (2000) Catarrhine photopigments are optimized for detecting targets against a foliage background. *Journal of Experimental Biology, Vol. 203, pp 1963-1986*

- Suzuki, K., Takahashi, R. (1997) Effectivness of color in picture recognition memory. *Japanese Psychological Research, Vol. 39, No. 1, pp 25-32*

- Switkes, E., Bradley, A., De Valois, K.K. (1988) Contrast dependence and mechanisms of masking interactions among chromatic and luminance gratings. *Journal of the Optical Society of America, A, Vol.5, pp 1149-1162*

- Syrkin, G., Gur, M. (1997) Colour and luminance interact to improve pattern recognition. *Perception, Vol. 26, pp 127-140*

- Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., Jacobsen, T., Arévalo, A. L., Vargha, A., Bates, E. (2005) Timed action and object naming. *Cortex, Vol. 41, pp7-25*

- Tanaka, J. (2001) in Humphreys, G.W., Forde, E.M.E. (2001) Hierarchies, similarity, and interactivity in object recognition: “Category-specific” neuropsychological deficits. *Behavioral and Brain Sciences, Vol. 24, pp 453-509*

- Tanaka, J., Presnell, L. (1999) Color diagnosticity in object recognition. *Perception & Psychophysics, Vol. 61, No. 6, pp 1140-1153*

- Tanaka, J., Weiskopf, D., Williams, P. (2001) The role of color in high-level vision. *TRENDS in Cognitive Sciences, Vol. 5, No. 5, pp 211-215*

- Tarr, M.J. (1995). Rotating objects to recognize them: A case study of the role of viewpoint dependency in the recognition of threed-dimensional objects. *Psychonomic Bulletin and Review, Vol. 2, pp 55–82*

- Tarr, M.J., Bülthoff, H.H., Zabinski, M. & Blanz, V. (1997). To what extent do unique parts influence recognition across changes in viewpoint? *Psychological Science, Vol. 8, pp 282–289*

- Tarr, M. J., Kersten, D., Cheng, Y., Rossion, B. (2001) It's Pat! Sexing faces using only red and green. *Journal of Vision, Vol. 1, No. 3, 337a (abstract)* http://journalofvision.org/1/3/337, DOI:10.1167/13337

- Tatler, B.W., Melcher, D. (2007) Pictures in mind: Initial encoding of object properties varies with the realism of the scene. *Perception, Vol. 36, No. 12, pp 1715-1729*

- Tew, J.P. (1990) *Normal confrontation naming performance under temporal stress.* Unpublished Master's thesis, University of Wisconsin, at Madison

- Thompson-Schill, S.L. (2003). Neuroimaging studies of semantic memory: Inferring 'how' from 'where.' *Neuropsychologia, Vol. 41, pp 280-292*

- Thorpe, S.J., Fize, D., Marlot, C. (1996) Speed processing in the human visual system. *Nature, Vol. 381 (6582), pp 520-522*

- Treisman, A.M. (1988) Features and objects: The fourteenth Bartlett memorial lecture. *The Quarterly Journal of Experimental Psychology, Vol. 40A, pp 201-237*

- Treisman, A.M.(1990) Variations on the theme of features integration: Reply to Navon. *Psychological Review, Vol. 97, pp 460-463*

- Tulving, E., Schacter, D.L. (1990) Priming & human memory systems. *Science, Vol. 247, No. 4940, pp 301-306*

- Tulving, E., Thompson, D.M. (1973) Encoding specificity and retrieval processes in episodic memory. *Psychological Review, Vol. 80, pp 352-373*

- van Turennout, M., Bielamowicz, L., Martin, A. (2003) Modulation of neural activity during object naming: Effects of time and practice. *Cerebral Cortex, Vol. 13, pp 381-391*

- van Turennout, M., Ellmore, T., Martin, A. (2000) Long-lasting cortical plasticity in the object naming system. *Nature Neuroscience, Vol. 3, No. 12, pp 1329-1334*

- Turk-Brown, N.B., Yi., D.J., Leber, A.B., Chun, M.M. (2007) Visual quality determines the direction of neural repetition effects. *Cerebral Cortex, Vol. 17, No. 2, pp 425-433*

- Tyler, L.K., Stamatakis, E.A., Bright, P. (2004) Processing objects at different levels of specificity. *Journal of Cognitive Neuroscience, Vol. 16, No. 3 , pp 351-362*

- Ullman, S. (1995) Sequence seeking and counter streams: A model for bi – directional information flow in the visual cortex. *Cerebral Cortex, Vol. 5, No. 1, pp 1-11*

- Ullman, S. (1996) *High-level vision: Object recognition and visual cognition.* Cambridge MA: MIT Press

- Ullman, S. (2004) Approaches to visual cognition. In Kanwisher, N. & Duncan, J. (ed.) *Functional Neuroimaging of Visual Cognition- Attention and Performance XX.* Oxford: Oxford University Press

- Ullman, S. (2006) Object recognition and segmentation by a fragment-based hierarchy. *TRENDS in Cognitive Sciences Vol. 11 No. 2, pp 58-64*

- Uttl, B., Graf, P. (1996) Object orientation information in semantic and episodic memory. *Canadian Journal of Experimental Psychology, Vol. 50, pp 87-103*

- Uttl, B., Graf, P., Santacruz, P. (2006) Object color affects identification and repetition priming. *Scandinavian Journal of Psychology, Vol. 47, pp 313-325*

- Vandenberghe, R., Price, C., Wise, R., Josephs, O., Frackowiak, R.S.J. (1996) Functional anatomy of a common semantic system for words and pictures. *Nature, Vol. 383, No. 19, pp 254-256*

- Van Essen, D.C., Anderson, C.H., Felleman, D.J. (1992) Information processing in the primate visual system: An integrated systems perspective. *Science, Vol. 255, pp 419-423*

- Vernon, D., Lloyd-Jones, T.J. (2003) The role of colour in implicit and explicit memory performance. *The Quarterly Journal of Experimental Psychology, Vol. 56A, No. 5, pp 779-802*

- Viggiano, M.P., Vanucci, M., (2002) Drawing and identifying objects in relation to semantic category and handedness. *Neuropsychologia, Vol. 40, pp 1482-1487*

- Viggiano, M.P., Vanucci, M., Righi, S. (2004) A new standardized set of ecological pictures for experimental and clinical research on visual object processing. *Cortex, Vol. 40, pp 491-509*

- Vitkovitch, M., Humphreys, G.W. (1991) Perseverant responding in speeded naming of pictures: It's in the links. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 17, pp 664-680*

- Vitkovitch, M., Humphreys, G.W., Lloyd-Jones, T.J. (1993). On naming a giraffe a zebra: Picture naming errors across different object categories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 19, pp 243-259*

- Vuilleumier, P., Henson, R.N., Diver, J., Dolan, R.J. (2002) Multiple levels of visual object constancy revealed by event-related fMRI of repetition priming. *Nature Neuroscience, Vol. 5, pp 491-499*

- Wichmann, F.A., Braun, D.I., Gegenfurtner, K.R. (2006) Phase noise and the classification of natural images. *Vision Research, Vol. 46, No. 8-9, pp 1520-1529*

- Wichmann, F.A., Sharpe, L.T., Gegenfurtner, K.R. (2002) The contributions of color to recognition memory for natural scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 28, No. 3, pp 509-520*

- Wiggs, C.L., Martin, A. (1998) Properties and mechanisms of perceptual priming. *Current Opinion in Neurobiology, Vol. 8, pp 227-233*

- Wilcox, T., Chapa, C. (2004), Priming infants to attend to color and pattern information in an individuation task. *Cognition, Vol. 90, pp 265-302*

- Wilshire, C.E., Saffran, E.M. (2005) Contrasting effects of phonological priming in aphasic word production. *Cognition, Vol. 95, No. 1 pp 31-71*

- Wilton, R.N. (1989) The structure of memory: Evidence concerning the recall of surface and background colour and shapes. *Quarterly Journal of Experimental Psychology, Vol. 41A, No. 3, pp 579-598*

- Wingfield, A., Brownell, H., Hoyte, K.J. (2006) Variable solutions to the same problem: Aberrant practise effects in object naming by three aphasic patients. *Brain and Language, Vol. 97, pp 351-356*

- Wippich, W., Mecklenbräuker, S. (1998) Effects of color on perceptual and conceptual tests of implicit memory. *Psychological Research, Vol. 61, pp 285-294*

- Wippich, W., Mecklenbräuker, S., Baumann, R. (1994) Farbwirkungen bei impliziten and expliziten Gedächtnisprüfungen. *Zeitschrift für experimentelle und angewandte Psychologie, Vol. 41, pp 315-347*

- Wise, R., Chollet, F., Hadar, U., Friston, K., Hoffner, E., Fracowiak, R.S.J. (1991) Distribution of cortical neural networks involved in word comprehension and word retrieval. *Brain, Vol. 114, pp 1803-1817*

- Woll, G., Cohnen, R., Kelter, S. (1979) Investigation of concept components among aphasic patients. *Zeitschrift für Klinische Psychologie - Forschung und Praxis Vol. 8, No. 3, pp 221-233*

- Wurm, L.H., Legge, G.E., Isenberg, L.M., Luebker, A. (1993) Color improves object recognition in normal and low vision. *Journal of Experimental Psychology: Human Perception and Performance, Vol. 19, No. 4, pp 899-911*

- Yao, A.Y.J., Einhäuser, W. (2008) Color aids late but not early stages of rapid natural scene recognition. *Journal of Vision, Vol. 8, No. 16, pp 1-13*

- Yago, E., Ishai, A. (2006) Recognition memory is modulated by visual similarity. *NeuroImage, Vol. 31, pp 807-817*

- Yip, A.W., Sinha, P. (2002) Contribution of color to face recognition. *Perception, 2002, Vol. 31, pp 995-1003*

- Zeki, S., Marini, L. (1998) Three cortical stages of colour processing in the human brain. *Brain, Vol. 121, pp 1669-1685*

- Zelinsky, G.J., Murphy, G.L. (2000) Synchronizing visual and language processing: An effect of object name length on eye movements. *Psychological Science, Vol. 11, No. 2, pp 125-131*

- Zimmer, H.D. (1995) Size and orientation of objects in explicit and implicit memory: A reversal of the dissociation between perceptual similarity and type of test. *Psychological Research, Vol. 57, pp 260-273*

- Zimmer, H.D., Steiner, A. (2003) Colour specificity in episodic and in perceptual object recognition with enhanced colour impact. *European Journal of Cognitive Psychology, Vol. 15, No. 3, pp 349-370*

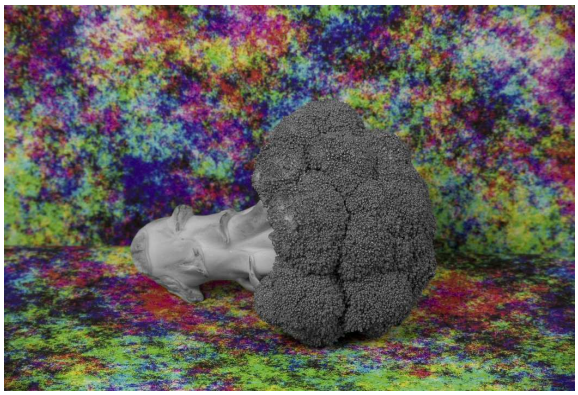
Appendix 1. Picture examples experiment 1 and 2

cocp coloured object coloured plain background

gocp grey object coloured plain background

gogp grey object grey plain background

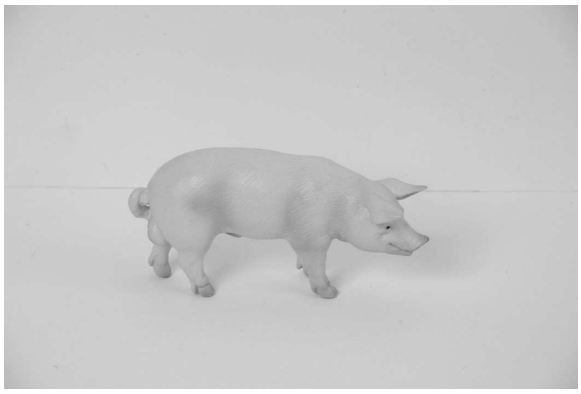
cocn coloured object coloured noise background



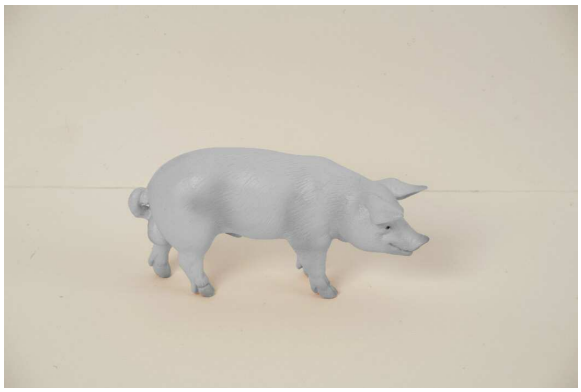
gocn grey object coloured noise background

gogn grey object grey noise background

Appendix 2. Picture examples experiment 3



gogp grey object grey plain background

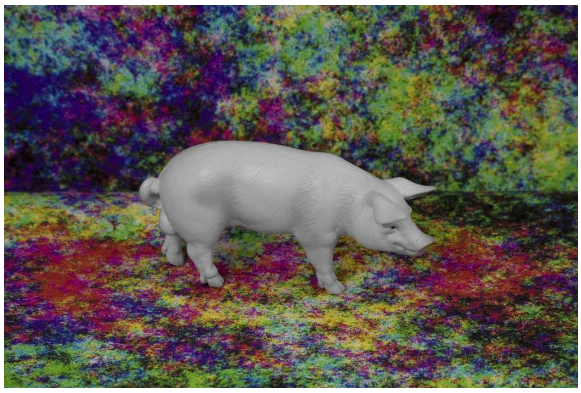


gocp grey object coloured plain background

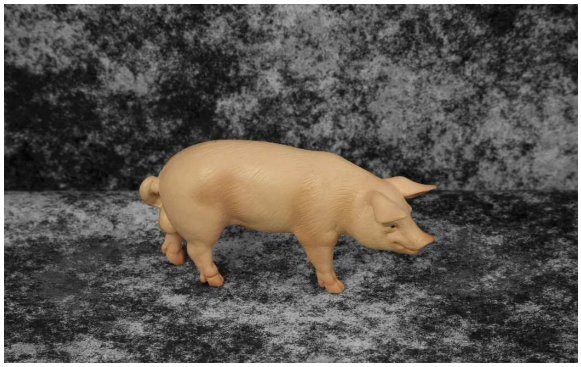
cogp coloured object grey plain background

cocp coloured object coloured plain background

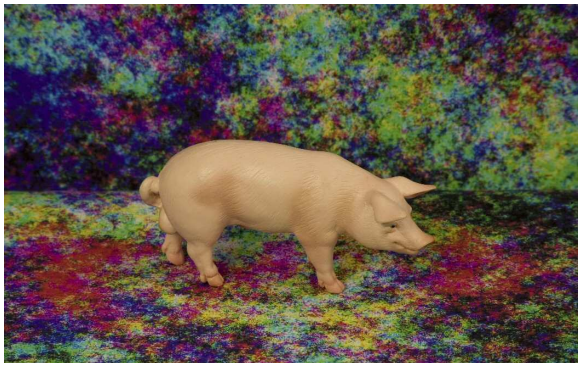
gogn grey object grey noise background



gocn grey object coloured noise background



cogn coloured object grey noise background



cocn coloured object coloured noise background

Appendix 3. Object list for experiment 1 and 2

Object List

	Object name and category	Object colour	Diagnostic colour values* 1000 - 5000 < 3000 = low > 3001 = high
	21 fruits, *high colour diagnostic*		
1	banana	yellow	4.818
2	grapefruit	yellow	high
3	lemon	yellow	4.545
4	orange	orange	4.909
5	strawberry	red	4.636
6	apricot	yellow-**orange**	high
7	mandarin	orange	high
8	coconut	brown	high
9	kiwi halves	green	high
10	peanut	yellow-**brown**	5.000
11	apple	red	3.455
12	honey dew melon	yellow	high
13	grapes	red	3.636
14	redcurrant	red	high
15	raspberry	red	high
16	pear	**green**-yellow	4.182
17	almond	brown	high
18	hazelnut	brown	4.455
19	cherry	red	4.727
20	peach	yellow -**red**	4.273
21	blueberry	dark blue	high
	19 vegetables, *high colour diagnostic*		
22	carrot	orange	5.000
23	tomato	red	4.636
24	radish	red	high
25	egg plant/ aubergine	dark purple	high
26	onion	brown	4.455
27	potato	brown	4.545
28	cucumber	green	high
29	peas	green	high
30	broccoli	green	high
31	Brussels sprouts	green	high
32	green beans	green	high
33	celery	green	4.818
34	red cabbage	purple	high
35	sweet corn	yellow	4.909
36	leek	green	high
37	pumpkin	orange	4.909
38	pepper	red	3.273
	1 vegetable, *low colour diagnostic*		
39	mushroom	brown	2.545

Object List

	Object name and category	Object colour	Diagnostic colour values* 1000 - 5000 < 3000 = low > 3001 = high
	25 animals, *high colour diagnostic*		
1	pig	pink	4.455
2	starfish	orange	high
3	alligator	green	4.545
4	frog	green	4.091
5	crab	green	high
6	camel	yellow-**brown**	4.545
7	lion	yellow-**brown**	4.545
8	kangaroo	yellow-**brown**	4.727
9	deer	brown	4.727
10	rabbit	brown	3.545
11	turtle	brown	4.091
12	fox	brown	4.364
13	owl	brown	3.818
14	elk	brown	high
15	seal	brown	4.091
16	horse	brown	3.545
17	elephant	grey-**brown**	4.727
18	bear / grizzly	brown	3.727
19	chicken	brown	3.636
20	squirrel	brown	4.273
21	hippopotamus	brown	high
22	giraffe	brown	4.545
23	sheep	beige	4.091
25	wild boar	grey-**brown**	high
	3 animals, *low colour diagnostic*		
26	dog	brown	2.909
27	snake	green	2.909
28	cat	brown	2.636
	5 other living things, *high colour diagnostic*		
1	cheese	yellow	high
2	chocolate	brown	high
3	spaghetti	yellow	high
4	piece of fir-wood	brown	high
5	fir cones	brown	high
	19 manmade objects, *high colour diagnostic*		***high***
1	fire extinguisher	red	high
2	fire truck	red	high
3	double deck bus	red	high
4	Santa hat	red	high
5	Swiss army knife	red	high
6	brick	red	high
7	flowerpot	red	high
8	bell	golden	3.727
9	crown	golden	3.455
10	lock	brassy	3.364
11	rubber ducky	yellow	high

Object List

	Object name and category	Object colour	Diagnostic colour values* 1000 - 5000 < 3000 = low > 3001 = high
12	wooden spoon	wooden	high
13	chopping board	wooden	high
14	cigar	brown	4.909
15	basket	brown	3.364
16	cork	light brown	high
17	no entry sign	red	high
18	life vest	yellow	high
19	toy tank	green	high
	49 manmade objects, *low colour diagnostic*		
	household items (30)		
20	hanger	brown	2.909
21	clothespin	blue	1.818
22	candle	red	1.545
23	toothbrush	yellow	1.182
24	coffee mug	orange	low
25	pencil	blue	1.909
26	vase	green	1.182
27	book	blue	1.818
28	ruler	yellow	2.182
29	filer	red	low
30	(salad) bowl	pink	1.091
31	pen	pink	1.091
32	watering can	green	2.182
33	screwdriver	silver/**red**	3.000
34	pincers / pliers	silver/**orange**	low
35	can opener	silver/**blue**	low
36	nutcracker	silver/**brown**	low
37	dustpan	yellow	low
38	window cleaner	silver-**green**	low
39	little pillow	pink	low
40	rubber gloves	yellow	low
41	sponge	yellow	low
42	teapot	green	low
43	sewing cotton	pink	low
44	wool	pink	low
45	umbrella	red	1.182
46	hot-water bottle	blue	low
47	scissors	silver/**red**	low
48	paintbrush	red	low
49	firelighter	purple	low
	toys (3)		
50	ball	orange	1.000
51	Lego	green	low
52	toy car	red	1.636
	clothes (17)		

Object List

	Object name and category	Object colour	Diagnostic colour values* 1000 - 5000 < 3000 = low > 3001 = high
53	gloves	blue	1.364
54	shoelace	brown	low
55	socks	green	1.000
56	Wellingtons	green	low
57	boots	brown	2.364
58	t-shirt	red	1.182
59	button	pink	1.000
60	tie	purple	1.182
61	handbag	brown	low
62	belt	green	3.000
63	shoe	light brown	2.091
64	necklace	turquoise	1.818
65	sandals	brown	low
66	men's shirt	blue	low
67	pullover / cardigan	red	low
68	bathing suit / swimming costume	blue	low
	10 abstract forms		***none***
1	cylinder	orange	none
2	trapezoid	green	none
3	spherical	red	none
4	hemispherical	red	none
5	pyramid	yellow	none
6	square	green	none
7	cube	yellow	none
8	pentagon	orange	none
9	cone	blue	none
10	rhomboid	blue	none

**Legend: ***Colour diagnostic values were taken from the Rossion & Pourtois study (2004) for those objects where values were available; all other objects were classified as high-, low-, or non-colour diagnostic.

Colours

yellow/ golden/ brassy	19	**yellowish**	**20**
beige	1		
orange	11		
red	28		
pink	7	**reddish**	**46**
purple	4		
blue / turquoise	12	**bluish**	**16**
green		**greenish**	**24**
brown / wooden	44	**brownish**	**44**

Colour diagnosticity

high colour diagnostic objects:	**87**
low colour diagnostic objects:	**53 plus 10 abstract forms**

Categories

Living things	:	**72**	
Non-living things	:	**68**	
Abstract forms	:	**10**	
Total	:	**150**	plus 4 training items

Appendix 4. Object list experiment 3

Object List experiment 3			
	Object name and category	**Object colour**	**Diagnostic colour values***
	6 fruits & 7 vegetables		
1	banana	yellow	4.818
2	orange	orange	4.909
3	strawberry	red	4.636
4	coconut	brown	high
5	apple	red	3.455
6	pear	**green**-yellow	4.182
7	egg plant/ aubergine	dark purple	high
8	onion	brown	4.455
9	potato	brown	4.545
10	cucumber	green	high
11	celery	green	4.818
12	sweet corn	yellow	4.909
13	pepper	red	3.273
	7 animals		
14	pig	pink	4.455
15	alligator	green	4.545
16	crab	green	high
17	horse	brown	3.545
18	chicken	brown	3.636
19	squirrel	brown	4.273
20	snake	green	2.909
	20 manmade objects		
21	clothespin	blue	1.818
22	candle	red	1.545
23	toothbrush	yellow	1.182
24	coffee mug	orange	low
25	pencil	blue	1.909
26	vase	green	1.182
27	book	blue	1.818
28	ruler	yellow	2.182
29	screwdriver	silver/**red**	3.000
30	pincers / pliers	silver/**orange**	low
31	sponge	yellow	low
32	teapot	green	low
33	wool	pink	low
34	umbrella	red	1.182
35	hot-water bottle	blue	low
36	firelighter	purple	low
37	Lego	green	low
38	toy car	red	1.636
39	socks	green	1.000
40	shoe	light brown	2.091

**Legend: ***Colour diagnostic values were taken from the Rossion & Pourtois study (2004) for those objects where values were available; all other objects were classified as high-, low-, or non-colour diagnostic.

Participant details of the aphasic subject group

Subject	*Gender*	*Age*	*Aphasia type*	*Severity*	*Diagnosis*	*weeks post onset*	*CA*	*D 15*	*P & P*
1	M	56	Anomic	severe	cerebral haemorrhage left parieto - temporal	38	0	2	4
2	M	59	Anomic	severe	atypical left cerebral haemorrhage	2	0	2	2
3	F	66	Broca's	severe	cerebral haemorrhage left frontal-parietal	15	0	2	6
4	M	68	Anomic	moderate	left MCA infarction	4	0	2	4
5	M	47	Thalamic Aphasia	moderate	left thalamic infarction	4	0	1	1
6	M	55	Broca's	medium	left MCA infarction	34	0	2	5
7	M	69	Anomic	moderate	cerebral haemorrhage left frontal - temporal	45	0	2	6
8	F	72	Anomic	moderate	TIA right hemispheric	52	0	1	3
9	F	48	Anomic	moderate	left MCA infarction	45	0	1	4
10	M	76	non classified	medium	left MCA infarction	4	0	2	6
11	M	79	Anomic	moderate	left MCA infarction	3	0	2	6
12	M	63	Anomic	medium	left MCA infarction	58	0	1	2
13	M	57	Anomic	moderate	aneurysm + left MCA infarction	4	0	1	1
14	F	59	Anomic	moderate	left MCA infarction	4	0	1	0
15	F	58	Anomic	medium	left basal ganglia + left MCA infarction	12	0	2	5
16	M	49	Anomic	moderate	left MCA infarction	5	0	2	4
17	F	79	Anomic	severe	left MCA infarction	1	0	2	6
18	F	46	Anomic	moderate	left thalamic infarction	22	0	1	3
19	M	68	Anomic	medium	left MCA infarction	9	0	1	4
20	F	56	Anomic	moderate	right MCA infarction	9	0	1	5
21	M	47	Anomic	moderate	left MCA infarction lacunar	4	0	1	4
22	M	50	Anomic	moderate	aneurysm + left cerebral haemorrhage	400	0	1	3
23	M	72	Transcortical Motor	medium	left basal ganglia infarction	2	0	2	6
24	F	57	Anomic	moderate	left basal ganglia + left thalamic infarction	401	0	1	2
25	M	45	Global	moderate	left MCA infarction	48	0	1	5
26	F	69	Anomic	moderate	left MCA infarction	6	0	1	5
27	M	57	non classified	medium	left MCA infarction	4	0	1	6
28	F	39	Anomic	moderate	left MCA infarction	12	0	1	2
29	M	47	Broca's	severe	left MCA infarction	50	0	1	3

Appendix 5 shows the participant details of the aphasic subject group. **Severity** stands for the severity of the specific aphasia type (e.g., severe anomic aphasia). Abbreviations: **MCA** = media cerebral artery; **CA** = Colour Associations, results for the "Colouring of Pictures Test" by Damasio et al. (1979); **D 15** = results of the Farnsworth Panel D-15 Test and the Lanthony15 Hue Desaturated Panel D-15 d Test (Richmond Products Inc., Albuquerque), **1** means normal, **2** means near normal; **P & P** = results for the "Three Pictures" component of The Pyramid and Palm Tree Test (Howard & Patterson, 1992), up to 6 errors are considered as normal.

Participant details of the German subject group

Subject	*Gender*	*Age*	*CA*	*D 15*	*P & P*
1	F	23	0	1	0
2	F	54	0	1	0
3	M	78	0	1	3
4	F	70	0	1	3
5	F	65	0	1	4
6	F	51	0	1	0
7	M	68	0	1	2
8	M	55	0	1	0
9	F	68	0	1	1
10	F	56	0	1	0

Appendix 6 shows the participant details of the German subject group. Abbreviations: **CA** = Colour Associations, results for the "Colouring of Pictures Test" by Damasio et al. (1979); **D 15** = results of the Farnsworth Panel D-15 Test and the Lanthony15 Hue Desaturated Panel D-15 d Test (Richmond Products Inc., Albuquerque), **1** means normal, **2** means near normal; **P & P** = results for the "Three Pictures" component of The Pyramid and Palm Tree Test (Howard & Patterson, 1992), up to 6 errors are considered as normal.

Participant details of the British subject groups

Subject	*Gender*	*Age*	*Group*	*CA*	*D 15*	*P & P*
1	M	23	1	0	1	2
2	M	64	1	0	1	0
3	M	40	1	0	1	2
4	M	23	1	0	1	0
5	M	28	1	0	1	2
6	F	45	1	0	1	0
7	F	20	1	0	1	5
8	M	20	1	0	1	3
9	F	22	1	0	1	3
10	M	36	1	0	1	1
11	F	19	1	0	1	2
12	M	27	1	0	1	2
13	F	20	1	0	1	0
14	F	46	1	0	1	1
15	M	24	1	0	1	1
16	M	35	1	0	1	0
17	F	26	1	0	1	3
18	F	28	1	0	1	2
19	F	27	1	0	1	0
20	F	22	1	0	1	2
21	M	20	3	0	1	2
22	M	33	3	0	1	0
23	F	37	3	0	1	4
24	F	32	3	0	1	1
25	M	42	3	0	1	1
26	F	28	3	0	1	5
27	F	52	3	0	1	1
28	M	27	3	0	1	0
29	F	56	3	0	1	0
30	M	20	3	0	1	1
31	F	32	3	0	1	2
32	M	53	3	0	1	1
33	F	23	3	0	1	0
34	F	25	3	0	1	1
35	M	19	3	0	1	2
36	F	26	3	0	1	0
37	F	22	3	0	1	0
38	F	20	3	0	1	2
39	F	37	3	0	1	2
40	F	25	3	0	1	2
41	F	56	6	0	1	1
42	F	31	6	0	1	1
43	F	23	6	0	1	1
44	F	23	6	0	1	1
45	F	25	6	0	1	3
46	F	26	6	0	1	0
45	F	48	6	0	1	1
46	M	30	6	0	1	0
47	F	47	6	0	1	1
48	F	33	6	0	1	2
49	F	23	6	0	1	2
50	F	19	6	0	1	5
51	M	24	6	0	1	1
52	F	43	6	0	1	0
53	F	24	6	0	1	1
54	M	35	6	0	1	1
55	F	20	6	0	1	2
56	F	27	6	0	1	2

Participant details of the British subject groups

Subject	*Gender*	*Age*	*Group*	*CA*	*D 15*	*P & P*
57	M	27	6	0	1	1
58	M	21	6	0	1	4
59	M	27	6	0	1	1
60	M	21	6	0	1	4

Appendix 7 shows the participant details of the British subject groups. Abbreviations: **CA** = Colour Associations, results for the "Colouring of Pictures Test" by Damasio et al. (1979); **D 15** = results of the Farnsworth Panel D-15 Test and the Lanthony15 Hue Desaturated Panel D-15 d Test (Richmond Products Inc., Albuquerque), **1** means normal, **2** means near normal; **P & P** = results for the "Three Pictures" component of The Pyramid and Palm Tree Test (Howard & Patterson, 1992), up to 6 errors are considered as normal.

Participant list experiment 3		
Subject	*Gender*	*Age*
1	M	36
2	F	18
3	M	28
4	F	28
5	F	32
6	M	23
7	F	20
8	F	20
9	F	20
10	M	34
11	F	27
12	F	19
13	M	23
14	F	19

Appendix 8 shows the participants list of experiment 3.