ELECTROPHYSIOLOGICAL CORRELATES OF PROCESSING UNATTENDED OBJECTS IN VISUAL COGNITION

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Abstract

Research is divided as to what degree visually unattended objects are processed (Lachter et al., 2008; Carrasco, 2011). The hybrid model of object recognition (Hummel, 2001) predicts that familiar objects are automatically recognised without attention. However under perceptual load theory (Lavie, 1995), when objects are rendered unattended due to exhausted attentional resources, they are not processed.

The present work examined the visual processing of images of everyday objects in a short-lag repetition-priming paradigm. In Experiments 1-3 attention was cued to the location of one of two objects in the first (prime) display, with the unattended sometimes repeated in the second (probe) display. ERP repetition effects were observed which were insensitive to changes in scale (Experiment 1) but sensitive to slight scrambling of the image (Experiment 2). Increasing perceptual load did not modulate these view-specific repetition effects (Experiment 3), consistent with the predictions of automatic holistic processing. In Experiments 4-7 a letter search task was used to render the flanking object image unattended under high load. In Experiment 5 distractor processing was observed in ERP even under high load. In Experiments 4, 6 and 7 a pattern of view sensitive/insensitive and load sensitive/insensitive repetition effects on RT (Experiment 4) and ERP amplitude (Experiments 6, 7) were observed that were difficult to interpret under either the hybrid model or perceptual load theory, but may reflect fast view-based and slow view-independent processing of objects.

Overall, the properties of the view-sensitive repetition effects were generally consistent with those associated with the automatic/pre-attentive processing of the holistic route of the hybrid model. However, differences between the processing of objects rendered unattended via a spatial cue or perceptual load indicate that the bottom-up driven hybrid model and perceptual load theory may benefit from the consideration of the interaction of top-down biasing of processing (Tsotsos et al., 2008).

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Chapter 1. Introduction and Background

1.1. Basic Rationale: Why Study Unattended Objects?

Consider driving in a new city without a navigation system. It is important to both navigate the traffic safely, but at the same time follow the signs to avoid getting lost. To stay on the right route, do we need to actively direct our attention away from the traffic to the signs themselves, or is any recognition of the information displayed still possible without attention? Does it make a difference if the information is displayed on the signs in a familiar way? Does the amount of traffic or displays on the dashboard (i.e. ‘clutter’ in a scene) affect how much information we can gain from the street signs?

The example above illustrates the interaction between attention and object recognition: we must attend to the task of navigating through traffic and we must also recognise the information on the street signs in order not to get lost. These tasks may interact; for example, attending more or less to the traffic may determine how well we can process objects in the periphery. The topic of this thesis concerns the way in which these aspects of attention and object recognition interact in our visual cognition. Indeed, Walther and Koch (2007) have argued that understanding the interaction between attention and object recognition is a requirement for constructing a full model of human visual subjective experience.

Whether unattended objects can be recognised at all has not been resolved (Lachter, Forster & Ruthruff, 2004) and it has been argued that their fate has still not been fully investigated from either the point of view of attention research (Carrasco, 2011) nor from that of object recognition research (Hummel, 2013; Walther & Koch, 2007). The goal of this thesis is to bridge these two areas, following the suggestion that the investigation of the recognition of attended and unattended objects will help to inform the nature of the internal representation of objects, which is still under debate in object recognition research (Pinto, Cox & DiCarlo, 2008; Peissig & Tarr, 2007).

One model of the few models of object recognition that makes clear predictions on the role of attention in object recognition is the hybrid model of Hummel (2001). It proposes that the shape information of attended and unattended objects are represented in a qualitatively different way, and that recognition is possible without attention for objects in familiar views.

The successful recognition of objects can be measured by repetition-priming. In such a paradigm, the first presentation of the object is termed the ‘prime’ display and the second is termed the ‘probe’. Priming is measured behaviourally as the difference in the naming accuracy or decrease in the naming time of an object at the probe display due to it having been presented previously at the prime display, compared to a baseline object that has not been seen previously at all (Bartram, 1976; Schacter, Delaney & Merikle, 1990). Priming has been described as “likely to be one of the most basic expressions of memory, influencing how we perceive and interpret the world” (Henson, 2009, p.1055) and priming is therefore an appropriate paradigm to examine the link between attention and format of object representations in memory. Thus all except one of the experiments in this thesis were based on a short-lag repetition-priming paradigm.

This thesis directly examines the effects of view on the visual processing of unattended objects, extending the current literature by using electroencephalographic (EEG) techniques. EEG are scalp-recorded voltage-potential changes that are associated with neural activity. By comparing the EEG locked to a certain event (for example a stimulus onset) an event-related potential (ERP) can be extracted. The ERPs for different experimental conditions can be compared directly to inform on the differences in neural activity associated with those conditions. One particular advantage of EEG is the high temporal sensitivity of the measurement of the brain activity in response to a stimulus in the order of milliseconds after its presentation (Rugg & Coles, 1995). Therefore, ERP can provide insight into when separate cognitive processes occur avoiding the problem of the aggregation of their effects by the time of behavioural and non-event-related fMRI response (Henson, 2009; Luck, 2001). Thus, the aim of using ERP measurements in this work was to tease apart potentially separate effects of view and attentional demands that are difficult to investigate behavioural measures alone.

This thesis concerns human visual object recognition, and particularly whether visual processing of objects can occur without attention. Here, an object is defined as an everyday object easily recognisable from its image displayed in a canonical view. All images used in the research studies for this thesis were black and white line drawings. ERP repetition-priming studies form the basis of the experimental work described here.

1.2. Outline and Scope of the Thesis

Chapter 1 of this thesis provides a background to the relevant areas of object recognition and selective attention to contextualise the rationale for the overall research questions. It begins with a discussion of the basic problems in understanding object recognition and how certain types of models have attempted to resolve these by proposing different ways in which we represent objects in long-term memory (LTM). It will be argued that the instances of these representations are restricted by whether objects are placed under attention or not. Rather than a full discussion of all object recognition models, one model that directly integrates the role of attention into object recognition is highlighted here: the hybrid model of object recognition (Hummel, 2001). This model provides the framework required for testing the specific properties of the recognition of unattended objects as is the aim of this thesis. The scope of this thesis is limited to the recognition of single non-face objects, rather than that involving multiple objects as in scene recognition.
Previous tests of the hybrid model have utilised a spatial cuing paradigm in which two objects were shown simultaneously, one cued and thus spatially attended, the other uncued and therefore unattended. However, it has been suggested that uncued objects can also be in receipt of attention if a central task is relatively undemanding in regards to attentional resources (Lavie, Lin, Zokaei & Thoma, 2009). Therefore, the question of how to distinguish attended from unattended locations is considered by examining the process of attentional selection. The perceptual load theory (Lavie, 1995) of attentional selection makes different predictions regarding the fate of unattended objects than the hybrid model, which were borne out in behavioral data (Lavie et al., 2009). In short, it is a hybrid model of attentional selection, proposing that if – and only if - attentional

demand for a central task is low, ‘ignored’ objects still receive residual attention, and are processed. Thus, these two theories are used as the framework to address our research questions: The hybrid model of object recognition will guide the tests of whether an unattended object can be recognised, and whether unattended objects can be recognised across changes in view. The perceptual load theory of attention is employed to ask how robust this processing of unattended objects is to another method of modulating attention: perceptual load. The aim of Chapter 1 is to provide the background for the overall research questions for the thesis, while the literature review specific to the relevant ERP studies used to form the experimental hypotheses is reserved for Chapter 2.

Chapter 2 also provides the specific experimental approach to the research questions and the choice of task. Studies testing both the hybrid model and perceptual load theory have used repetition-priming paradigms in an object-naming task. In this thesis repetition-priming is also chosen for all but one of the experimental tests, here modified for ERP and eye-tracking measurements. Some theoretical background on the acquisition of ERP will be given and this is followed by an overview of the literature on observations of relevant ERP effects that provide the explicit basis for the specific experimental predictions of this thesis. The general methods for the acquisition and analysis of the data for this thesis are described in the second part of Chapter 2. Eye-tracking measures are used in Experiment 4 and these are outlined in that chapter.

Chapters 3 to 9 describe the experimental studies for this work, and in Chapter 10 the results are brought together and implications for object recognition research are discussed.

1.3. What is Object Recognition?

Recognising objects forms such an essential, and usually effortless, part of our daily experience that the complexity of understanding the processes involved can be easily overlooked (Humphreys, Riddoch & Price, 1997). Keysers, Xiao, Földiák and Perrett (2001) note that the mechanisms underlying biological object recognition are not well understood, and equally its implementation in computer models is still not straightforward (DiCarlo & Cox, 2007; Pinto et al., 2008).

Put simply, functional accounts of object recognition must relate how, on first encountering an object, its retinal image is encoded (described) into an internal representation. The accounts must then also explain the processes that, on a subsequent encounter with the same object, lead to a successful match of the input retinal image of an object to its description in long-term memory, resulting in recognition. Therefore, the properties of recognition rely upon how we internally represent objects (Marr, 1982), and, as stated by Riesenhuber (2000), any theoretical models of human object recognition must be constrained by neurobiology. Most models of object recognition do indeed follow the functional hierarchy of the visual areas of the brain, which is outlined below. A detailed account of the neurobiology of the visual system will not be given here, and the focus will rather be to describe the route of light from an input image through the brain until it reaches areas associated with object recognition. The emphasis of this chapter is a functional approach to the stages of object processing.

1.4. The Neurobiology of the Visual System

As shown in Figure 1-1, light reflected from outside objects enters the eye and is received by the photoreceptors of the retina whose ganglion cell axons bundle together to form the optic nerve, which proceeds along the inferior surface of the brain. The area that can trigger a neural activity, the ‘receptive field’ of the optic nerve has been shown to be concentric with either a centre on or centre off structure (Kuffler, 1953). The optic nerve from each eye crosses at the optic chiasm. The fibres leaving the chiasm are known as the optic tract and lead to the lateral geniculate nuclei (LGN), which are small bilateral areas of the thalamus at which 80% of the axons terminate. These LGN consist of 6 layers, of which the top four layers extend mainly from the fovea and are termed parvocellular from the Latin “parvus” meaning small, with respect to the magnocellular (“magnus” meaning large) bottom two layers which extend mainly from the periphery. The magnocellular cells (M-cells) and parvocellular cells (P-cells),[1] have been found to transmit different types of visual information (e.g. Merigan, Katz & Maunsell, 1991; Bullier, 1995; Bar et al., 2006). The properties relating to M-cells and P-cells are maintained along the output axons (termed the optic radiation) leading to the primary visual area of cortex, V1 (Brodman area 17). V1 is the first point at which information from both eyes is combined. It is known as striate (i.e. layered/striped) cortex, and is composed of 6 layers. The LGN axons terminate in the 4th layer (which is itself further sub-striated).

These early visual areas in primary cortex are considered to be retinotopic. That is, the cells contribute to a one-to-one map of the visual field, preserving topographic (location) information directly. This is illustrated by the instances of scotoma, in which damage to specific areas in V1 causes a location-specific blindspot on the retina (Wickens, 2009). These earliest visual areas are also known to be orientation-sensitive, with simple cells with small receptive fields tuned to different orientations (Hubel & Wiesel, 1962, 1977).

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[1] The M- and P- cells actually represent only 20% of the total input to LGN from the retina, with the majority actually from the brainstem and visual cortex, which may be involved with top-down feedback for example to sharpen the visual image, or to control jumpiness from saccadic movement, Noda, 1975).

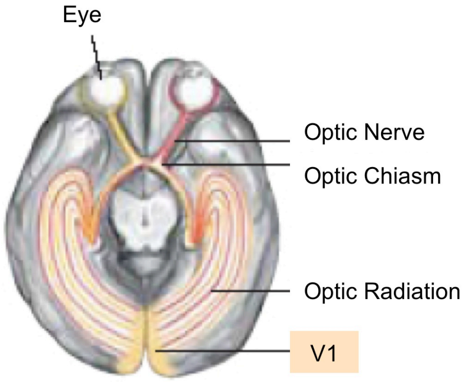

Figure 1-1: Illustration of human early visual areas (adapted from Logothetis, 1999).

The primary visual cortex then leads to the secondary, extrastriate, regions of visual cortex (V2, V3, V4 & V5, as shown in Figure 1-2). These regions are associated with the higher order processes of object recognition (although see Tong, 2003, for discussion of recognition linked directly with V1). Progressing through the hierarchical regions of the visual system, the receptive field sizes increase and also begin to respond to more complex stimuli (Kravitz, Vinson & Baker, 2008; Logothetis, Pauls, Bülthoff & Poggio, 1994).

One area of the brain that has been particularly studied in depth with respect to its involvement in object recognition is the lateral occipital complex (LOC), as reviewed by Grill-Spector, Kourtzi and Kanwisher (2001). According to Grill-Spector et al., the LOC can be defined as the region of the fusiform gyrus (an anterior region of the ventral visual stream) that shows more activity in response to objects of a structured shape rather than to textures or scrambled images. Thus the LOC has been considered to be sensitive to higher-level shape information, rather than the lower-level features of images, as is the case for the primary visual cortex.

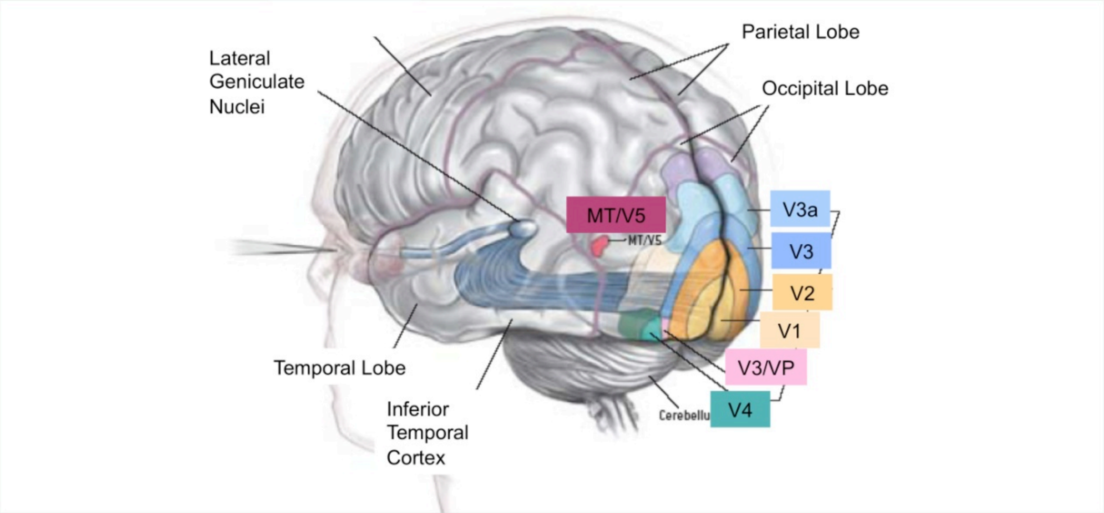

Figure 1-2: Hierarchical visual areas in cortex (adapted from Logothetis, 1999).

It has been shown that there are two pathways for the flow of visual information through secondary cortex, one is a more dorsal route and the other more ventral (e.g. Goodale & Milner, 2006), and this is briefly described below.

1.4.1 Two Visual-Streams of Object Processing

The divergence of two distinct pathways for visual information from about V2 in the cortex is the basis of the influential two visual-systems approach (Goodale & Milner, 1992; Schneider, 1969; Ungerleider & Mishkin, 1982), which dissociates a ventral (from striate to inferotemporal cortex) stream from a dorsal stream (from striate to posterior parietal cortex) of visual processing. These streams are considered to be functionally separated either due to receiving different types of visual information (Ungerleider & Mishkin, 1982) or due to different processing of the same input information (Goodale & Milner, 1992).

Ungerleider and Mishkin (1982) proposed a ventral ‘what’ stream involved in object vision distinct from a dorsal ‘where’ stream involved in spatial vision. Ungerleider and

Haxby (1994) described the evidence for these routes based on the results of studies on monkeys with lesions to temporal (dorsal) and parietal (ventral) cortical areas performing an object discrimination task and a landmark discrimination task. The monkeys were rewarded on choosing a familiarised object or location respective to the task condition. They were then lesioned, and tested on their retention of the task demands. Inferior temporal lesions were associated with reduced performance on visual discrimination based on pattern, object shape and colour, but no deficit on visuo-spatial tasks such as guided reaching (Gaffan, Harrison & Gaffan, 1986). In contrast, parietal lesions resulted in reduced visuo-spatial performance, but no deficits in visual discrimination (Mishkin & Ungerleider, 1982). Ungerleider and Haxby also linked these properties to human visual areas, describing how deficits of visuo-spatial performance or recognition were linked to occipito-parietal and occipito-temporal lesions respectively by postmortem (Newcombe, Ratcliff & Damasio, 1987). Ungerleider and Haxby also claimed that certain neurological conditions offer further support to the two routes hypothesis. One example was of object agnosia and prosopagnosia (where patients are able to detect an object or face without being able to recognise it) observed after occipito-temporal lesions. Another example was of the spatial cognition problems such as optic ataxia (where patients are able to identify an object but are unable to move their hand towards it effectively) that are observed after occipito-parietal lesions.

Goodale and Milner (2008) suggested that although both routes process location and structure information, the way that they process the information and then transmit it differs according to the goals of ‘vision for perception’ in the ‘what’ route or ‘vision for action’ in the ‘how’ route (Brown, Moore & Rosenbaum, 2002; Goodale & Milner, 1992; Milner & Goodale, 2008). The dorsal stream transforms ‘moment-to-moment’ information into a coordinate-based description to allow action such as accurate grasping. The ventral stream transforms the perceptual input into the component characteristics and spatial relations which provide a stable description of the object in order to “parse the scene, and to think about objects and events in the visual world” (Milner & Goodale, 2008, p. 774). There is also an additional subcortical pathway for visual information, known as the retinotectal pathway. This route does not extend through the LGN, bypassing also V1 and V2. Kass and Lyon (2007) describe how the output of the pulvinar (bilateral nuclei in the thalamus) separately feed the dorsal and ventral cortical routes. The subcortical pathway has been linked with the sensitivity to salient stimuli such as faces (Pasley, Mayes & Schultz, 2004), rather than in object recognition as is the case for the higher cortical areas. The three streams are illustrated in Figure 1-3.

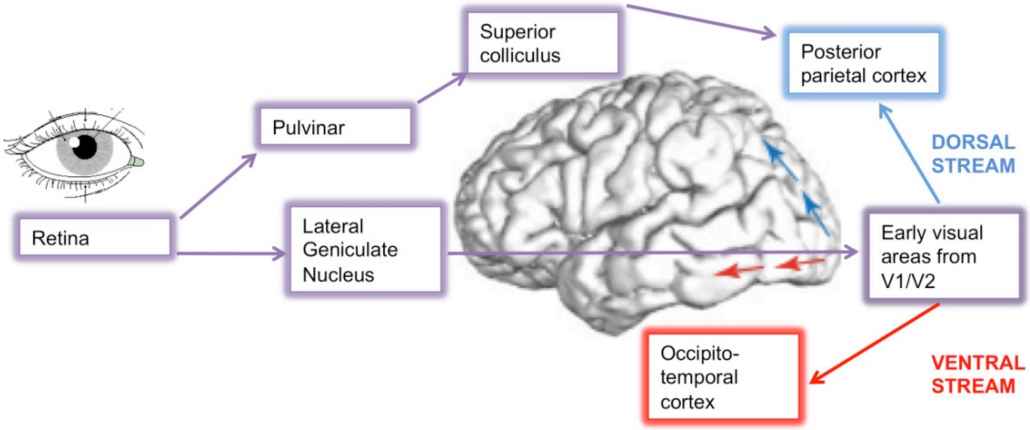

Figure 1-3: Schematic of the dorsal and ventral visual pathways in human cortex adapted from Goodale & Westwood (2004). Also shown is the subcortical, retinotectal, pathway.

Reviews of the two-streams account can be found in Cardoso-Leite and Gorea (2010), Goodale and Milner (2006), Milner and Goodale (2008) and Westwood and Goodale (2011). Some authors have suggested that there is rather some integration of the two routes (Farivar, 2009; Grill-Spector, 2003), or a three-pathway model (Kravitz, Saleem, Baker & Mishkin, 2011), or even a patchwork model of about 40 inter-connected visual areas (de Haan & Cowey, 2011). The dissociation between the ventral and dorsal streams' involvement in visual processing for the goals of identifying an object (what) or locating it (how/where) are relevant to this thesis because it suggests that a hybrid model of visual processing is required. Indeed, Thoma and Henson (2011) have recently demonstrated that cortical areas in the dorsal and ventral stream map onto one hybrid model of object recognition (Hummel, 2001), which will be discussed in Section 1.11.

1.5. The Stages of Object Processing

The stages of visual processing that are required for the recognition of an object can be broadly separated into perception and recognition (e.g. Schendan & Kutas, 2003; Lamberts & Freeman, 1999). Perceptual processes (occurring within around 200 ms of the presentation of the object) are concerned with the first detection and encoding of the visual scene by our sensory systems (the eye and striate cortex). Such processing includes basic figure-ground segregation, that is, the separation of the to-be-identified object from the background, and also some extraction of low-level visual features such as colour, edges and contour. In contrast, recognition processes are generally considered to be higher order processes, both functionally, for example, concerned more with the matching of the percept resulting from the perceptual processes to an object description in long-term memory, and also neurologically, involving extra-striate cortex (Riesenhuber & Poggio, 2000). The object descriptions may then lead to the activation of further conceptual associations with the object, for example linking an image of a cat to the knowledge that it is an animal, and that the word ‘cat’ begins with the letter ‘c’ in English, and so forth. The differences in perceptual and conceptual descriptions and the networks of associations are discussed further in Barsalou (2008) and Barsalou, Spivey and McRae (2012).

When a participant is asked to identify an object there are different taxonomic levels for that response. For example, a ‘chair’ (basic level name) can be described as a ‘piece of furniture’ (superordinate level) or as a ‘kitchen chair’ (subordinate level) as described by Rosch (1999). Thus a hierarchy in the levels of naming is formed. Rosch (1976) proposed that the basic level name is that which most easily comes to mind when asked to name an image. Rosch (1999) described how the basic level was also the most inclusive level, at which members share most characteristics (e.g. chairs have a ‘seat’ and a ‘support/legs’) compared to the more abstract superordinate level (e.g. different furniture might only share some characteristics: chairs, desks, lamps have quite different features) or the more specific subordinate level (e.g. kitchen chairs compared to armchairs).

Analogous to this hierarchy of levels of naming, different levels of visual processing can be associated with the information required for a response appropriate to each of these levels. For example, categorisation can be demonstrated by those tasks such as simply asking participants whether they recognise an object or not, this being the basis of old/new (same/different) recognition paradigm. In such categorisation tasks participants may be taken through a learning phase and then asked whether certain stimuli have been presented to them previously. Other examples of categorisation tasks are judgements of stimuli as living vs. non-living, or size judgement (whether or not it fits in a shoe box e.g. Henson, Rylands, Ross, Vuilleumeir & Rugg, 2004) and gender categorisation. It has been suggested that such categorisation relies on the lower-level visual properties of an image. For example Lamberts, Brockdorff and Heit (2002) have associated perceptual processes with those required for an old/new response. Further, it has been suggested that categorisation may only require low-level perceptual processing of the ‘gist’ of an object for recognition e.g. by Thorpe, Fize and Marlot (1996). In their study they showed that categorisation is a very fast process, specifically that it is possible to identify whether there is an animal presented in a natural scene after only about 150 ms after a very brief presentation (20 ms). Thorpe et al. took this as an indication of fast feed-forward gist processing, arguing that there was insufficient time for top-down influence.[2]

The study by Thorpe et al. (1996) demonstrated the fast categorisation of whether an animal was present or not, but the level of the knowledge of that animal is not completely clear. On one hand, it may be that the animal was classified as ‘animal’. On the other hand, there may have been access to its basic level name ‘tiger’. Alternatively, the task may be regarded as detection of an animal from the background. Grill-Spector and Kanwisher (2005) have suggested that detection is as fast as categorisation, but in their study, the categorisation task required the participants to name objects at their basic level. Detection was tested by participants’ responses to everyday objects vs. textures. For the categorisation task participants had to name the objects at basic level across ten

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[2] It has also been indicated that top-down factors may modulate very early perceptual processes (Hseih, Vul & Kanwisher, 2010; Hochstein & Akhissar, 2002).

categories, for example ‘face’, ‘dog’. For the identification task, participants had to name the same objects but at the subordinate level, for example ‘Harrison Ford’, ‘German Shepherd’. Grill-Spector and Kanwisher found that categorisation was as fast as detection for natural images. Subordinate level identification took longer (by 65 ms) than categorisation. Their behavioural study could not determine whether identification and categorisation used different mechanisms, or whether identification simply took longer than categorisation. However, neuroimaging work (Halgren, Mendola, Chong & Dale, 2003; Liu, Harris & Kanwisher, 2002) does indicate that segmentation and categorisation occur at the same time (but see Martinovic, Gruber & Müller, 2008, for an argument for categorisation only at 200-400 ms after stimulus onset).

Tsotsos, Rodríguez-Sánchez, Rothenstein and Simine (2008) have also described the timeline of the tasks of discrimination, categorisation and individual identification in their model of object recognition. Discrimination is the first level, and this can be divided into sub-tasks. Tsotsos et al. also term detection, categorisation and identification in a similar manner to Grill-Spector and Kanwisher (2005) above. Detection requires the extraction of the object from the background ‘noise’. Categorisation is a between-category task (e.g. faces vs. dogs) that they state requires the access to a prototype. Identification is within-category task that requires a response at the subordinate level of naming. Categorisation, requires a single feed-forward pass of about 150 ms. Individual identification follows a refinement of identification from the category to individual level and thus is possible about 65 ms after categorisation.

Therefore, although termed ‘categorisation’ in both the work of Grill-Spector and Kanwisher (2005) and Tsotsos et al. (2008), it is basic level naming that is suggested to be achieved fast, and subordinate level naming that is slower. However, it has also been suggested that categorisation (superordinate level –e.g. ‘animals’) is faster than basic level identification (e.g. ‘cat’). Fast categorisation and slower basic level identification performance is linked to a global to local processing bias (Navon, 1977), seeing the forest before the trees, also termed a coarse to fine direction of processing in scene perception (Hegdé, 2008). However, there has been much debate over whether the global whole is decomposed into constituent elements, or whether local elements are integrated into a complete whole. Indeed, the processes of integration or decomposition may be dissociable as discussed in Behrmann, Peterson, Moscovitch & Suzuki, 2006). Categorisation and basic level recognition present differences in task demands that can then bias processing towards more global or local processing. For example, in basic level recognition, if the stimuli to be distinguished have similar constituent parts, as is the case for faces (Farah, 1992; Humphreys & Riddoch, 1984; Jolicoeur, 1990), fine-detail differences in local information (metric differences) are required (Triesman & Kanwisher, 1998). However, if the stimuli are very different, as is the case for many man-made objects, basic level recognition need only rely on the extraction of certain defining features or parts. Alternatively, the global shape characteristics may be sufficient for either recognition or categorisation. Grill-Spector and Kanwisher (2005) have shown that silhouette information is sufficient for fast (real vs. non-real) categorisation, and Hayward (1998) stresses the importance of outline shape information (i.e. not the internal parts that make up the object) in the recognition observed from object silhouettes. This may be due to categorisation relying on the lower level visual processing which occurs early in the timeline of recognition. A schematic figure of the stages of object processing and the timeline of categorisation and basic level recognition is shown in Figure 1-4. It does not include the possibility that the task demands bias the type of processing (e.g. local or global) for simplicity.

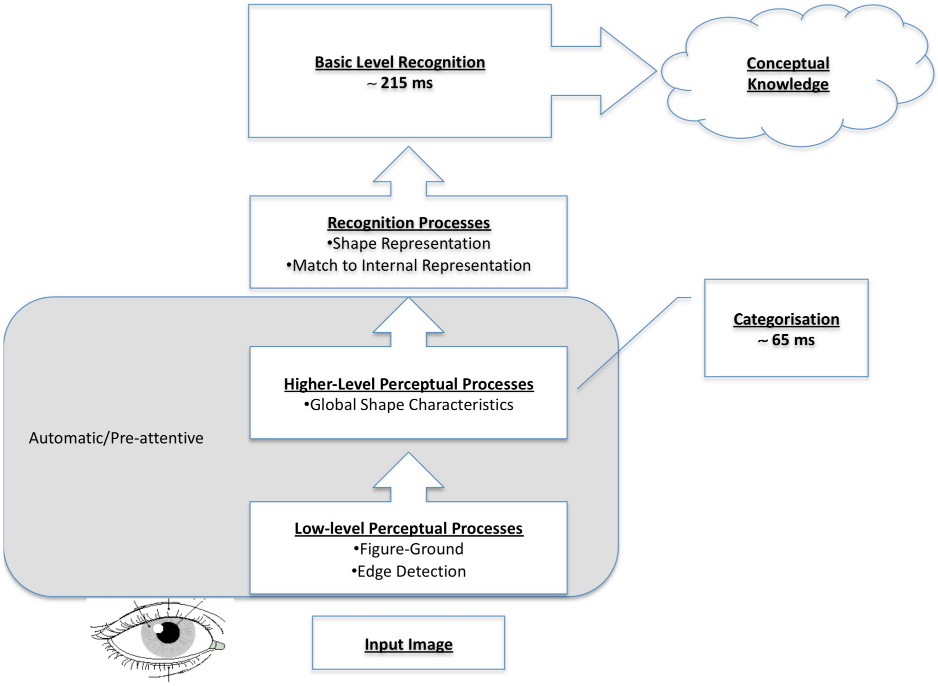

Figure 1-4: Schematic of the levels of object processing.

1.5.1 Explicit vs. Implicit Recognition

Another aspect of object recognition is whether it is possible without subjective awareness. That is, recognition may be explicit, when participants are aware of having recognised the object. Recognition may also be implicit, when evidence of recognition of objects can be found without participants themselves being aware of having recognised the objects. Participants may also be aware, or not, of having seen an image before. The dissociation between explicit and implicit memory is revealed by whether recognition is dependent on the conscious access of a pre-existing representation. Explicit recognition is based on the conscious comparison of the test item against representations coded in a learning phase of an experiment or from familiar objects. Implicit recognition is based on the unconscious access of a representation. This can be measured by direct and indirect-tests of recognition respectively (Graf & Schacter, 1985; Richardson-Klavehn & Bjork, 1988).

Evidence for dissociable memory systems has been observed in neuropsychological patients. For example, Warrington and Weiskrantz (1970) found that although people with amnesia showed worse performance than controls for recall and recognition tasks, they still showed the same advantage for previously seen words when identifying degraded versions of those words on subsequent presentation. Non-brain-injured people have also been observed to show better performance on a word-stem completion task (Graf, 1984) due to having previously seen the complete words, but without recalling them directly.

Participants can also be presented with a stimulus without their conscious awareness of it. This may be achieved by presenting it at a subliminally for a very short time (Bar & Biederman, 1998) or through binocular rivalry (Bahrami, Carmel, Walsh, Ress & Lavie, 2008). Alternatively, attention can be directed away from the stimulus, either by directing attention to another spatial location (e.g. Stankiewicz, Hummel and Cooper, 1998), or to another temporal location (e.g. Shapiro, Caldwell and Sorenson, 1997), or indeed to another characteristic of the stimulus such as in the case of overlapping (but differently coloured) stimuli, in which attention is directed to one colour only, (e.g. Ballesteros, Reales and Garcia, 2007).

McAuliffe and Knowlton (2009) compared the time required for object identification priming against old/new recognition memory. After seeing objects for a variety of duration times, participants were then asked to identify them in a probe phase. It was found that 75 ms was sufficient for successful recognition tested by an implicit old/new task, but that 150 ms was required for identification by explicit naming. The authors suggested that this indicated that different types of representations support old/new recognition and identification: Old/new recognition memory may be associated with early hierarchical areas coding low-level features of "gross shape, contrast or overall luminance" (p. 219) whereas object identification is associated with higher levels based on more specific shape representations. Whether implicit and explicit memory reside in separate and dissociable systems or share the same perceptual encoding resources is the subject of some debate (Graf & Schacter, 1985; Henson, 2003; Ratcliff & McKoon, 1988; Turk-Browne, Yi & Chun, 2006).

Research on implicit and explicit memory has often used repetition-priming as a tool to measure recognition. A feature of such a paradigm is its flexibility in being able to probe differences between perceptual/conceptual and implicit/explicit recognition. Repetition-priming paradigms will be used in the experimental work of this thesis and have also been used to test various theories of object recognition that will be described shortly. Therefore repetition-priming will be described briefly below before returning to the theoretical issues of object recognition.

1.6. Repetition-priming

In a repetition-priming paradigm, the response upon the presentation of a (probe) stimulus that has either been presented previously as a prime is compared to that upon presentation of a previously unseen (unprimed) stimulus. Behaviourally, priming is measured as the difference in naming speed or accuracy due to having seen the probe image previously during the prime display compared to that of a previously unseen image. Researchers use the term ‘positive priming’ (Bartram, 1976; Schacter et al., 1990). when recognition performance is improved for repeated compared to non-repeated items (i.e. faster and more accurate performance on e.g. naming), whereas in negative priming (Tipper & Driver, 1988; Conlan, Phillips & Leek, 2009) naming speed is slower, or accuracy is worse, due to having previously seen the image.

In his reviews on priming, Henson (2003, 2009) has proposed a distinction between perceptual vs. conceptual components (Roediger & McDermott, 1993), and how this is supported by findings of dissociations in Alzheimer’s (Gabrieli et al., 1994). In patients with Alzheimer’s the early sensory areas are preserved and allow intact perceptual priming. However, the damage to frontotemporal regions is associated with disrupted conceptual priming.

The repetition-priming paradigm used in many behavioral studies with non-clinical populations also uses perceptual and conceptual priming tasks (e.g., Biederman &

Cooper, 1992). For example, by measuring the priming from an image that is presented in an identical visual format/view to the probe compared to one in which the view is changed, the amount of perceptual priming may indicate whether the memory representations are view-sensitive. In contrast, conceptual priming (Biederman & Copper, 1992) can be measured by using, for example, an identical image compared to one that is of an object with the same name but a different visual form (e.g. an upright vs. grand piano).

Related to the distinction between perceptual and conceptual priming is the role of familiarity of the object. Examples of familiar objects are everyday objects (as used in this thesis), famous faces and words. Priming from such objects will depend on the access of long-term memory representations. However, the priming from unfamiliar objects, such as novel objects, anonymous faces and letter strings are more likely to be associated with perceptual representations (Henson, 2009). Priming from familiar stimuli has been shown to be greater than for unfamiliar stimuli (Bowers, 1994).

In order to understand the priming under different task conditions, models of priming have divided into episodic (instance) or structural (abstractionist) theories (Henson, 2003). In episodic theories, any instance (exposure) of a stimulus can leave a trace of its processing. In structural theories, it is a pre-existing representation that undergoes a modification such as a lowered threshold or residual activity. Henson presents a component-process model in which several processes such as mapping or transformation may be involved in resulting priming, and it is the overlap between the processes involved at the prime and probe presentations that determine the amount of resultant priming and thus, processes involved at the probe will be facilitated from the prior processing.

1.7. View-sensitivity of Object Recognition: The Viewpoint Debate

An important property of human object recognition is the ability to quickly recognise an object even if it is shown from a different viewpoint/view as in a previous encounter.

This is the concept of ‘object constancy’ (Lawson, 1999; Turnbull, Carey & McCarthy, 1997) or ‘stimulus equivalence’ (Bruce, Green & Georgeson, 2004).

One aspect of object constancy relates to the question of how we can accommodate recognising an object from a viewpoint that we have not previously encountered. In everyday life, at a given moment, each object will project a particular image at the retina. Just by moving our head, differences in for example viewing angle mean that the same object can project a number of different retinal images, which are still recognised as belonging to the same object. Whether it is as ‘easy’ to recognise an object when the present and original view of the object are different is termed the question of view-sensitivity.

Experimental studies have demonstrated that recognition performance can either worsen upon view-changes (; Hayward & Tarr, 2000; Jolicoeur, 1985; Lawson & Jolicoeur, 1998; Tarr, Bulthoff, Zabinski & Blanz, 1997) or remain unaffected (Fiser & Biederman, 2001; Biederman & Cooper, 1992). This raises the question of how the empirical evidence for both view-dependent and view-independent recognition can be accounted for by a model of human object recognition. The view-sensitivity of object recognition is traditionally linked to the issue of how objects are represented in long-term memory, the subject of the next section.

1.8. The Mental Representation of Object Shape

Hummel (2013) has argued that the mental representation of objects is mainly reliant on the representation of shape. Although other features, for example surface texture or colour are also important in recognition (Price & Humphreys, 1989; Rossion & Pourtois, 2004; Vurro, Ling & Hurlbert, 2013), information from shape is generally found to be more helpful for recognition than that based on, for example, colour (Biederman & Ju, 1988; Mapelli & Behrmann, 1997; Ostergaard & Davidoff, 1985; Wurm, Legge, Isenberg & Luebker, 1993). Broadly, the ways in which shape can be represented can be compared to how they match the retinal projection of the image (Edelman, 1998; Yantis, 2000). That is, the representation may be a direct match to the retinal projection, or be deconstructed into a more abstract description. Figure 1-5 illustrates simplified versions of two ways in which one object can be described. One example is via a direct, encoding of the image presented to the retina on a particular instance, which is therefore view-based, rather analogous to a photograph. The second example is via a decomposition of the component parts of the object encoded into an abstract description.

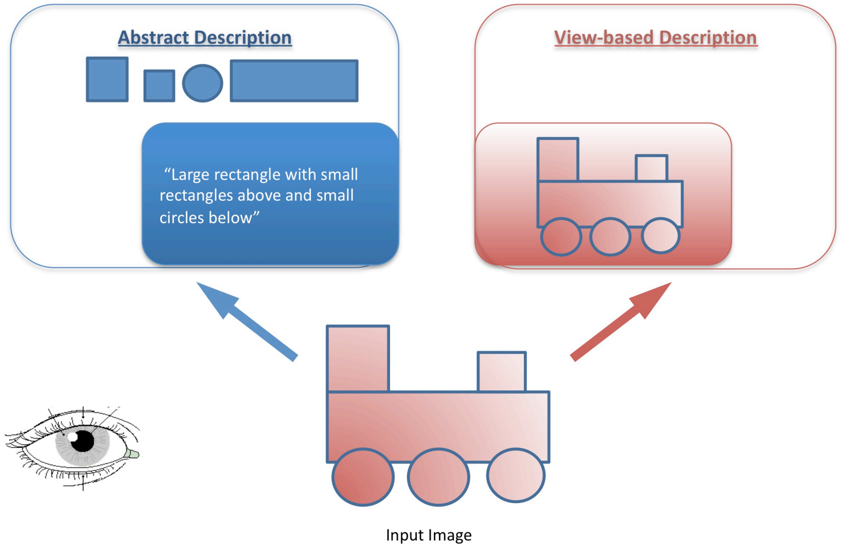

Figure 1-5: Simplified examples of a view-based description and an abstract description of an image.

The way in which these two types of representation can account for the view-dependence or view-independence of recognition that has been shown empirically will be described after an overview of the mental representation of shape. The four properties of shape representation proposed by Hummel (2013) differentiate theories of object recognition and explain those models' predictions of the view-sensitivity of recognition. Therefore, they are outlined briefly below.

The first property is the way in which a set of primitives is defined. This forms the 'vocabulary' of shape elements with which an object shape can be described. These elements can be at the level of individual pixels (Liu, Knill & Kersten, 1995), or discontinuities at edges or their properties at vertices or both (Edelman, 1990; Fukushima

& Miyake, 1982; Lowe, 1987; Poggio & Riesenhuber & Poggio, 2002), volumetric parts (Marr & Nishihara, 1978) or the categorical properties of object parts (Biederman, 1987; Hummel, 2001). Some examples of 3D volumetric elements, akin to the 'geons' used in Biederman's (1987) recognition-by-components (RBC) model of object recognition described in more detail in Section 1.8.1, and how two of the same elements can be used to describe both a cup and a bucket are shown in Figure 1-6.

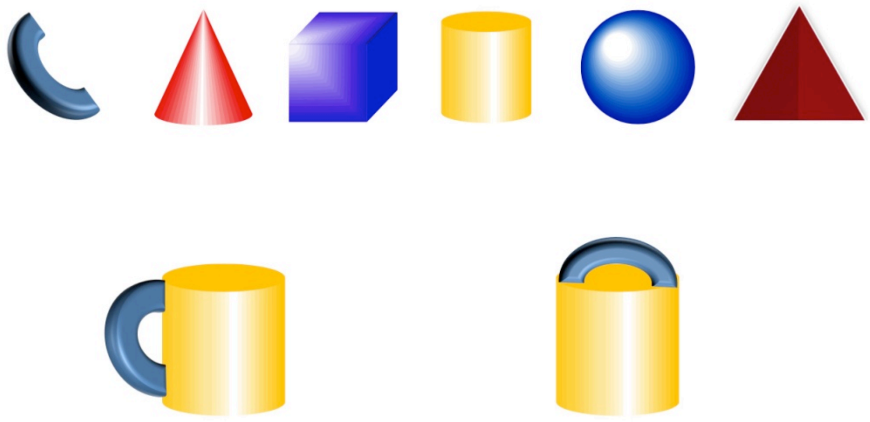

Figure 1-6: Examples of volumetric elements and examples of assembly into a cup and bucket.

The second property of shape representation is the definition of a reference frame in which the primitives are encountered. The reference frame can be oriented with respect to the viewer ('view-centered') or the object itself, as is illustrated in Figure 1-7. The location of the primitives may also be encoded in some combination of viewer and object-centred reference frames (Hummel, 2001; Hummel & Stankiewicz, 1996; Olshausen et al., 1993; Ullman, 1989).

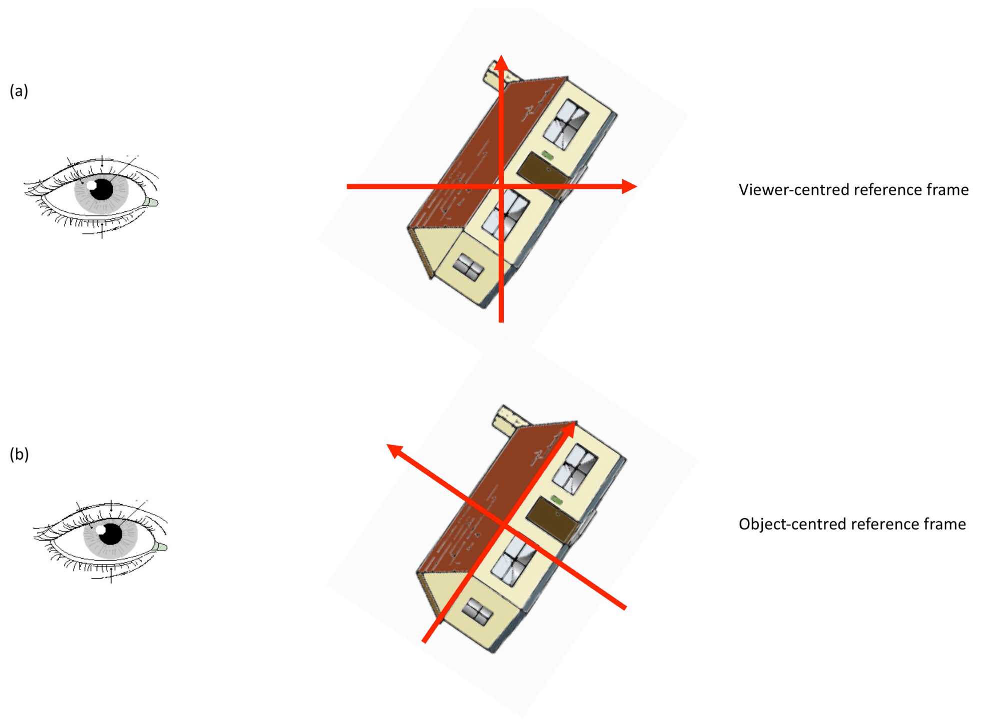

Figure 1-7: Illustration of (a) viewer-centred and (b) object-centred reference frames. Object image from the stimulus set of Rossion and Pourtois (2004).

The third property of shape representation is the definition of a ‘vocabulary of relations’ (Hummel, 2013). This determines how the arrangement of the primitives within the reference frame can be described. One option is that the primitives are located by their coordinates with respect to the origin of the reference frame (Edelman & Intrator, 2001; Olshausen et al., 1993; Poggio & Edelman, 1990; Riesenhuber & Poggio, 2002; Ullman, 1989; Ullman & Basri, 1991). Alternatively, the primitives can be described by their relationship to one another. For example, in the case where the primitives are volumetric parts, a cup can be defined as a curved cylinder (i.e. the handle) side-attached to a straight cylinder (i.e. the container). A bucket can be defined as a curved cylinder top-attached to a straight cylinder (Biederman, 1987; Hummel & Biederman, 1992; Marr & Nishihara, 1978). This type of description is not limited to volumetric parts and has also been suggested similarly for surfaces (Leek, Reppa & Arguin, 1995). The relations can be categorical, for example above vs. below, or metric, for example larger vs. smaller (Hummel & Stankiewicz, 1996; Jüttner, Petters, Wakui & Davidoff, 2013). Examples of a coordinate-based and a categorical relation description are shown in Figure 1-8.

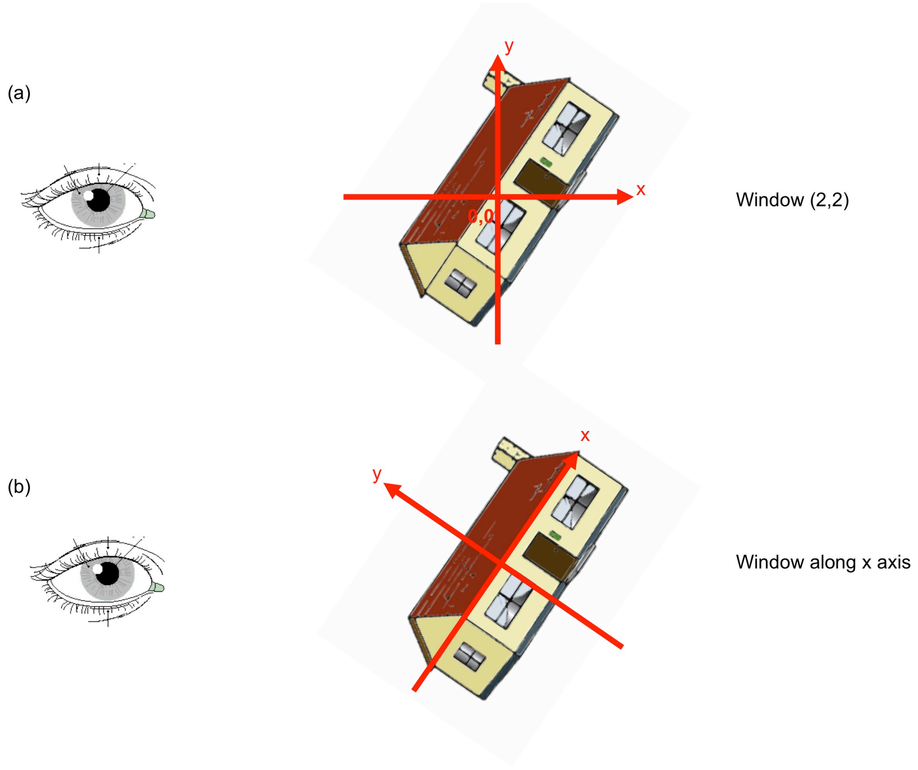

Figure 1-8: An example of spatial relations between the house-parts of window and door defined by (a) coordinates and (b) categorical relations. Object image from the stimulus set of Rossion and Pourtois (2004)

The fourth property of shape representation is that of the definition of configural information. This defines how the parts of an object are related, that is, how they are bound to one another in a certain configuration. Configural representations can be considered as falling into two types (although see Maurer, Le Grand & Mondloch, 2002 for a discussion of the ambiguity over the definition of the term 'configural' especially with respect to the face recognition literature).

The first type of configural representation is an analytic description in which the parts and their relations are explicitly and separately defined and can also be retrieved separately (Hummel & Biederman, 1992; Hummel & Holyoak, 1997, 2003). This is also known as a structural description. Taking an example of a cup, the descriptor for the handle and that for the container are activated separately to the descriptor for 'side-attached'. Therefore, to arrive at the configuration of cup 'handle side attached to container', those descriptors must be bound together during the process of recognition. The second, 'holistic', type of description is akin to the idea of a mental 'snapshot'– in the sense that objects – like faces (e.g., Yin, 1969) - are usually recognised in-one-piece rather than piecemeal fashion, meaning that the information of the type of part (or feature) and location information encoded 'all-in-one' and thus cannot be retrieved separately. For the example of the cup, the handle and its location beside the container are already bound together as a feature at a certain location in the reference frame. Holistic effects on recognition are demonstrated by the 'ineffability' of face recognition (Mangini & Biederman, 2004). For example, you may be able to recognise a celebrity, without being able to remember the colour of their eyes. This inability to recall the details of specific feature has also been demonstrated in certain non-face stimuli such as balloons (Kent & Lamberts, 2006). A detailed holistic description includes the component and location information albeit inseparably (Palermo & Rhodes, 2002; Thoma, Hummel & Davidoff, 2004), and is not the same as a 'gist' of an object. An illustration of analytic and holistic representations is shown in Figure 1-9.

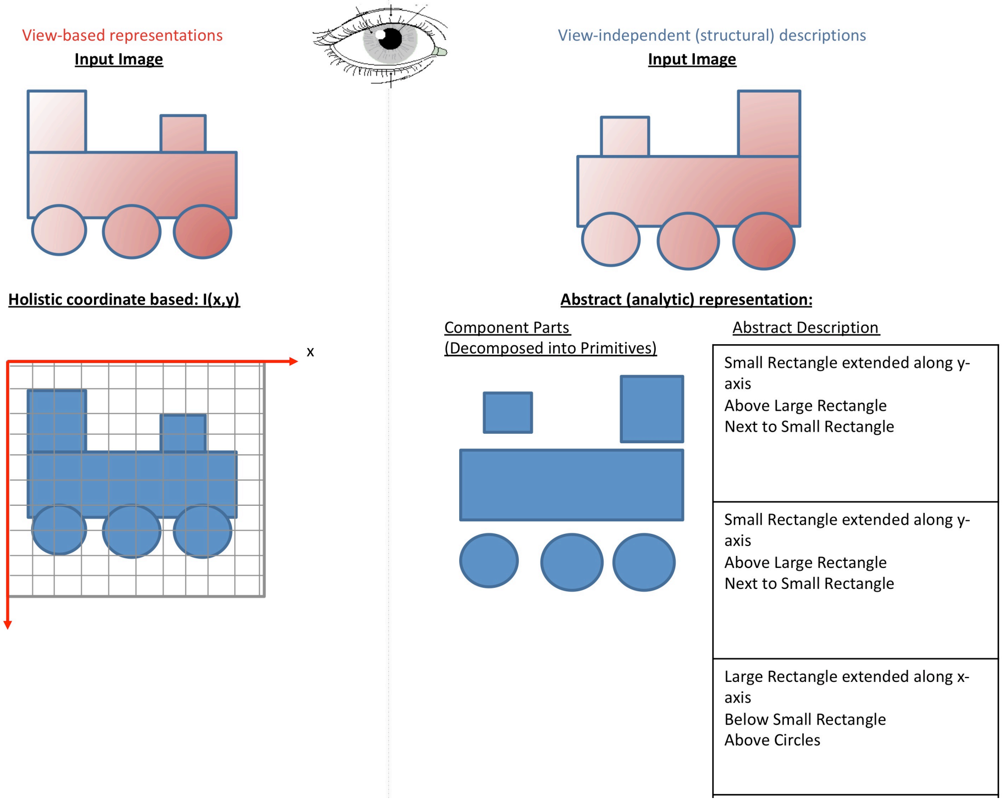

Figure 1-9: Schematic of analytic and holistic descriptions.

In order to recognise the object on a later encounter, the input image must be matched to the internal representation. Thus, as shown in Figure 1-10 if the object is shown in another view on a later encounter, in a view-based, holistic, case the current view must first be aligned to that of the internal representation. This implies a delay in recognition that depends on the degree of view-change, that is, resulting in view-dependent recognition. In contrast, in an abstract, analytic, case the current description already matches that of the internal representation and so recognition does not suffer any delay, that is, resulting in view-independent recognition.

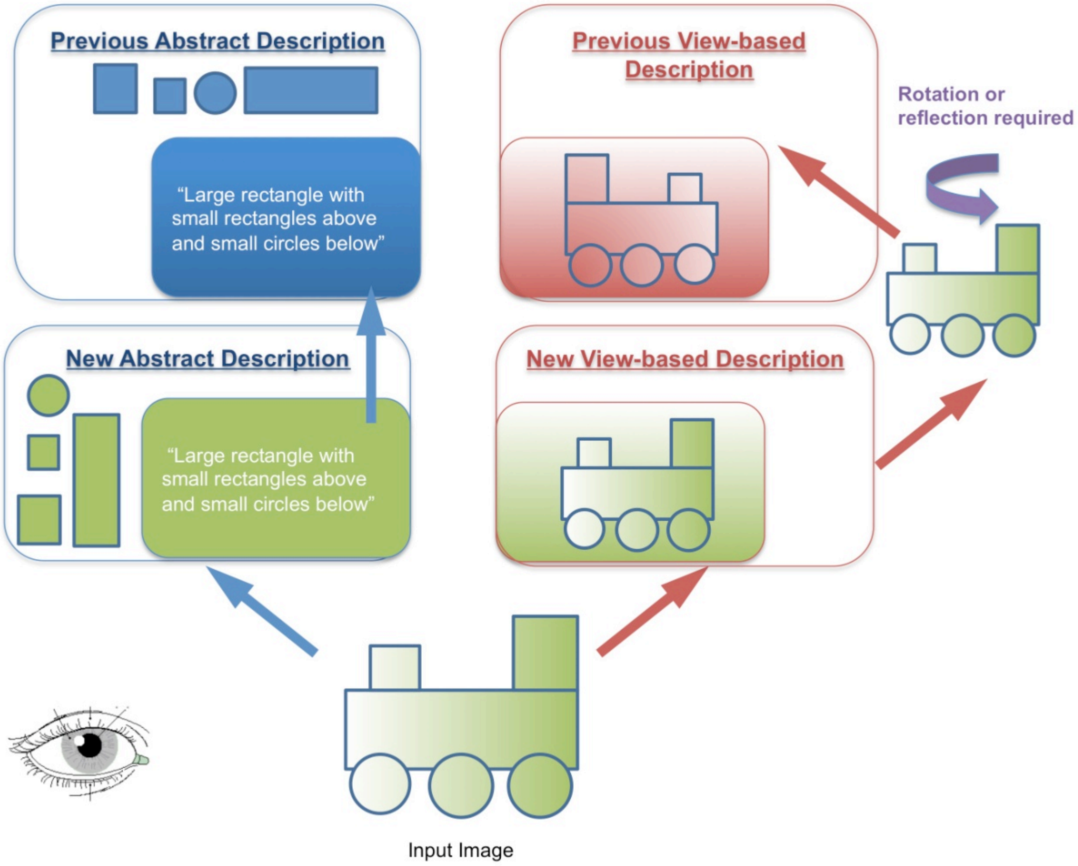

Figure 1-10: Recognition of an object upon a view-change.

A brief discussion of theories based on either view-based or structural descriptions will follow, as this relates to the question of whether and how unattended objects may be represented differently from attended objects. A detailed discussion of their merits is beyond the scope of this thesis and can be found in, for example, Thoma and Davidoff (2007), Hummel (2013) and Peissig and Tarr (2007). The focus here is in highlighting their differences, particularly in their predictions for the view-sensitivity of recognition, in order to argue (as Hayward 2003; Milivojevic, 2012; Hummel, 2013) that one or other type of theory alone may not be sufficient to account for all the types of human recognition that have been observed.

1.8.1 Analytic Representation/Theories of View-independent Recognition

Analytic, or structural descriptions are relational-based. They rely on decomposing the object image into component parts and representing these abstractly in addition to, and independently of, their spatial relations in either object-centred frames (Marr & Nishihara, 1978) or viewer-centred frames (Biederman, 1987; Hummel & Biederman, 1992). This type of representation forms the basis of the influential computational model of Marr (1982) and the recognition-by-components (RBC) theory of Biederman (1987). Both theories stem from the need to account for the problem of object constancy, and so predict view-invariant recognition as long as the visible parts give rise to the same identical structural descriptions. The basic levels of processing for Marr’s computational model begin with the figure-ground processes of separating the object from its background. The first stage detects the edges of the object through finding points of discontinuity in intensity maps that defines boundaries/edges. Information about whether these edges join at concavities or convexities results in information about the basic overall shape of the object. Following this the processes of decomposition into constituent elements begin. In Marr’s model these elements are ‘generalised cylinders’, and an example of how these can be assembled into a representation of a human shape is shown in
Figure 1-11.

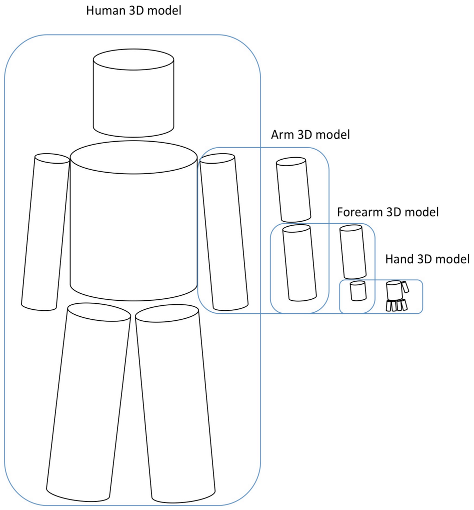

Figure 1-11: Generalised cylinders (adapted from Marr & Nishihara, 1978).

In Biederman’s RBC model, the generalised cylinders are replaced by a vocabulary of various geometric 3D shape primitives termed ‘geons’, some examples of which are shown in Figure 1-12. These geons are defined by the geometric properties of the contours of the shape’s surface. These properties fall into two types, the first of which are termed non-accidental properties (NAPs). These are categorical properties such as whether a surface is straight vs. curved or parallel vs. non-parallel. The second type are termed metric properties (MPs). These are continuous variables describing the degree of a property, such as how curved a contour is.

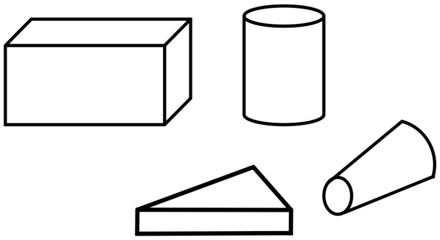

Figure 1-12: Examples of geons (adapted from Biederman, 1987).

Biederman (1987) has compared these geons to phonemes in natural language. He proposes that, like the many words that result from a set of phonemes, geons also provide a way of describing many objects using a finite set of shape elements. The key to this variety of descriptions is that in the RBC model the geons and their spatial relations with respect to each other are explicitly and independently encoded. Figure 1-13 shows some examples of different objects that can be made from the same geons.

RBC was implemented computationally (Hummel & Biederman, 1992) as JIM (Jim and Irv's Model) and, unlike Marr's theory has been extensively tested both behaviourally (Biederman & Bar, 1999; Biederman & Cooper, 1991, 1992; Biederman & Ju, 1988) and more recently with neuroimaging (e.g. Kim, Biederman, Lescroart & Hayworth, 2009).

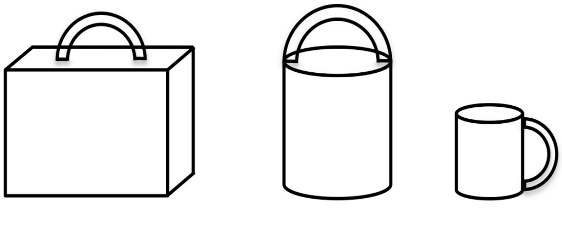

Figure 1-13: Different objects based on similar geons but different spatial configurations (adapted from Biederman, 1987).

As long as the component parts and their configuration are visible an object should be as recognisable in a novel view compared to that in which it was first encountered. The explicit and independent coding of component parts and relations in analytical (structural) object descriptions allows for the object knowledge that we experience in our everyday object-knowledge: We ‘know’ that a ‘typical’ cup handle is side-attached to its main container. In contrast view-based models, the properties of the cup would be ‘fixed’ to only that specific cup in the initial presentation view. This manner of encoding thus presents a computational problem in that in order to result in the same object knowledge permitted by analytic descriptions, for a view-based model every view encountered of each object would have to be encoded. Therefore, matching an input object to its description in LTM could potentially be very demanding in terms of costs in time and processing resources. This does not tally with the speed and ease of recognition performance that is observed in humans. Such computational problems are avoided with analytic representations (Hummel 2001; Hummel & Biederman, 1992). However, as is discussed in Section 1.10, an important limitation of structural descriptions is that they require attentional resources for the encoding of part and relation information.

View-independent theories have been criticised because they cannot easily explain the recognition of new members of a category (Edelman, 1998; Riesenhuber & Poggio, 2000; Tarr & Vuong, 2001). For example, the constituent geons of two exemplars of the same category may differ substantially (‘kitchen chair’ vs. ‘office chair’) but need still to be accepted into the same category (‘chairs’). However, RBC does predict different naming times for same compared to different category exemplars. In a priming paradigm, more priming would be expected from a prime that was another category member than from a non-member. Within the same category, the priming is expected to be more for an identical or changed view of the same exemplar to that from another exemplar. This pattern of priming was confirmed by the behavioural priming study of Bartram (1976).

Modifications of these models include the addition of more details on metric properties of the representation which may help to derive differences between geons and improve model performance (Hummel, 2013; Jüttner et al., 2013).

However, structural description models have been criticised, and Tarr, Williams, Hayward and Gauthier (1998) have argued that, instead, “view-based theories provide a natural account for the types of viewpoint effects found" (p. 277). In their study examining viewpoint effects on the recognition of single geons, they ran nine experiments including match-to-sample, sequential matching and naming[3] tasks using both 3D shaded renderings and line drawings. Tarr et al. concluded that none of the results of their experiments demonstrated view-independence even at the level of geons.

1.8.2 Holistic Representation/Theories of View-dependent Recognition

Holistic descriptions are more akin to a pictorial 'snapshot' of the image in which the object's features are directly mapped onto a coordinate-based description (Hummel, 2001). This ties features with their location in a viewer-centred reference frame. Therefore in order to recognise an object in a different view to that previously encountered, generally, the new input image must undergo a geometric transformation prior to matching to the internal representation of the object in LTM. Graf (2006) has divided view-based models of object recognition relying on holistic representations into three types. In alignment models, some kind of geometric transformation/alignment or normalisation (Tarr & Pinker, 1989) of the image is required to match it to the representation for recognition. In view-interpolation models, it is the difference between the novel view and the stored view that is compared (Bulthoff & Edelman, 1992). In pooling and threshold models the hierarchical pooling of information from view-specific cells provides a generalised representation from a variety of views (Perrett, Oram & Ashbridge, 1998; Riesenhuber & Poggio, 2000; Wallis & Bulthoff, 1999).

In all these models, recognition of an object in a different view to that at original encoding is expected to be less efficient (i.e. delayed or degraded, Kravitz et al., 2008) with respect to that of an object in an identical view to that at encoding. This sensitivity of the recognition to the view of the object is observed in the delay of recognition of objects after picture-plane rotation of familiar objects (Jolicoeur, 1985; Lawson & Jolicoeur, 1998; Hayward & Tarr, 2000) and for depth-rotation (Tarr, Bulthoff, Zabinski & Blanz, 1997; Logothetis, Pauls, Bulthoff, & Poggio, 1994 in monkeys). It has also been

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[3] Example names were 'brick', 'soap'

found in the depth-rotation of novel objects such as wire-like stimuli that have been compared to bent ‘paperclips’ and rounded structures (Edelman & Bulthoff, 1992) and blocks (Tarr, 1995). More cases of the view-dependence of recognition have bee reviewed by Kravitz et al. (2008) who especially considered position (location) dependence, and Graf, Kaping & Bulthoff (2005) who especially considered the congruency effects of facilitated recognition when target objects are presented in a congruous, rather than incongruous view with respect to distractor objects.

The view-based models outlined above were employed to account for the view-dependence that is seen in many cases of recognition. However, they have been criticised (Graf, 2005, 2006) for not accounting for the observed recognition advantage for different objects that appear in a similar orientation or size. The empirical evidence has tended to rely on research using stimuli that are harder to define in terms of parts and relations, such as those stimuli resembling paperclips bent into different forms. Such stimuli are arguably not processed in a similar way than to everyday objects, but rather require more view-based strategies. Liu et al. (1995) have gone further and suggested that 2-D shape representations are not sufficient for human performance.

1.9. Accommodating Both Types of Representation in one Model of Object Recognition

The division of theories into those predicting view-dependent and independent recognition performance has formed the basis of the long-standing viewpoint debate in object recognition. A review of research of the last 20 years on object recognition theories and the viewpoint debate by Peissig and Tarr (2007) discusses the move from structural-description models in 1980s, to view-based models in the 1990s. In their review Peissig and Tarr argue the case for view-dependent recognition, but they acknowledge that there is empirical support for both view-dependent and view-independent recognition. A number of explanations for the observation of both types of view-sensitivity have been offered as follows.

Generally, discrepant results may be assimilated into one or other type of theory by raising methodological difference (Johnston & Hayes, 2000), or exceptions based on the types of stimuli (Bartram, 1976; Cooper & Brooks, 2004; Cooper & Wojan, 2000; Laeng, Carlesimo & Caltagirone, 2002). Discrepant results have also been put down to the geometry of the stimuli (Hayward & Williams, 2000) or the ease of segmentation into parts and relations (Biederman & Gehardstein, 1993). Other considerations are the familiarity of the stimuli (Collinshaw & Hole, 2000) or the viewing conditions (Christou & Bulthoff, 2000) and the tasks used (Biederman & Subramaniam, 1997; Hummel, 2013; Liu, Knill & Kersten, 1995; Milivojevic, 2012).

Additionally, models can themselves be adapted to account for more or less view-sensitivity. Even a template model can produce predictions generalising over view if given a sufficient number of templates. A structural description model can also be conceptualised as more view-sensitive by adding more information in its description, for example, the viewing angle (see Hummel, 2001; Stankiewicz & Hummel, 2002). Some examples of hybrid models with properties of both view-based and structural description models have also emerged. Examples of hybrid models that have emerged from view-based models include those of Edelman and Intrator (2000, 2001) and the ‘chorus of fragments’ model of Newell, Sheppard, Edelman and Shapiro (2005), in which recognition involves a test of similarity to a prototypical shape rather than the derivation of metric properties. View-invariant models include those of Riesenhuber and Poggio (1999, 2000) who have included a role of attention and feedback for learning, and Hummel (2001) who included the role of attention in modulating between two parallel recognition routes, one resulting in view-dependent recognition and the other in view-independent recognition.

This thesis takes up the suggestion that both types of representation (Hayward 2003; Milivojevic, 2012) need to be accommodated in one model of human object recognition, and that one solution to accommodate this proposition is to consider the role of attention in gating different types of object recognition processing (Hummel, 2001). One alternative option for the accommodation of both types of representation in one framework is its conceptualisation within a serial account, as would be supported by the observation of fast (view-dependent) categorisation relative to slower (view-independent) identification (Grill-Spector & Kanwisher, 2005; Milivojevic, 2012). For example, the LTM representation itself may change over time from an initial view-dependent to final view-independent generalisation (Riesenhuber & Poggio, 1999). Behavioural studies have indicated that the recognition of an object may become more view-independent with time. For example Hummel and colleagues have shown view-dependent priming after an inter-stimulus interval of less than 2 s, whereas Fiser and Biederman (2001) showed view-independent priming after lags of the order of several minutes (but see Harris, Dux, Benito & Leek, 2008). However, from these results alone it is not clear whether the LTM representation changes with time or if both types of representation exist but one is more short-lived than the other. For example, Stankiewiz et al. (1998) suggested that the automatic holistic representation is short-lived (< ~3 s), whereas the controlled analytic representation provides long-lived priming (> ~5 mins).

Another way to accommodate both view-dependent and view-independent representation, is if the two types of representation exist independently and in parallel as has been suggested by certain neuropsychological case studies (Davidoff & Warrington, 2001; Turnbull, 1999) and the neurobiology of visual system (Burgund & Marsolek, 2000; Goodale & Milner, 1992). For example, the two representations may reside separately in areas of the right and left cortical hemispheres as in the proposed two dissociable lateralised neural subsystems of Burgund and Marsolek (2000), with view-dependent storage of objects in the right hemisphere and view-independent storage in the left hemisphere. This dissociation found support in the findings of Koustaal et al.'s (2001) event-related fMRI repetition-priming study in which coloured line drawings of everyday objects were shown repeated as an identical image, or one with the 'same-name-but-different-exemplar' (SNDE), or a different object entirely (unprimed). Participants were required to make a size-judgement of each presentation. The behavioural priming (i.e. the decrease in naming time due to having previously seen the object) was greatest for the identical image. Priming was also found for the SNDE. The fMRI activity showed a decrease in activity associated with repeated stimuli, termed 'repetition suppression', for occipito-temporal and frontal areas, for both types of repeated object. In the right midfusiform area of the brain the repetition suppression was greater for the identical image than for the SNDE. Overall, these results indicated that representations in the left hemisphere are more abstract, view-independent, whereas in the right hemisphere they are more perceptual (visual-form) and view-based.

In another fMRI study, Vuilleumier, Henson, Driver and Dolan (2002) also found some lateralisation of view-sensitivity. In their long-lag repetition-priming study the view, size and exemplar of an object was manipulated between prime and probe display. Participants were required to categorise objects as ‘real’ (everyday objects) or ‘nonsense’ (novel, but structurally possible). Behavioural priming was found for the real objects, and this was independent of size, but greater for identical compared to view-changed images. They found repetition suppression for both types of object in the lateral occipital cortex (LOC), within which the repetition effects in the left hemisphere was view-independent whereas in the right hemisphere they showed view-dependence. In Vuilleumier et al.’s study, they additionally found that an area in the left inferior frontal cortex generalised over exemplars and was possibly associated with priming of covert naming, but that this generalisation was not seen in the fusiform regions. Thus within the ventral regions, both view-independence and view-dependence were observed, but lateralised to the left and right areas of the fusiform respectively.

Further support that these visual pathways show different properties of view-sensitivity consistent with a parallel processing account for recognition has been shown in neuropsychological patients such as those discussed by Turnbull (1999). He has suggested that there are two recognition systems with different view-sensitivity, and that in the first instance the ventral stream aims to provide view-independent recognition, but if this is not possible, for example due to sub-optimal viewing conditions, recognition will fall back on viewer-centred recognition from the dorsal stream.

Davidoff and Warrington (2001) described a patient, FIM, with damage to bilateral parieto-occipital regions. FIM showed a difficulty discriminating between mirror-reflected images. They suggested that this implied that although a view-independent recognition system was intact to allow identification of the objects, a view-dependent system must have been impaired. This supports the suggestion that the ventral stream is more view-independent and the dorsal stream more view-dependent. Patients with parietal lobe damage have also shown greater impairments in recognising objects that have been rotated in the picture-plane Karnath, Ferber & Bulthoff, 2000; Turnbull, Beschin, & Della, 1997).

Further supporting that the ventral stream is associated with abstract representation was the fMRI study with blind participants by Pietrini et al. (2004). They found that even tactile recognition associated with ventral regions of fusiform gyrus was more category-related (faces, shoes and bottles).

In their fMRI study James, Humphrey, Gati, Menon & Goodale (2002) used 3D rendered images of common objects that were repeated in either identical or plane-rotated views to test the difference in the view-sensitivity of the activation in the ventral and dorsal visual pathways. They termed the decrease in activation on the repetition of the objects as ‘priming’ and found that there was a region in the temporo-occipital cortex (in the ventral pathway) that showed this priming for repeated objects regardless of whether they were shown in the same or rotated view. They also identified a region in the intraparietal sulcus (in the dorsal pathway) that only showed this priming for identical views.

More recently, Thoma and Henson (2011) also compared the view-sensitivity of recognition due to configural changes in view, by vertically splitting line drawings of everyday objects in half and swapping the horizontal locations of each (an example of such a stimulus is given in Figure 4-1). In this short-lag repetition-priming fMRI study, participants performed a (covert) basic-level naming task. Thoma and Henson identified view-sensitivity in a right intra-parietal region in which activity was increased with repetition (repetition enhancement). View-independence was identified in a region of the left mid-fusiform, which was associated with a decrease in neural activity upon repetition (repetition suppression).

As previously discussed in Section 1.4.1, two routes for object recognition are traditionally proposed in the brain. The ventral (from striate to inferotemporal cortex) stream associated with object identification and the dorsal stream (from striate to posterior parietal cortex) associated with object location information. These make a natural progression from the magnocellular and parvocellular pathways and their termination in different layers of V1. Therefore, it has been suggested that the types of visual information that are fed into the dorsal and ventral routes may also be separated very early on in visual processing. Bar et al. (2006) have suggested that the magnocellular cells are particularly sensitive to low spatial frequencies (LSF), and as these project mainly to parietal areas in the dorsal route, the type of information available for location (rather than identity) is more global in nature. In contrast, the parvocellular cells are particularly sensitive to high spatial frequencies (HSF), and as these project more into the temporal cortex in the ventral route, the type of information available in this case is fine-grained detail. Bar et al. go on to propose that the two types of information are integrated in the orbito-frontal pre-cortical region resulting in final identification. Thus, the faster MP-LSF information provides a subset of possible matches, and the result finalised once the slower PP-HSF information has been integrated.

In summary, there is empirical evidence for both view-dependent and view-independent recognition, and thus both holistic and analytic representation. Further, there is support for parallel routes associated with distinct view-dependent and view-independent recognition in the neurobiology of the visual system. The tests of the recognition of unattended objects presented in this thesis will be based on the framework provided by the functional model of object recognition -the hybrid model (Hummel, 2001) - which also proposes parallel recognition routes. Key to this model is the distinction between holistic and analytic representations based on their requirements of attentional allocation for binding, and upon which the hybrid model depends.

1.10. The Role of Attention in the Binding of Object Representations

Thus far, it has been described how the two types of representation in LTM (holistic and analytic) in object recognition are based on their properties of shape representation, and that these types of representation lead to different predicted properties of view-sensitivity in recognition. One way to accommodate both representations in a hybrid model by introducing the role of visual spatial attention in object recognition will be discussed. The role of attention is in determining the type of binding between an objects component parts and their relations (Treisman & Gelade, 1980).

In this thesis a stimulus is termed as attended when it is spatially (as opposed temporally) selected. A peripheral stimulus that is still visible in the visual array will be termed unattended when spatial attention is not allocated at that location. Other forms of attention, notably object-based attention, based on some salient features of an object (for example, attention might be drawn to selectively by faces as you are waiting for a friend in a café) will not be discussed further here.

Once visual attention has been focused and is sustained, it has been implicated in increasing the sensitivity of the earlier perceptual levels of processing a visual image (for a review see Pessoa, Kastner & Ungerleider, 2003). For example, fMRI studies have shown that at the locus of attention is associated with increased spatial resolution (due to high spatial frequency sensitivity, Carrasco, Loula & Ho, 2006), reduced receptive field size (Desimone & Duncan 1985) and a retinotopically-specific signal enhancement (Beck & Kastner 2009). Spatial attention has also been implicated in increased neuronal firing rate (Maunsell & Cook, 2002). In contrast, the unattended location shows a baseline reduction in neuronal activity at the unattended locus (Smith, Smith & Greenlee, 2000) and decreased spatial acuity (Montagna, Pestilli & Carrasco, 2009). However, of particular relevance to this thesis is the role of attention in binding component parts and relations of an object into a complete description (Hummel, 2013).

Analytic and holistic representations are distinguished by the way in which the component parts and relations of an object are 'fitted together' or bound. Analytic representations require that the object component parts and their relations are encoded independently of each other, and this is performed during the recognition process – 'on the fly' (Hummel, 2013). Analytic descriptions are dynamically bound. In contrast, holistic representations encode the parts and relations 'all-in-one' (Hummel, 2013), and because of this instantaneous nature of encoding in a coordinate based system. Holistic descriptions are statically bound. Similar to Hummel's model (2001) Treisman and Kanwisher (1998) state that, "attention is required to bind features, to represent three-dimensional structure, and to mediate awareness" (p. 218), supporting that visual attention appears to be an essential part of achieving a view-independent representation (also Treisman & Schmidt, 1982, Hummel & Stankiewicz, 1996).

The role of visual attention in binding has been discussed in, for example, the feature integration theory (FIT) of Treisman and Gelade (1980). In this theory, the action of attention is to serially bind features such as colour, orientation (defined as ‘separable’) and shape (defined as ‘integral’). Attention is required to perceive these features in their correct combination; without attention the ‘free-floating’ features may result in random or top-down knowledge-driven incorrect combinations, or “illusory conjunctions” (e.g. Friedman-Hill & Wolfe, 1995). Treisman and Gelade give the example of an image of a green sun that without attention can be falsely recalled to have been shown as a yellow sun, based on the top-down effect of prior knowledge (as attention was not allocated to the image during encoding, the correct binding of colour and shape was not possible). FIT has been used to distinguish between automatic (pre-attentive, or without attention) and serial processes in the phenomenon of ‘pop-out’ in visual search. In support of this is the finding for different cortical areas associated with serial visual search and conjunction from TMS studies (Ashbridge et al., 1997).

1.11. The Hybrid Model of Object Recognition: Incorporating Both Types of Binding and Representation in one Model of Object Recognition

The review of the literature in object recognition so far has shown that there is a strong suggestion of at least two types of object representations proposed to account for view-generalisation - analytic and holistic representations. They differ in way that shape is encoded, and importantly a further distinction lies in the fact that they can be distinguished by their attentional requirements for binding parts. Although many theories are based on only one type of representation, there are a number of arguments for accommodating both types in one model of human object recognition (Hummel, 2001, 2013; Hayward, 2003; Milivojevic, 2012).

One argument for incorporating both types of representation in one model of object recognition follows from the previous argument for accommodating both (analytic and holistic) types of representation to account for the view-independent and view-dependent recognition performance that is observed empirically. Since the format of representation is associated with a different type of binding (dynamic vs. static, see Section 1.10), it thus also follows that both type of binding must also be accommodated, and with them, their separate attentional demands. Further evidence for a requirement for both types of binding is found from neuropsychological case studies that have indicated that these types of binding are dissociable (Humphreys, 2001; Behrmann et al., 2006).

Hummel (2013) has proposed that both types of binding are required in terms of accounting for the flexibility and fast speed of observed human recognition performance. He suggests that dynamic binding (e.g. the neuronal synchrony of JIM (Hummel & Biederman, 1992, see Section 1.8.1) may not be able to account solely for all fast forms of recognition that have been empirically observed (Hummel, 2013). However, although static binding could account for the speed of recognition, it cannot account for the view-independence or recognition that has also been demonstrated empirically.

One argument for analytic rather than holistic representation is the combinatorial problem of representational units required for the latter (Hummel, 2001). This problem relates to the great number of units required to cover all the eventualities of representing objects. This arises because static binding requires the pre-tuning of representational units to fire for certain conjunctions of object features and locations. For example, in order to distinguish a cup from a bucket requires one unit already pre-tuned to a straight cylinder to the right of a curved one and another already pre-tuned to a curved cylinder above a straight one to distinguish a cup from a bucket. Therefore, more generally, a great many pre-tuned units is required to cover all the eventualities of such conjunctions –this is the combinatorial problem. In contrast, dynamic binding can use a set number of representational units (e.g. a type of geon or a type of spatial relation) each of which can be used in a number of combinations, providing more flexibility in the description of an object (Hummel & Biederman, 1992). However, a dynamically bound structural description requires attention and "is necessarily time consuming and capacity limited" (Hummel, 2013, p. 492). In short, an analytic representation does not reflect the fast speed of recognition that is observed empirically.

Another argument for accommodating both types of binding in one model of object recognition is that although attending to an object allows its recognition, there is also evidence of the recognition of unattended objects, which would not be possible with an analytic representation described in JIM. In addition, this recognition of unattended objects is at a higher level as that which might be expected by FIT alone, under which a full representation is arrived at only for the attended image. In contrast, only a “shapeless bundle of basic features” (Wolfe & Bennett, 1997) result from the unattended image. Recognition of unattended stimuli beyond low-level visual matching of a bundle of features has also been shown empirically from a number of studies based on interference effects and positive and negative priming.

An example of an interference effect is the Stroop effect from 1935 (Stroop, 1992). In this task, the names of colours are printed either in the same colour as the name (congruent, e.g. ‘blue’ printed in blue ink) or in a different colour (incongruent, e.g. ‘blue’ printed in red ink). Participants are required to name the colour of the ink, however, the interference from the colour name is demonstrated by worse performance when the name is printed in an incongruent compared to congruent ink colour. Interference effects have also been found in many studies where the unattended distractor flanks the target (Eriksen & Eriksen, 1974; Tipper & Driver, 1988).

Further evidence for high level object recognition without attention comes from negative priming effects, in which it takes longer to identify a previously seen object, was found by Tipper (1985) who showed negative priming at level of meaning. DeSchepper and Treisman (1996) used overlapping pairs of closed pattern novel shapes, in different colours (green and red) with the task to attend to one or the other colour and then answer whether the probe was same or different. They found that the shapes presented for less than 700 ms produced negative priming, which was long-lasting over a month. Although they found no evidence of explicit recall, implicit recognition was found to be robust. This finding of long-lasting implicit recognition of unattended objects was supported by Vuilleumier, Schwartz, Duhoux, Dolan & Driver (2005) in their fMRI study again using superimposed stimuli. They found that unattended images can leave a long-term memory effect, although again this was only behaviourally demonstrated by indirect-tests (i.e. not explicit recall).

Positive priming, where identification is faster due to having previously seen the object, has also been found using line drawings (e.g. Stankiewicz & Hummel, 1998, 2002; Thoma, Davidoff and Hummel, 2007; Thoma, Hummel & Davidoff, 2004). It has been indicated that whether positive or negative priming is found depends on the difficulty of selection of the target stimuli involved in the task (Hummel, 2013; Stankiewicz et al. 2008).

Models relying solely on analytic (dynamically bound) representations, cannot account for the recognition of unattended objects, as attention is required for dynamic binding. Although models relying solely on holistic (statically bound) representations would allow for the recognition of unattended objects, for these models the problem of accounting for view-independent recognition still remains.

It is possible that a number of features may be processed in parallel and pre-attentively in order to guide attention towards them and then to allow subsequent binding and recognition as suggested by Wolfe and Horowitz (2004). In their account, features including colour, motion, orientation, size and spatial frequency and shape, line termination, closure and depth are described as those likely to guide, or draw, attention. Li (2002) has proposed that processing continues to a higher, more abstract level, the outcome of which then guides attention. The possible role of the recognition of unattended objects in guiding attention towards them for further processing is discussed in Section 1.12.

In contrast, the hybrid model of object recognition (Hummel, 2013), rather than relying on attention being guided to an object before recognition can take place, proposes a dual route model. Recognition via one route based on analytic representation requires the allocation of attention, whereas the other parallel route based on holistic representation does not require attention at all. This model thus accommodates both types of representation and their complementary nature, modulated by attention. Attending to an object will result in both holistic and analytic processing and thus view-independent recognition, whilst inattention will result in only holistic processing and thus view-dependent recognition. Hummel (2013) has stated that, “Together, the automatic holistic route to recognition and the effortful relational one give us the best of both worlds: We can be as fast and automatic as a view-based model most of the time, and as smart as a structural description when we need to be” (p. 46).

1.11.1 Description of JIM3

The computer implementation of the hybrid model is now discussed. Hummel's (2001) implementation, named JIM3, is an extension of the implementation of the RBC structural description model, JIM. In JIM3 a parallel, unattended holistic route is added to the original analytic route. A schematic of the model is shown in Figure 1-14.

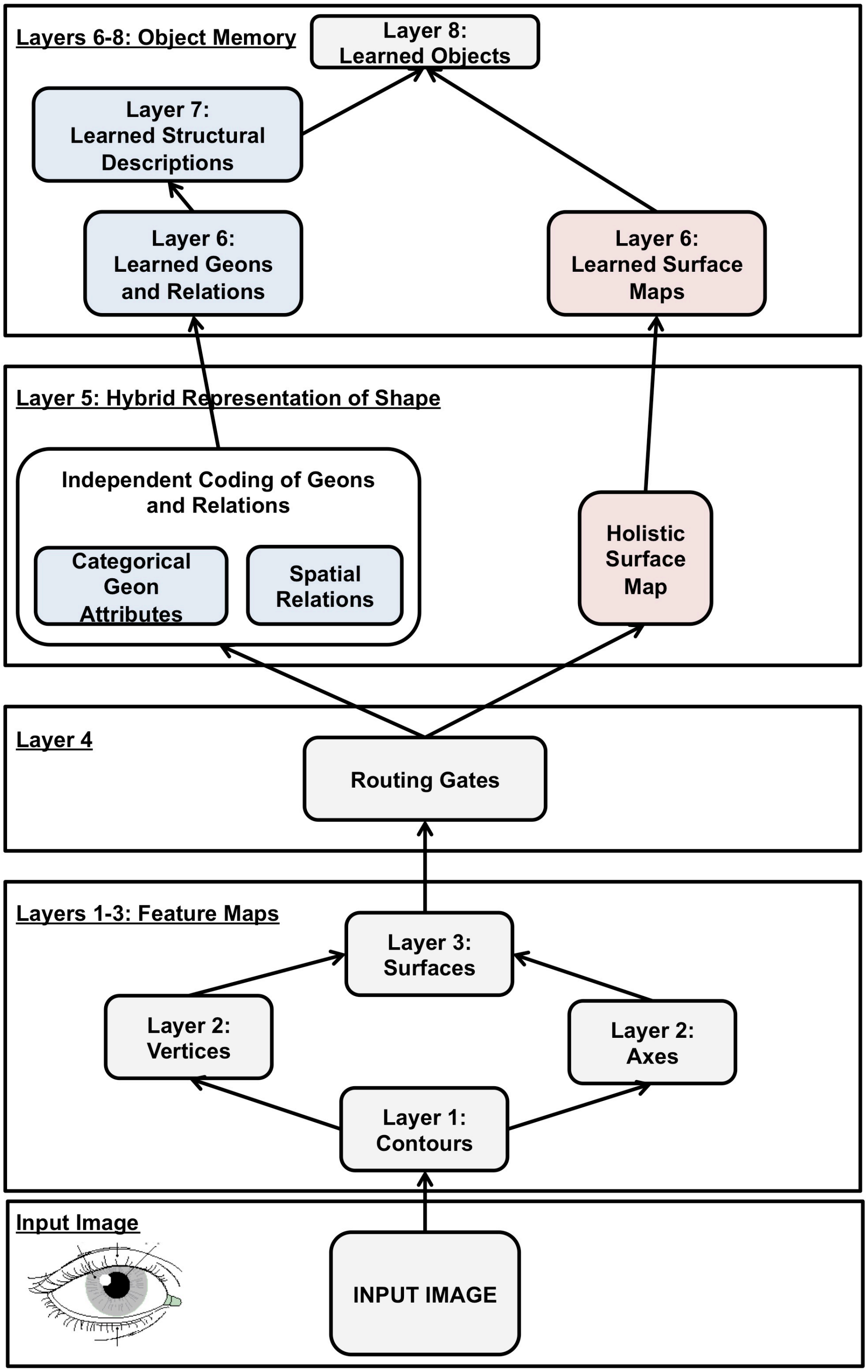

Figure 1-14: Schematic of JIM3 (adapted from Hummel, 2001). The red boxes correspond to the holistic, unattended, route and the blue boxes to the analytic, attended, route of recognition.

The model consists of eight layers each associated with a type of visual processing, from the earliest perceptual processing in Layer 1 up to the final object knowledge in Layer 8. Each layer is outlined below.

Layers 1 and 2 of the model represent low-level perceptual processes (similarly to those of JIM). Layer 1 detects contours from edges, while Layer 2 represents the vertices and axes of symmetry.

Importantly, in JIM3 (in contrast to JIM), Layer 3 combines these outputs of Layers 1 and 2, to output the shape properties of the surfaces. These surface properties are specifically restricted to those that are relevant to shape (and thus not colour etc). The output of Layer 3 is still retinotopic, that is, the spatial organisation of the description matches the retinal projection of the image. The five surface properties (ellipticity, parallelism, concavity, truncation and planarity) are categorical and derived from the properties of the vertices and axes of symmetry of the surface.

Layer 4 is comprised of ‘routing gates’ and is the first point of distinction between the holistic and analytic routes. The surface properties of Layer 3 are passed separately to each route in Layer 5. There, in the analytic (attended) route, the surface properties are used to infer the geon attributes (such as properties of orientation, axis etc) that are coded independently and in addition to coding spatial relations. However, in the holistic (unattended) route, the surface properties are ‘copied’ directly as a function of their location (with respect to 17 locations in a circular reference frame) forming a ‘holistic surface map’. Thus, Layer 5 consists of both analytic and holistic representations of shape. The holistic representation by a low-resolution surface map bypasses the explicit coding of geons and relations and instead accesses stored surface maps or learnt objects directly in Layer 6, leading to identification in Layer 8. The analytic representation accesses the stored combinations of geons and spatial relations in Layer 6 and these are compared with stored structural descriptions in Layer 7. Identification follows in Layer 8. Layers 6-8 are concerned with encoding the resultant patterns of activity into long-term representations.

In summary, in the Hummel model if an object is visually attended, a structural (analytic), description is established that allows view-independent recognition. The ‘automatic’ holistic description is generated in parallel (in case of an object presented in a familiar view) and provides a parallel route to recognition. This view-advantange is tempered by the suggested short lifetime of the holistic description, which implies that the recognition advantage for an object shown in the same view will only be found shortly after the first view of the object, and will be lost within some minutes (Stankiewicz et al., 1998).

Without attention, recognition is still possible as it is no longer restricted to the attentionally-demanding structural description. Rather, the holistic description will allow recognition, and this will show a degree of view-sensitivity. Stankiewicz and Hummel (2002) predicted that as the reference frame of the holistic map is viewer-centred while the map itself is object-centred, recognition performance will be equivalent for view-changes of translation and scale. However, recognition performance should be degraded with changes of the internal configuration of parts and relations, such as mirror-reflection, inversion (turning an image upside-down). These novel predictions on the view-sensitivity of the recognition of unattended objects provide the essential framework for the current investigation.

1.11.2 Support for the Hybrid Model

The predictions on the view-sensitivity of recognition as a function of attentional allocation have been directly tested in a number of behavioural studies based on repetition-priming paradigms (e.g. Stankiewicz et al., 1998). In a typical experiment two images are shown side by side, one of which is spatially cued (surrounded by a box) and participants are asked to name the object depicted by the image in the box. This is the prime display. Participants are then shown a probe display, comprised of a single image. An example of a prime and probe dispay is shown in Figure 1-15.

The probe image is either the same as one of those presented at prime, or a completely different object. In the case of a primed probe, the presentation at prime is in the same view as previously seen, or changed in some way, for example, mirror reflected (as in Stankiewicz et al., 1998). The experiment conditions are then attended identical-view, attended view-changed, unattended identical-view, unattended view-changed, as well as unrepeated conditions.

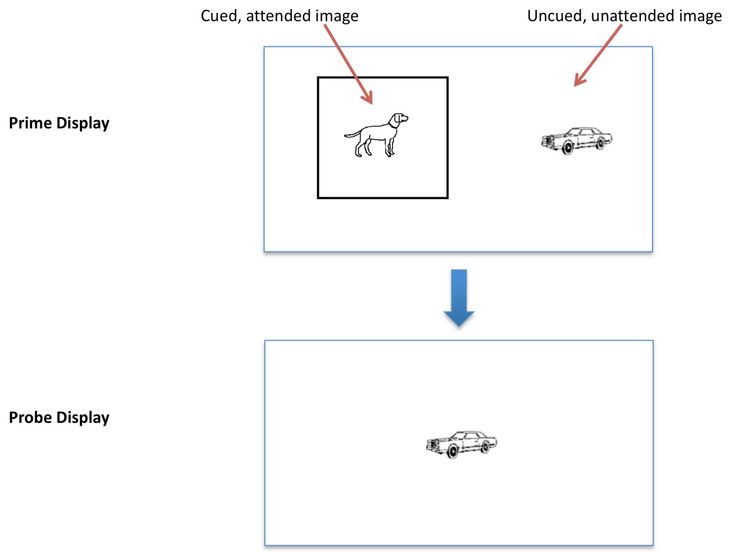

Figure 1-15: Example of a prime and probe display for a spatial cuing priming task.

According to the hybrid model, when a prime object has been attended and is subsequently repeated, priming results via both the analytic and holistic routes. When the prime object has been attended, but shown in a different view to that at the probe display, recognition and hence priming can only be achieved via the analytic route. When the prime object has been unattended, only the holistic route can be activated, thus priming can only result from identical views of the prime and probe objects.

The priming from the unattended objects has been demonstrated to be robust to changes between the view of the prime and probe of translation and scale (Stankiewicz & Hummel, 2002) but not robust to changes such as mirror-reflection (Stankiewicz et al., 1998), picture-plane rotation (Thoma et al., 2007), or depth-rotation (Thoma & Davidoff, 2006). In contrast, the attended objects were shown to be robust to such view-changes.

In the study of Thoma et al. (2004), a view-manipulation of splitting an image was used, and an example of such an image is shown in Figure 4-1. To produce the split image, the vertical midline of the intact image was found and each resulting half image slid over to the other side, for example, a horse's head and neck would be moved to behind its body and tail. In their Experiment 1 Thoma et al. confirmed that split images only resulted in priming when they had been attended, and Experiment 2 confirmed that the priming found was not purely due to name or concept priming. This was achieved by comparing the priming from a split image to that from an object with the same name, but a different visual exemplar (e.g. a grand piano compared to an upright). Although the different exemplars did result in priming when attended, they did not result in priming when unattended, supporting that the priming of unattended object relies on the image characteristics. In Experiment 3 of their study, Thoma et al. tested the priming from an unattended split image prime for an identical split image probe. This was to ensure that the priming (from identical images) was not due purely to low-level similarities between the prime and probe image, or just a diagnostic feature (e.g. horse's head still discernible although not in the right spatial relation to its body). Priming was observed from attended split images, but not unattended split images. This further supported the proposal that the holistic priming truly results from an object description in long-term memory (i.e. the priming is conceptual rather than perceptual).

However, the view-dependent recognition of previously unattended images has not always been found. In their fMRI study, Vuilleumier et al (2005) investigated the repetition effects from superimposed line drawings, in cyan and magenta, of everyday objects. Attention was controlled by asking participants only to monitor the objects of one colour. View-sensitivity was tested using mirror-reflections of the image. Vuilleumier et al found that although there was no evidence of behavioural priming for unattended objects on explicit-tests, that priming was observed in indirect-tests. A decrease in BOLD activity (repetition suppression) in right posterior fusiform, lateral occipital and left inferior frontal regions on the repetition of attended primes and an increase (repetition enhancement) in bilateral lingual gyri on the repetition of unattended primes was observed. However, no view-sensitivity was seen for the activity related to the unattended objects.

Thoma and Henson (2011) did find view-dependent repetition effects in their fMRI study, which directly adapted the Stankiewicz and Hummel (1997) behavioural paradigm. They used a basic level naming task and line drawings as stimuli. Further, rather than using the mirror-reflection viewpoint manipulation, they used split image primes as used in the behavioural study by Thoma et al (2004). Thoma and Henson found that repetition suppression was found in a left mid-fusiform region, regardless of the view (split, or intact) of the prime as long it had been attended. However, there was repetition enhancement in a right intraparietal region, but only for intact primes, and here regardless of attention. These give neuroscientific support to the functional hybrid model, with a ventral (analytic, requiring attention) route and a dorsal (holistic, independent of attention) route.

1.12. The Role of Attention in the Two-systems Account

Indirect support for the hybrid model comes from the attentional requirements for the dorsal and ventral visual pathways. Neuropsychological case studies have also shown a link between certain attentional conditions and problems with binding. For example, parietal lobe (dorsal route) damage can be associated with the condition of extinction (inattention) in the contralesional visual field in which patients appear to ignore stimuli presented to that side. This is usually assumed to reflect an impairment of orienting attention to the contralesional side (Marrett et al, 2011). Vernier and Humphreys (2006) found that a patient with right parietal lobe damage had difficulty recognising reflected images in the contralesional field implying that attention is required for discriminating reflected images, and hence object-centred representations.

In 1992, Goodale and Milner speculated that the dorsal route, areas of which have been termed the ‘fast brain’ by Bullier (2001), might process information without awareness, and thus more automatically than the ventral route. Damage to V1 has been associated with the condition of Blindsight (Radoeva et al, 2008) in which patients may not be aware of perceiving stimuli on the contralesional visual field, but are still able to act on them, e.g. grasping, thus indicating that the intact dorsal route of recognition does not rely on awareness. Further evidence for information being processed without awareness in the dorsal route is found in the fMRI study by Fang and He (2005), in which they used interocular suppression to prevent participants’ awareness of object images. Dorsal regions were activated without awareness, and this was more so for stimuli depicting tools.

More recently, Milner (2012) has reviewed the links between consciousness and the dorsal route. Attention is often linked with awareness, and it has been indicated that some brain regions, some very early such as primary visual cortex and amygdala (Tootell, 1999; Carrasco, 2001), are activated automatically, without awareness. There is some evidence that attentional modulation can be observed in subcortical areas as early in the visual processing stream as the lateral geniculate nuclei (LGN) (O'Connor, Fukui, Pinsk, & Kastner, 2002). However, some studies using event-related fMRI designs (Martínez et al, 1999; Di Dusso, Martínez & Hillyard, 2003; Olson et al, 2001) and MEG (Noesselt et al, 2002) have indicated that although the attentional modulation occurs in cortical areas that are early in the visual stream, that this modulation actually occurs temporally later (150-250ms post-stimulus onset) than expected for it to be associated with initial stimulus perceptual processing (60-90ms post-stimulus). Thus Di Russo et al have suggested that top-down feedback from higher levels of cortex is responsible for the attentional modulation of these early visual areas rather than a bottom-up selection mechanism.

One suggestion for a role of recognition without attention in the dorsal route is that it serves a function to guide attention to those objects for further processing. Goodale and Milner (2008) have suggested that the dorsal route controls the orienting of attention and thus feed into the ventral route processes of recognition, and support for this comes from the implication of parietal regions in attentional switching or control (Serences, 2005). Marrett et al (2011) have tested a Dorsal Stream Attention Hypothesis, in which attentional shifts are triggered as a result of the visual encoding that occurs in the dorsal stream. Marrett et al suggested that the dorsal and ventral streams show distinct roles in perception and attention, but interact possibly through re-entrant processes to enhance perception. Importantly, the dorsal route appears to trigger action without the cue having to reach awareness.

The dorsal stream attention hypothesis, and other models that propose methods of the guidance of attention towards features of interest for further processing for recognition can help to better answer the question posed by Walther and Koch (2006), "How can we attend to objects before we recognize them?" (p. 1395). Recent models of attention in object recognition (as reviewed in Walther & Koch, 2007) have addressed the nature of attentional guidance. However, these are more relevant to the question of improving the efficiency of visual search and so do not explicitly describe the properties of recognition without attention. These models will be discussed further in Section 1.17 after first considering the issue of attentional selection next.

1.13. Attentional Selection: The Question of Distinguishing Attended From Unattended

The following part of this chapter now turns away from the field of object recognition towards that of visual attention and examines how the predictions from the hybrid model for the recognition of unattended objects fit with the present research into visual attention. In her review of visual attention, Carrasco (2011) suggested that the fate of unattended stimuli is not yet resolved. An unattended stimulus is one that has not been selected for scrutiny under attention. However, the question of how and when attentional selection is achieved is still under some debate, and as Kanwisher and Wojciulik (2000) state, “the crux of this debate concerns the processing fate of unattended stimuli” (p. 91). Although the hybrid model predicts that the recognition of unattended objects is possible, it has only made explicit that spatial attention modulates the two routes. It assumes an all-or-nothing processing whereby on the simultaneous presentation of, for example, two objects, upon one object being attended/selected (and fixated), the other will not be in receipt of any attention (Stankiewicz et al, 1998). However, the model does not explicitly describe the selection mechanism required to modulate its two routes. Research into visual attention has demonstrated that attention itself may be a finite resource (that is, capacity-limited, e.g. Desimone & Duncan, 1995; Kahneman, 1973; Lavie, 1995) and that the mechanism of its allocation depends on many factors e.g. task-demands (Serences, Liu & Yantis, 2005; Yantis, 2000). The hybrid model assumes that the analytic route will be potentially limited by capacity restraints but the holistic route is assumed to be free of capacity restraints (Hummel, 2002).

Previous tests of the hybrid model have relied on spatial cuing to control spatial attention. This is a technique that has often been used to probe attentional effects (Serences et al, 2005). In such a paradigm, the timing of the cue is such that it allows one fixation to the cued target object thereby ensuring that it is attended. The presentation time of this display is too short to allow a saccade to the flanking uncued object, which thus remains unfoveated and thus unattended. However, a lack of foveation does not necessarily imply a lack of attention as has been demonstrated by Lavie and colleagues in their tests of perceptual load theory (discussed next). In Lavie et al’s (2009) study, unfoveated task-irrelevant images resulted in priming. Further, exhausting attentional capacity for a central task then eliminated this priming, thus going against the assumption of automatic processing proposed for the holistic route of the hybrid model.

In order to test the generalisability of the predictions from the hybrid model under different conditions of attentional selection in this thesis, they will be directly contrasted with those derived from perceptual load theory. Therefore perceptual load theory is now described, itself a hybrid model of attentional selection.

1.14. Perceptual Load Theory

The importance of attention in object processing has been described in Section 1.10. Attention is an “energy-hungry resource” (Carrasco, 2011). This limits our ability to process everything in our visual field with the same intensity, and imposes a requirement of the selection of certain parts of the visual display at which to allocate attentional resources. The selection debate in attention research concerns the question at which locus in time a certain part of the visual array receives focused attention and is therefore processed further up to the stage of response selection, whereas the rest of the array is not (Driver, 2001; Lachter et al, 2004).

Models of early selection include the influential filter model of attention of Broadbent (1958). In this model limited processing resources result in a bottleneck, and so an attentional filter is required to preserve only attended information and filter out that which is unattended. In Broadbent’s model the attentional filtering based on low-level physical properties, e.g., colour. Another early selection model is that of Treisman and Riley (1969) in which, rather than 'lose' the unattended information, an attenuator increases the signal to noise for the attended vs. unattended information. Such models predict that unattended objects will not be recognised, and have been supported by the studies of, for example, Neisser and Becklen (1975) and Rock and Guttman (1981).

In contrast, late selection theories suggest that all items in a visual array can be perceived and visually processed to some level of recognition, before selecting one area of interest and inhibiting all else. One such model (Deutsch & Deutsch, 1963) proposed that what information 'gets through' depends on the comparative importance of the competing stimuli. Such models predict that unattended objects can be recognised, and have been supported by those studies demonstrating priming or distractor influence from unattended objects (Stankiewicz et al, 1998; Driver & Tipper, 1989).

In their review Lachter et al (2004) have argued against late selection theories stating that there is "no identification without attention" (p. 880). Instead they suggest that the processing of unattended stimuli is limited to the "registration of simple physical features" (p. 880) and that any findings for the recognition of unattended objects can be put down to attentional 'slippage'. When slippage occurs, attention is allocated to irrelevant items, even if this is unintentional. They argue against the possibility of attentional 'leakage', under which the processing of irrelevant items occurs despite a lack of attentional allocation to them, and which is argued for the holistic processing of the hybrid model. Leakage implies that the selective filter is not completely effective in restricting further processing. The concept of slippage maintains the assumption that attention is required for recognition, but in contrast, leakage falsifies the idea of a completely selective filter.

One influential account to resolve the selection debate has been proposed in the perceptual load theory of Lavie (1995). Perceptual load theory assumes that attention is a capacity-limited resource and proposes that selection can be early or late depending on the perceptual demands of the visual display. In tasks of low perceptual demand, spare attentional capacity spills over to task-irrelevant objects, which are then automatically processed, resulting in late selection. In tasks of high perceptual load that exhaust attentional capacity, no attention is available to the task-irrelevant objects, which receive no further processing, and is therefore akin to early selection ideas.

In the framework of perceptual load theory, it is implicitly assumed that attention is required for recognition (as in Lachter et al, 2004) suggesting that in low perceptual load a distractor stimulus will be processed equivalently to the target as in fact they are both ‘attended’ (Lavie et al., 2009). Lavie et al (2004) describes two mechanisms for selective attention, the first, “a rather passive mechanism, whereby irrelevant distractor interference is prevented simply because the distractors are not perceived when there is insufficient capacity for their processing. The second mechanism is a more active mechanism of attentional control that is needed for rejecting irrelevant distractors even when these are perceived (in situations of low perceptual load)” (p. 339).

1.14.1 Support for Perceptual Load Theory

The empirical support for this model has been reviewed in Lavie (2005, 2010). Typically, in these studies participants are asked to perform a letter search task in which they are asked to identify, for example, whether an ‘N’ or a ‘Z’ is shown in the letter array display. Perceptual load is manipulated by the number of other letters that are shown in the array: For high load the target letter is shown amongst 5 other letters, for low load the other letters are replaced by circular placeholders. A distractor letter is shown simultaneously flanking the letter array, and this letter can be congruent to the target (i.e. the same letter), incongruent (the other possible response) or neutral (a different letter completely). The degree of distractor influence is measured by the amount an incongruent distractor slows the response to the letter search task. An example display is shown in Figure 1-16.

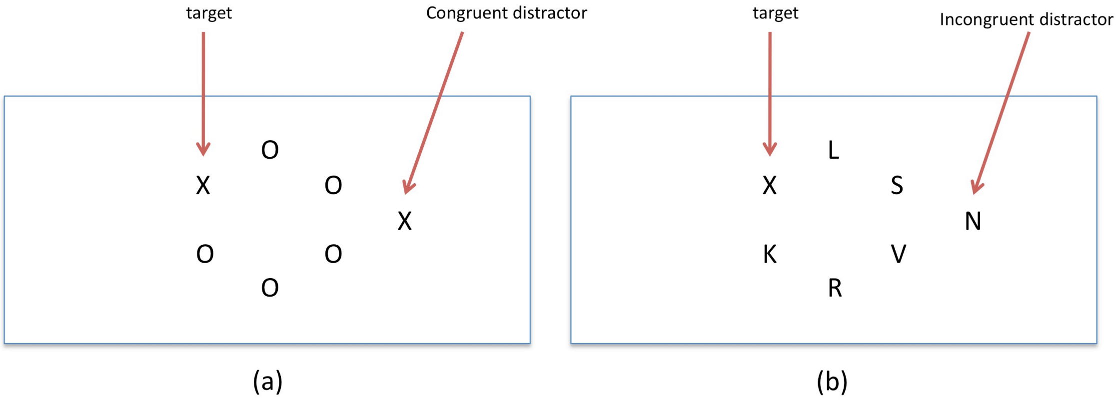

Figure 1-16: Typical presentation for a low (a) and high (b) perceptual load task from Lavie (2005).

It has been found in a number of variations of this type of task (Lavie, 2005) that the distractor influence demonstrated under low load is reduced under high load. In addition to the numerous behavioural studies, more recent fMRI studies have localised certain neural areas modulated by perceptual load (Wei, Szameitat, Müller, Schuber and Zhou, 2013; Xu, Monterosso, Kober, Balodis and Potenza, 2011).

Perceptual load theory has not been without controversy (Khetrapal, 2010) and one suggestion is that the empirical results taken as support for perceptual load may actually be accounted for by a dilution account (Tsal & Benoni, 2010a, 2010b; Torralbo & Beck, 2008; Keysers & Perrett, 2002; but Lavie & Torralbo, 2010). The dilution account proposes that the effect of introducing a greater number of potentially interfering and competing nontargets in a ‘high load’ display is that it dilutes the influence of the distractor, which is in fact processed equivalently under ‘low’ and ‘high’ load displays. Further discussion of this controversy will be reserved for the General Discussion chapter of this thesis.

1.15. Types of Attention: Endogenous vs. Exogenous

One important feature of perceptual load theory is that it proposes that the allocation of attention is stimulus-driven, that is, bottom-up or exogenous, in contrast to top-down or endogenous (Posner, 1980; Müller & Rabbitt, 1989). Endogenous attention is that which is under top-down, task-driven, voluntary control, and can thus be considered to enforce early selection. Exogenous attention is that which is involuntary and driven bottom-up by the stimuli, and thus can be considered to allow for late selection. Experimentally, to manipulate endogenous attention participants can be instructed to attend to a particular stimulus feature, e.g. colour or location, or are prompted to attend via a cue. Such cuing studies have been used extensively to study the effects of attention (Serences et al, 2005). Exogenous attention has been associated with the onset of a salient or novel (unexpected) object or feature such as colour, shape, however, there is some evidence that bottom-up and top-down attention may interact (Folk, Remington & Johnston, 1992). For example, Xu et al (2011) suggested that perceptual load may not be simply reliant on bottom-up processing, but that there was some interaction with top-down factors, too. They suggested that in high load there was an additional top-down control associated with the inhibition of distractors.

In the tests of the hybrid model so far, spatial cuing paradigms have been used. This promotes endogenous attention to the cued spatial location after the onset of the cue, which itself promotes exogenous attention. However it must be considered whether the possibility of exogenous attention at the uncued object - when it onsets simultaneously with the cued object - can be dismissed. The timing of the presentation of the spatial cue and prime display certainly restrict the possibility of fixation to the uncued object. However, Lavie et al (2009) have indicated that fixation is not necessary for the recognition of an object. The results of Shapiro et al (1997) indicated that stimulus saliency can affect attentional allocation, and Rauschenberger (2001) indicated that the global characteristics of shape draw attention. Therefore, this raises the question of whether even after attention has been cued to a particular location, a somewhat salient nontarget such as a familiar object can provoke exogenous attention. In this thesis, perceptual load is used as an alternative method to cueing in order to manipulate spatial attention, and serves to contrast exogenous control to the endogenous spatial cuing method.

1.16. Reconciling Perceptual Load Theory and the Hybrid Model of Object Recognition

Perceptual load theory and the hybrid model do not share the same predictions for the processing of unattended objects. Specifically, perceptual load theory proposes that only under high perceptual load at the central task can peripheral task-irrelevant objects be considered unattended, and will not receive any processing. In contrast, the hybrid model predicts that a holistic route of recognition is activated without attention. Thus, an unattended object image will result in the activation of a holistic representation and can therefore be recognised, even under high perceptual load. Although such recognition will be robust to changes in translation and scale, it will be sensitive to configural view-changes, as outlined in Section 1.13. In terms of the spillage and leakage accounts of Lachter et al (2004), perceptual load theory relies on the spillage of attention to task-irrelevant images under low load for them to be processed, whereas the hybrid model suggests that there is leakage through the selection filter by familiar objects.

One study to date has compared the predictions of perceptual load theory with those of the hybrid model of object recognition (Lavie, et al 2009). In their behavioural short-lag repetition-priming study they ran a number of experiments investigating the view-dependence for task-irrelevant flanker objects under low or high perceptual load. In Experiments 1 and 2 the prime display consisted of a target object and a flanking distractor object (line drawing). In Experiment 1 for the low load condition, the target object was presented among two circle place-holders, and in the high load condition, the target object was presented with two scrambled (meaningless) objects. Priming from the distractor objects was observed under low, but not high load. In Experiment 2, the low load condition consisted of an upright object image, and the high load conditions consisted of an upside-down image. As in Experiment 1 priming from the distractor objects was observed in low, but not high load conditions. Experiment 3 used a letter search task for the manipulation of perceptual load. Here a central circular array of letters was displayed containing either an “X” or “N” simultaneously to a flanking non-target distractor object image. On presentation of the letter search, participants were required to respond which letter had appeared. Then, after the probe display, they were required to name the probe object. In low load, the other 5 letters in the array were all “O”s, whereas in high load, the other letters were “K”, “R”, “V”, “S” and “L”. As in Experiments 1 and 2, Experiment 3 found that high load eliminated priming from the distractor objects. None of these experiments manipulated the view of the non-target object, and this was tested in Experiments 4a and b. Experiment 4a employed a left-right mirror reflection view-change, and Experiment 4b employed a depth-rotation using 3D photo-realistic images. In both experiments, only the case of low load was used.

In Experiments 4a and b view-independent priming under low load was observed. As noted in their discussion of the experiment, this was in contrast to the predictions from the hybrid model for view-dependent recognition of the non-target object regardless of the perceptual load at the target. As none of the experiments used cuing, relying only on perceptual load to control attention, Lavie et al suggested that this might indicate a “profound difference between the effects of cuing on attention and that of load” (p. 1354). They went on to suggest that spatial attention might specifically affect analytic representation, but that perceptual load might affect both analytic and holistic representation.

Therefore, the first discrepancy between the findings for priming based on using spatial cuing compared to perceptual load paradigms is that priming was eliminated under conditions of high perceptual load. This is not predicted by the hybrid model, under which the recognition of unattended objects is capacity-free and so as long as there is no view-change, priming is predicted to be resilient to high load.

The second discrepancy pertains to the view-sensitivity of the priming from the distractor object under low perceptual load. That is, the behavioural tests of Lavie et al (2009) indicate that under low load, a peripheral irrelevant distractor object results in view-independent priming. However, the hybrid model assumes that if one object is under spatial attention, that another simultaneously presented is without attention, and thus would predict view-dependent priming.

One possible difference between the Lavie et al (2009) study and those supporting the hybrid model of object recognition is that in the Lavie et al study, attention was manipulated exogenously by perceptual load whereas those studies supporting the hybrid model have used spatial cuing, rather promoting endogenous control. Further, the spatial cue provides a natural grouping effect from the way that the square encloses the target stimulus, possibly limiting attention to the non-target more efficiently than in the perceptual load manipulation, under which the entire visual array might benefit from more processing before settling on the ‘appropriate’ central location. Therefore, the control of spatial attention both via a spatial cue and perceptual load will be used for comparison in the research for this thesis.

Both the hybrid model and perceptual load theory are feed-forward models of processing and do not elaborate on top-down influences. The hybrid model assumes that the presentation of a familiar image will automatically activate the holistic route of recognition. Perceptual load theory assumes that under low load conditions, task-irrelevant stimuli will automatically receive further processing, whereas high load conditions automatically prevents their processing. However, as mentioned in Section 1.12, top-down knowledge of task-demands can bias bottom-up processing (Desimone & Duncan, 1995), and guide attentional selection, which is the topic of the next section.

1.17. Models of Top-down Guided Attention Object Recognition

The role of a route for the visual processing of unattended objects in providing a basis for attentional guidance such as that suggested by the dorsal stream attention hypothesis (Marrett et al, 2011) described in Section 1.12, is also seen in some of the functional object recognition models that have incorporated a role for ‘pre-attentive’ information to guide attention to certain object locations or features. Once attention is allocated, the stages of object recognition then follow. Such guided attention models were first conceived with the aim to solve the problem of ‘crowding’ (Korte, 1923; Levi 2008) that is found in purely feed-forward object recognition (i.e. without attention) models. As explained by Riesenhuber (2005) these bottom-up models struggle to explain how we can recognise objects in cluttered scenes, something we must do in everyday life, and he suggested that one way to guide attention is through top-down influence based on object-knowledge.

Desimone and Duncan (1995) have described how before the allocation of attention, all visual input can be considered potentially relevant, and compete for attentional resources to provide the processing required to complete a given task. In order to complete a certain task, top-down knowledge of the visual features that are relevant (salient) to successful task-completion must be held in an “attentional template” (p. 199). An example of a salient target feature would be the colour yellow when searching for a banana. The features may also relate to shape or location.

Olshausen, Anderson and Van Essen (1993) suggested that the initial, pre-attentive, feed-forward pass of the visual array may be implemented by the dorsal stream. This first pass extracts the low-level visual features present in the visual array. These features are then used to describe a “saliency map” (Koch & Ullman, 1985) of the visual array. In Oshausen et al’s model, the area that is most potentially salient defines the attentional window, and the information within this window is passed to the ventral stream for further visual processing (now under attention) to provide a view-independent representation. Olshausen et al suggest that the pulvinar is a candidate ‘army general’ for this routing of information between the dorsal and ventral streams. The representation of unattended objects in this model is left at the low-level visual processing stage described as ‘blobs’. Such a blob would be view-centered and based on luminance contrast, however, it is not clear whether this might preserve some coarse outline shape information.

Itti and Koch (2001) also proposed a first attentional shift directed by the dorsal route, determined by top-down knowledge from the ventral route. Features such as intensity, colour, contrast, motion, are pre-attentively processed in parallel at several spatial scales, and the authors suggest that ‘simple judgements’ are possible of unattended objects.

Navalpakkam and Itti (2003) adapted Itti and Koch’s (2001) model to include the learning of an object representation based on its low-level features and then using that representation top-down to increase the saliency of those features. They suggest that you can “Buy attention, get object recognition” from a shared resources model. By attending to the target, the orientation, colour and intensity of a few locations around that target are also encoded into a feature vector. These are combined to acheive a general representation of the target. Thus by searching for a given (already learnt) target, those learnt features bias the saliency map and so the target draws attention to allow recognition. They suggest that this sharing of resources across attention and object recognition helps identification with only 'elementary' pre-attentive information. They propose that such a model might not require any explicit coding of shape to get a "first rapid detection and some recognition" (p. 5). Another model adapting the use of a saliency map is that of Walther and Koch (2006) in which the saliency map is used to infer the extent of a 'proto-object' in the window of attention. Walther et al, also propose a 'gentler' modulation by attention to recognition in monitoring the entire visual field rather than the typical all-or-nothing approach.

One recent model that is of particular interest to the work in this thesis is that of Tsotsos et al (2008) who explicitly formulated how attention, binding and recognition link together. They assumed that the architecture of the visual system is fixed, and so that the only possibility for the flexible 'tuning' of the system to match task demands is through defining the amount of time allocated. Tsotsos et al proposed that attention, recognition and binding are all made of multiple processes. They suggested that selection acts top-down and that guidance is integrated into the visual hierarchy, and not a distinct component. Attention is used both for selection to optimise search, and also in feature binding – reminiscent of both the perceptual load theory and the hybrid model. Their selective tuning model incorporates a feed-forward pass with sparser coding of the attended location. There is also a feedback pass whose winner-takes–all (WTA) process for the strongest top-level response, then results in the inhibition of the surrounding area. Tsotsos et al define stages of recognition and the resulting effect on different recognition tasks and the type of binding that is required. The process of tuning begins with the priming[4] of attentional allocation, for example by fixation cues, spatial cues or success criteria. This is described as a top-down tuning mechanism before stimulus onset – requiring a long processing time of about 300-100ms prior to onset. This is followed by

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[4] NB. Not behavioural priming, rather a tuning mechanism.

the stimulus onset, which begins the feed-forward process through the already ‘tuned’ pathway.

The next stage is discrimination. Tsotsos et al stated that this could be divided into sub-tasks, one example being categorisation. Categorisation only requires a single feed-forward pass of about 150 ms, with no location information involved in for completition. Categorisation uses convergence binding, which relies on the explicit coding of each percept by certain neurons. From this, the stage of individual identification requires lower level information in order to refine identification from the category level to the individual level. This takes about 65 ms, consistent with the time for categorisation vs. basic level naming observed behaviourally by Grill-Spector and Kanwisher (2005). Identification requires feedback tracing back down through the hierarchy to recover the lower level neurons that caused the WTA at the highest level. It uses a partial recurrence binding can stop at any point on downwards progression through hierarchy. An inappropriate interrupt could cause an illusory conjunction.

The final stage of Tsotsos et al’s model is that of localisation, and the output of this stage is required to complete a behavioural motor response to the target. Localisation information is only present at the lowest level of visual hierarchy, so requires completion of the downward progression and so takes about 250 ms or more to complete. Full recurrence binding is required to get the location and spatial extent of the target.

Tsotsos et al stated that in their model, that “segmentation is not immediate in the Marr sense” (p. 128) and that “detection occurs before localization and that correct binding occurs after localization” (p. 131). This model provides a detailed account of the stages of attention and object recognition, however, even in this model, it is rather difficult to place a ‘truly’ unattended object as some pre-processing has already tuned the system to allocate attention and so it implies a fast allocation of attention rather than that performed without attention.

In summary, most of the guided attention models described here assume a pre-attentive ‘sweep’, in which processing may, or may not, be weighted by top-down knowledge. This is followed by the narrowing of a window of attention at a selected region of highest salience, followed by a serial approach to the processing of that selected area of the visual array. The interaction between bottom-up and top-down attention in models is reviewed in more detail by Walther and Koch (2007). The models described here tend to concentrate on improving the guidance for attentional selection, or the efficiency of visual search, and the remaining unattended part of the visual array is left to various degrees of low-level feature extraction stages. Therefore, they represent a midpoint between the two bottom-up hybrid model and perceptual load theory under which unattended objects are either processed to automatic shape recognition (hybrid model) or not processed at all (high load of perceptual load theory). Although they do not offer any direct predictions for the nature of the representation of unattended objects, they do inform how selection may not be based on bottom-up processes alone.

1.18. Summary of Chapter 1

In this background chapter it has been argued that to understand how an object is recognised it must first be considered how it is represented in long-term memory. This may be via a view-based or a structural description, resulting in view-dependent or view-independent recognition respectively. There is considerable evidence for both types of recognition, reinforced by the types of recognition supported by each of the dorsal and ventral visual pathways in the two-route account. Further, these pathways have been shown to have distinct attentional demands. One model that mirrors this accommodation of both types of representation, modulated by attention is the hybrid model of object recognition (Hummel, 2001). The particular interest of this thesis is in the route for recognition that is possible without attention, that is, the holistic route.

Under the hybrid model, the recognition of unattended objects relies on a holistic, statically bound, description, which leads to view-invariant recognition under translation and scale transformation, but which will be view-sensitive to configural transformations altering spatial locations of the objects component parts. This is predicted to be automatic (mandatory, fast and capacity-free) and it has been shown that this is somewhat in line with the properties of shape processing suggested for the dorsal visual stream.

The behavioural studies of Hummel and colleagues have provided good evidence for holistic recognition, and further that this can take place without attention. The hybrid model has also found support indirectly by neuroimaging studies using unattended objects and the properties of object recognition in neuropsychological patients. The fMRI study of Thoma and Henson (2011) was a direct test of the model and made significant headway in giving the hybrid model further grounding in the brain. However, as described in Section 1.13, it has also been suggested that there is “no recognition without attention” (Lachter et al, 2004, p. 880), and this leads to the first research question of this thesis.

Research Question 1: Can repetition effects associated with the recognition of unattended objects be observed with ERP and if so, does the view-sensitivity of the repetition effects conform to that predicted under the assumptions of the hybrid model?

Although the hybrid model accommodates many of the properties of human object recognition, it does not fully consider the mechanism of selection, and direct support for it is based mainly on one type of control of spatial attention –spatial cuing. In order to test that these results are generalisable, it is necessary to consider alternative methods of manipulating attention.

Further, although the hybrid model assumes that the holistic route acts in an automatic (fast, capacity-free and mandatory) fashion, it does not further consider the effects of capacity-limits of attention on recognition. In contrast, in the field of visual attention research, accounts of capacity-limited attentional resources have been proposed as a resolution to the selection debate. One such account, perceptual load theory (Lavie, 1995), bases selective attention on the stimulus-driven properties of the visual display, and assumes that without attention, no processing and thus no recognition is possible. Perceptual load is of particular interest here as the one investigation (Lavie et al, 2009) that has compared the predictions for the recognition of unattended objects from perceptual load theory and the hybrid model has found discrepant results to those predicted by the hybrid model. Specifically, there were two discrepancies between studies whose results support the hybrid model and the Lavie et al study. Firstly, Lavie et al found that priming was extinguished for distractor objects under conditions of high perceptual load (assumed unattended). Under the hybrid model, the holistic route acts without attention, thus predicts priming even under high load. Secondly, Lavie et al found that under low perceptual load conditions, priming for the distractor objects was view-independent. Under the hybrid model, attending to one object renders the other unattended, thus the priming from the distractors is predicted to be via the holistic route and thus view-dependent. This leads to the second research question for this thesis.

Research Question 2: How are the ERP repetition effects from ‘unattended’ peripheral task-irrelevant objects affected by perceptual load? Does perceptual load modulate view-dependence as found with spatial cuing paradigms?

The experiments in this thesis examine whether the ERP repetition effects are eliminated under high perceptual load and their view-sensitivity under both high and low load. To this end two of the experiments reported here use direct manipulations of view and perceptual load in the same experiment rather than just controlling for one or other aspect as in previous studies.

1.19. Summary of the Rationale for Choice of Experimental Task and ERP Measurement Technique

The main topic of this thesis is the visual processing of unattended objects. The behavioural findings have shown mixed results for and against such processing (Lachter et al, 2004). ERP measurement is chosen here with the aim of providing insight into such discrepant behavioural results. ERPs provide a measurement of neural activity in the order of milliseconds after the stimulus presentation. This avoids the temporal lag associated with behavioural results during which many processes may have interacted and summed such that it is difficult to tease their different effects apart (Henson, 2004). Both the previous tests of the hybrid model and the Lavie et al (2009) study used short-lag repetition-priming paradigms. Priming is useful in investigating specific presentation conditions that affect the recognition of an object (Henson, 2009). The naming task ensures that objects are recognised to a basic level and has been shown to be view-sensitive (e.g. Stankiewicz et al, 1998).

Thus to summarise the choice of task:

1. Repetition-priming is chosen because it is a good measure of fast, automatic processing, as assumed by the holistic route of the hybrid model. Also it allows the direct investigation of effects of view and load on recognition (Bruce et al, 2000).
2. Short-lags between the prime and probe are chosen because this enhances the view-sensitivity of the priming (e.g. Bindemann et al, 2008; Henson, et al, 2004; Stankiewicz & Hummel, 1998).
3. The naming task is used because this implies that objects are recognised and so associated with the match to a long-term representation, rather than relying on a superficial match of low-level visual features. The view-sensitivity of priming has also previously been found in naming tasks (e.g. Stankiewicz & Hummel, 1998; Thoma et al, 2004, 2007).
4. ERP is chosen because of its high temporal sensitivity, useful to examine the fast processes associated with the automatic recognition of the holistic route and also to tease apart effects that may have summed by the response time of behavioural results.

1.20. Experimental Strategy for Thesis

The first aim of this thesis was to find evidence for the shape recognition of unattended objects as predicted by the hybrid model of object recognition in the form of ERP repetition effects, and characterise the view-sensitivity of those repetition effects. Experiments 1 & 2 thus address the first research question:

- Experiment 1 was designed to establish ERP repetition effects from unattended objects.

- Experiment 2 then addressed whether the view-sensitivity of the repetition effects conformed to the predictions of view-sensitivity for the holistic route of recognition of the hybrid model.

The next aim was to then test whether the repetition effects from unattended objects were affected by perceptual load.

Experiments 3 – 7 thus addressed the second research question:

- Experiment 3 used the same spatial cuing paradigm that has been previously used to test the hybrid model, but with an extra factor of perceptual load included in order to examine whether ERP repetition effects were modulated by perceptual load.

Experiments 4-7 used a letter search task to manipulate levels of perceptual load that was used in the study of Lavie et al (2009). Attention to task-irrelevant objects was manipulated by varying perceptual load in this letter search task.

- Experiment 4 was a behavioural study partially replicating that of Lavie et al (2009) who found discrepant results in regards of flanker object recognition compared to predictions by the hybrid model. The behavioural study was extended to also check for covert eye-movements during the prime display.
- Experiment 5 was an ERP study investigating whether high perceptual load in the letter search task eliminated the influence of peripheral distractor images.
- Experiment 6 extended the behavioural Experiment 4 to examine the view-sensitivity of ERP repetition effects of unattended objects under perceptual load. The effect of repetition effects on changes in view (intact vs. split) of flanker images was investigated.
- Experiment 7 was a follow-up ERP study to that of Experiment 6 but replacing the view-change manipulation to inverted (i.e. upside-down) images.

Chapter 2. Event-Related Potentials (ERP) and General Methods for Thesis

2.1. EEG in Cognitive Neuroscience

Electroencephalograpy (EEG) is the non-invasive measure of the electrical voltage changes at the scalp and provides a direct measure of the electrochemical changes of neuronal populations in the brain (Churchland & Sejnowski, 1998). First recorded in humans by Berger (1929), it has been described as the, "reaction time for the 21st Century" (Luck et al 2000, p. 22).

One particular advantage of EEG lies in its high temporal sensitivity, which is of the order of milliseconds (Rugg & Coles, 1995). EEG measures the neuronal response to a stimulus within milliseconds of its presentation. In contrast, behavioural and fMRI measures incorporate a timelag between the stimulus presentation and the measured response. Behavioural measures rely upon a motor response, and fMRI measures rely on the measurement of changes in blood-oxygenation level (BOLD). The changes in BOLD can take of the order of minutes. Both behavioural and fMRI measures thus reflect the aggregation of a number of processes that occur between stimulus presentation and the measured response to it (Postle & Corkin, 1999). As EEG measures the neuronal response during this period of timelag, it can be useful in separating the effects of those interacting processes.

Further, whereas fMRI has high spatial and low temporal sensitivity, EEG has high temporal but low spatial sensitivity. Thus EEG and fMRI provide complementary measures that can inform on the possible network of cortical regions involved in cognitive processes in more detail (see also Henson, 2003). Techniques such as event-related fMRI and source localisation can provide better temporal sensitivity to fMRI measures and spatial sensitivity to EEG measures. Magnetoencephalography (MEG), which is the measurement of magnetic fields provided by the electrical activity of the brain, can provide both good spatial and temporal resolution.

EEG is thus a useful direct measure of the effect of neural processes that are involved in cognition. In order to characterise the cognitive processes behind object recognition, behavioural tests are based on careful experimental design that aim to separate out such processes in response to a certain psychological task. The question of how the neural response changes to certain experimental conditions is difficult to establish from raw EEG signal alone. This is because of the relatively small signal from those neurons that are involved in the processes relating to the specific experimental condition compared to the background brain activity (noise). Thus, in addition to careful design relating to the experimental conditions, it is also necessary to consider the improvement of the ratio of signal to noise (S/N). The S/N can be improved by increasing the number of trials and by averaging a large number of responses. The time-locking of the EEG to a certain experimental event, such as the stimulus onset, enables the examination of the timeline of effects that follow. The resultant waveform is an event-related potential (ERP) and before discussing how these are derived and interpreted in more detail, a brief overview of the neural activity leading to EEG is given next.

2.1.1 Electrogenesis of EEG

There are two main types of neuronal electrical activity, action potentials and postsynaptic potentials, which are briefly outlined below (following Luck, 2005). Action potentials are discrete spikes travelling the length of the axon, releasing neurotransmitters. These tend to be short-lived, of the order of a millisecond. When the neurotransmitters reach the postsynaptic cell and bind to receptors on its membrane, ion channels then open or close. The flow of ions results in a current flow between the cell membranes, which in turn results in a voltage potential across the cell membrane, termed the postsynaptic potential. These tend to be longer-lived of the order of tens or hundreds of milliseconds. It is these postsynaptic potentials that are measured by EEG. The measurement of action potentials relies on measures such as single-unit recordings, which are an invasive measure from the insertion of a microelectrode.

Figure 2-1 illustrates how the ion flow within a cell results in a voltage potential at the scalp. The current resulting from the flow of ions within the cell is termed the primary current. This primary current can be imagined as a battery, with positive and negative voltages at its poles. Current flows from positive to negative voltage. Therefore, the primary current presents a current dipole from the positive (source) and negative (sink) voltage. Due to the nature of electrical conduction through matter, a secondary, or volume current is set-up whose flow is from the positive to negative potential of the dipole. The potential measured at the scalp electrode is a summation of the dipoles (dipole layer) resulting from the synchronous activity of a population of similarly oriented neurons. The summed dipole is termed the equivalent current dipole. EEG signals are associated with dendritic potentials. Axons tend to be randomly oriented, in which case the potentials will cancel on summation and therefore cannot be measured by EEG.

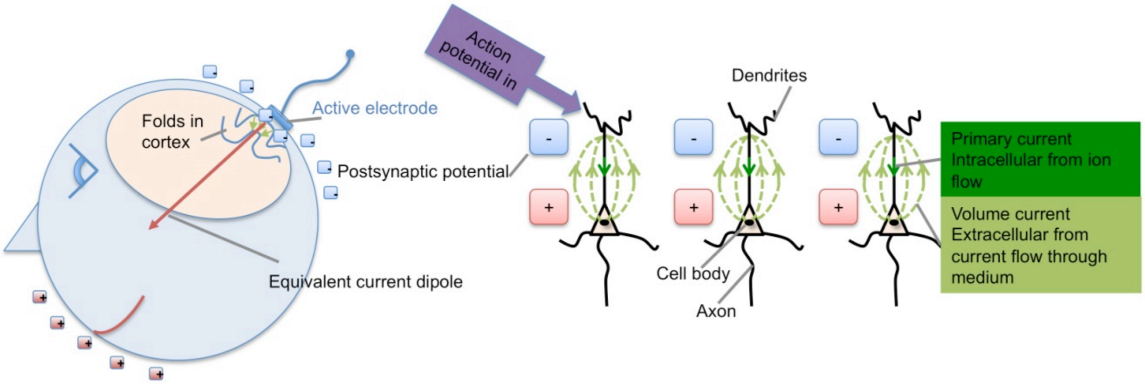

Figure 2-1: Illustration of processes of electrogenesis of EEG.

2.1.2 Derivation of ERP

A useful technique in EEG research is to derive an event-related potential (ERP), which is the EEG time-locked to a specific stimulus event for a given experimental condition. Comparing the ERP between conditions then provides a measure of the difference in neuronal activity between those conditions.

In order to derive an ERP for each participant, the raw EEG signal from each experimental condition must first be identified and then averaged together. This procedure results in an ERP at each electrode site that is the average of their responses in each experimental condition. The resultant ERP after segmenting and averaging the signal is shown in Figure 2-2.

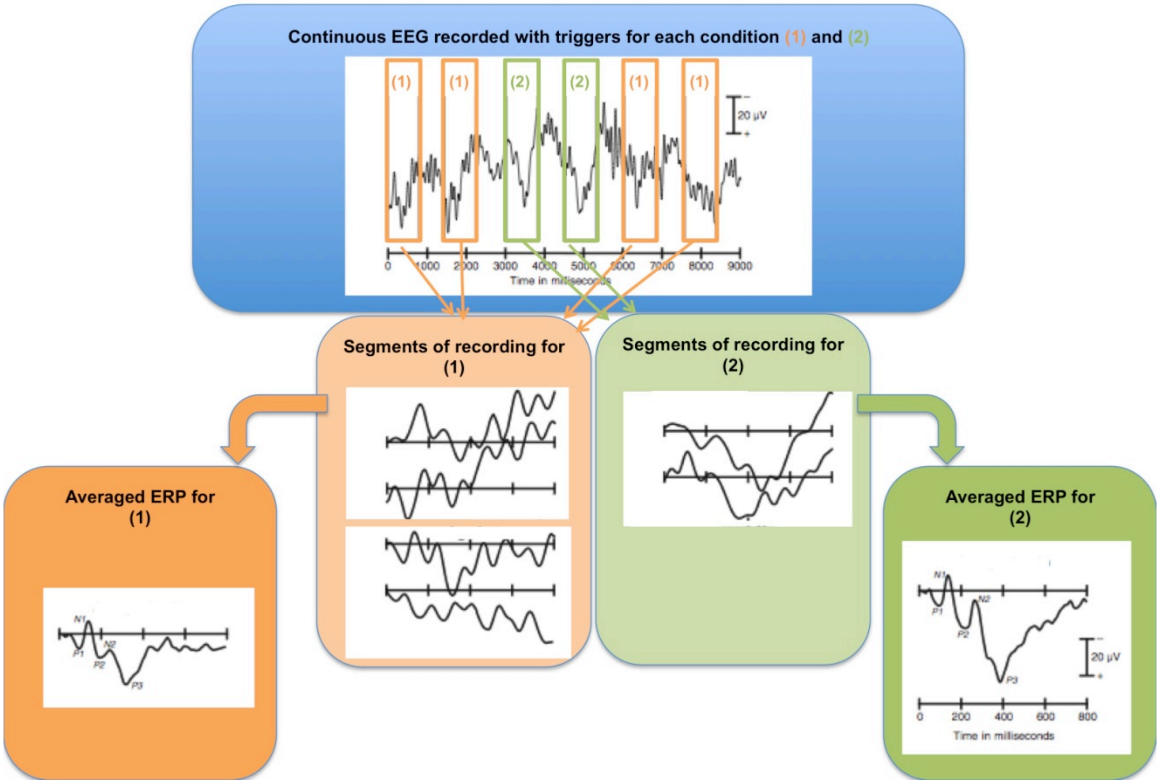

Figure 2-2: Extracting an ERP from raw EEG in two experimental conditions (adapted from Luck, 2005).

The pre-processing of the raw EEG that is necessary to maximise S/N is described in detail in Section 2.3. The properties of the ERP waveform can then be statistically analysed to infer the effect of the experimental conditions under test. Typical features of an ERP waveform associated with visual processing are described next.

2.1.3 Interpretation of ERP

The ERP waveform is the voltage potential as a function of time. An example of an ERP waveform is shown in Figure 2-3. An ERP waveform can be derived for each electrode placement on the scalp, and thus provides a measurement of the neuronal response to a stimulus across time and scalp-location.

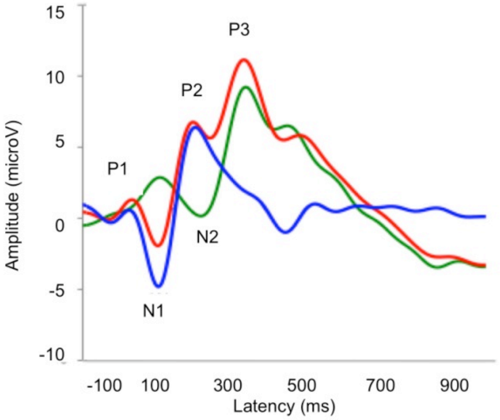

Figure 2-3: Example of an ERP waveform adapted from McFadden and Rojas (2013).

The waveform can be seen to comprise a series of peaks and troughs in voltage amplitude that arise at certain time-points (latencies). There is a historical convention to depict ERP waveforms with the negative amplitude increasing up the y-axis. However, Picton et al (2000) have stated that both this and depictions with positive amplitude increasing up the y-axis have been used, and thus it is important to make this clear in any figures. In this thesis, as in Figure 2-3, the amplitudes are shown with positive voltages increasing up the y-axis.

Some of the peaks and troughs are associated with specific experimental manipulations and certain cognitive processes and are thus termed ERP components (Luck & Kappenman, 2011). The convention for naming components is to use the polarity of the potential and the approximate time at which it occurs. Thus the positive-going potential observed at around 100 ms after stimulus onset is termed the P100. The negative-going potential observed at around 170 ms is named the N170. However, as discussed in Luck (2005), the latencies of these components show some flexibility according to the experimental conditions under which they are generated. Thus, an alternative, ordinal, naming system is also useful. Here, the P100 is known as the P1 (the first positive peak), followed by the N1, then the P2, N2, P3. However, Luck also notes that the N400 is often the second negative-going component, thus the N400 is the more appropriate name.

By examining the differences in waveforms between conditions, certain inferences in the activity related to cognitive processes can be made. Otten and Rugg (2005) discuss the distinction in the types of inferences that can be made with and without prior knowledge of the association of waveform changes with certain cognitive processes (i.e. the functional significance of components). If it is assumed that a specific cognitive process results in “specific and invariant patterns of neural activity” (p. 5), then a change in ERP across scalp location and amplitude between conditions will imply that different cognitive processes are associated with those conditions. Further, where different temporal distributions are found, it can be inferred that the cognitive process has a different onset between conditions. However, the onset time of the component should not be taken as the onset of the cognitive process, rather the “onset latency should be viewed as an upper bound on the time by which cognitive processing started to differ” (p. 12). If the difference between ERP across condition is purely in amplitude, it can be inferred that the same cognitive process is ‘engaged to a different degree’ (with the same neuronal generator but with a quantitative difference).

As described in Kappenman and Luck (2011) care must be taken in interpreting changes in ERP components (associated with specific neural or cognitive processes) as distinct from changes in the waveform within the same time windows of those components. It is important to appreciate that the peaks and troughs of the waveform are the result of the summation of a number of latent components that may reflect a number of independent processes. Thus, a certain profile for the ERP waveform does not necessarily imply the involvement of a specific ERP component. Luck's (2000) definition of an ERP component is "scalp-recorded neural activity that is generated in a given neuroanatomical modules when a specific computational operation is performed" (p. 63). Thus, changes of amplitude at a given peak cannot be equated to differences in the size of a component, nor changes of the latency of a peak to differences in component timing. See also Kappenman and Luck (2011) for a detailed discussion of the problems in defining ERP components.

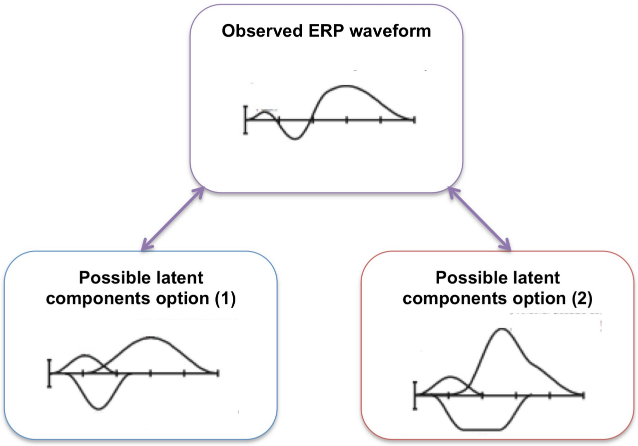

Figure 2-4: Summation of different ERP latent components result in the same profile for the observed waveform (adapted from Luck, 2005).

Also, again as a consequence of the measurement of a summation of neural responses, it is important to keep in mind that although an ERP is extracted for each electrode site, it cannot be simply inferred that this is the location of the neural activity that drives it. This inference cannot be made because the electrical properties disperse through the whole of the head and so the resultant equivalent current dipole reflects interactions between the individual dipoles and their alignment that are summed. Another inference that cannot be made from ERP is that of causality.

Lastly, a null observation of an ERP does not necessarily imply that there was no neuronal change and only means that none was detected. This may, for example, be due to the alignment of the neurons resulting in an electric field whose relation to the scalp cannot be detected. The influence of the alignment of the dipoles upon the EEG measurement for example from two parallel areas of cortex can lead to a cancellation of current due to dipoles aligned in opposite directions. Cancellation of the current prior to reaching the electrode can also occur if neurons are randomly aligned, arranged radially or the voltage sources and sinks are too close to one another causing a ‘closed field’.

2.1.4 Visual ERP components

The main ERP components associated with visual processing (as in Luck, 2005) are outlined below.

C1

The C1 does not show a consistent polarity and is the earliest visually evoked ERP component. As described in Di Russo et al (2003), the C1 has an onset latency of around 50-90 ms, and is found at electrodes placed centrally (along the scalp midline) at a posterior site. Di Russo et al describe how the C1 has been associated with the first response in primary visual cortex for a number of reasons. The first reason is that the C1 has been localised to the calcarine cortex near V1. The second reason is that the C1 onsets so soon after visual stimulus presentation. Finally, the C1 also shows characteristics of retinotopy such that stimuli presented to the upper and lower visual field show opposite polarity potentials (Di Russo et al, 2001; Mangun, 1995; Martinez et al, 1999) that would be consistent with the properties of primary visual cortex. The C1 is also sensitive to low-level visual features of an image such as spatial frequency and lightness contrast (Luck, 2005). The C1 is thus also associated with pre-attentive processes and support for this is found in studies showing that it is unaffected by whether a stimulus is attended to or not (Di Russo et al, 2003).

The C1 is small for stimuli presented on the horizontal axis and combines with the P1 into a single wave (Luck, 2005). All the images used to for the experiments in this thesis use such horizontally presented stimuli, thus the C1 will not be investigated here.

P1

The P1 is a positive-going component that onsets at around 60-90 ms post-stimulus, found at lateral occipital sites and peaking between 100-130 ms. The P1 is also sensitive to low-level visual features of an image, e.g. the latency of the P1 is found to depend on stimulus contrast (Luck, 2005). The P1 has been localised to two areas in extrastriate cortex, with an early portion associated with the middle occipital gyrus in the dorsal stream and a later portion with the fusiform gyrus in the ventral stream (Di Russo et al, 2002). However, Luck (2005) notes that as many areas are activated within 100 ms of the presentation of a visual stimulus that they may also contribute to the P1 wave.

The P1 is also sensitive to spatial attention (Hillyard, Vogel & Luck, 2000). Therefore, the P1 will be examined in the experiments of this thesis.

N1 (N170)

The N1 is a negative-going wave between 100-200 ms that is made up of several subcomponents. The earliest peaks at 100-150 ms post stimulus onset and is seen at anterior sites, and two later sub-components peak between150-200 ms post stimulus and are seen at posterior sites, and localised to parietal and lateral occipital regions (Luck, 2005). The lateral occipital N1 has also been shown to be larger for discrimination over detection tasks (Hopf et al, 2002; Vogel & Luck, 2000).

The N170 is a negative-going wave between 140-200 ms associated with face processing (Bentin et al, 1996; Rossion et al, 2000). It peaks at about 170 ms and is found at right-lateralised lateral occipital sites. There is some debate as to how face-specific the N170 is (Bentin, 1996; Bentin & Carmel, 2002; Carmel & Bentin, 2002; Itier & Taylor, 2002; Jemel et al, 2009; Rossion 2000; Rossion, Curran & Gauthier, 2002; Rebai, Poiroux, Bernard & Lalonde, 2001). However, it is also found for non-faces, and an inversion effect (an indication of sensitivity to configural processing) can be found for non-face stimuli when participants show expertise in recognising them when upright (Rossion et al, 2002).

The N1 is also sensitive to spatial attention (Hillyard et al, 1998; Mangun, 1995). The time window of the N1 will also be examined in the experiments in this thesis.

N2 family

These relate to the negative-going wave in the time window of 200-350 ms. There are two subcomponents of the N2 that are of interest to this thesis, the N2pc and the N250. The N2pc is named for the posterior contralateral negativity that occurs in the time window of 200-300 ms. The N2pc is elicited when spatial attention is allocated to one visual field (Luck & Hillyard, 1994). The voltage amplitude is more negative at the contralateral (compared to ipsilateral) electrode site to the visual field at which spatial attention has been allocated. In the presentation displays used in the research work of this thesis the attended targets are presented to one or other side of the screen. Thus the N2pc will be used to examine the attentional demands in the studies presented here.

The N250 is the negative-going wave in the time window of about 180-290 ms at inferior temporal electrode locations. There is some debate as to the subdivision of this component (Martín-Loeches et al, 2005; Gosling & Eimer, 2011), and here the interest is in the ampltidue modulation within the time window of the N250r, which was identified by Schweinberger, Pickering, Burton and Kaufmann (2002) in response to the repetition of faces. The N250r is found to be maximal within the time window of around 220-290ms, at inferior temporal electrode locations. As the N250r has been found to be sensitive to repetitions of non-objects as well faces (e.g. Martín-Loeches et al, 2005) and further because it is sensitive to the view of the repeated image (e.g. Bindemann, Burton, Leuthold & Schweinberger, 2008) it will be investigated in the studies presented here.

P3 family

The P3 is a positive-going wave, between 250-500 ms, and is also made up of a number of ERP components (Luck, 2005), sensitive to the probability of a target item appearing within a train of non-targets. Thus, it is often investigated using an‘oddball’ paradigm in which the ERP elicited to infrequent targets is compared to frequent non-targets. As the frequency of target stimuli is the same for all targets in the experiments of this thesis, the P3 will not be investigated here.

2.2. Review of ERP in Object Recognition and Spatial Attention

The previous discussion of the most well known visual ERP components (Luck, 2005) has identified the P1, N1 (N170), N2pc and N250 as relevant to the research work presented here. As described in Chapter 1, behavioural tests of the nature of the recognition of unattended objects have examined the effects of view and perceptual load priming in a short-lag repetition-priming paradigm. Therefore, in order to formulate the specific ERP predictions for the experiments of the present thesis, it is necessary to identify the sensitivity of the ERP components to the factors of load, view and repetition. Specifically, it is necessary to consider what effect on the waveform, that is, direction of amplitude change or change in component latency, is predicted from a change in each experimental factor. These ERP effects need to be defined in terms of their time windows in the waveform and the electrode sites at which they will be observed.

The short-lag repetition-priming paradigm provides the opportunity to investigate ERP time-locked to the initial prime presentation as well as to the probe presentation. The prime-locked ERP provide insight into the levels of object processing and attentional allocation associated with the initial prime presentation. That is, by testing for effects of view, the amount of object processing associated with the different displays can be inferred. Testing for effect of view at the prime presentation, serves as a check of the manipulation of perceptual load. For example, if load is not found to have an effect at the probe, but effects are found at the prime, this would mean that the repetition effects are robust to the effects of load. Testing whether certain displays promote more or less attentional allocation will inform the effectiveness of the spatial cuing and perceptual load controls on spatial attention.

The probe-locked ERP, however, will be the main interest of this thesis. The presence of a repetition effect requires that the prime has been processed in order to cause the difference between repeated and unrepeated conditions. By examining the modulation of such repetition effects by view it will be possible to test view-dependent and view-independent models of object recognition. That is, the effects of view and perceptual load will inform the type of object representation that is employed and under what attentional conditions.

Therefore, the first part of the following review of ERP literature[5] identifies those ERP components that are sensitive to view and load, and how these factors modulate the waveform. These are relevant for the examination of the prime-locked ERP. The second part of the review concerns the probe-locked ERP components, which must be sensitive to repetition, and the expected amplitude modulation on the waveform upon repetition identified. In order to use these ERP repetition effects to test the hybrid model and perceptual load theory, the interactions between View x Repetition, Load x Repetition, and Load x View x Repetition must be examined. Therefore, the last part of the review discusses those studies that have examined the effects of view and load on repetition effects.

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[5] This review focuses on non-face objects, although some studies from face-processing literature will be discussed where similar effects have been found to those using non-face stimuli.

2.2.1 ERP and Object Processing

Effects of View

The effect of the view of an object upon the ERP waveform can inform the timeline of object recognition, as demonstrated by the study of Schendan and Lucia (2010). This study is discussed in order to identify view-sensitive components and their modulation with view.

Schendan and Lucia (2010) investigated the time course of object recognition in their combined ERP/fMRI study. Participants were asked to categorise intact (vs. scrambled) images of familiar objects. By comparing the response to intact vs. scrambled images, the time course of the activation of object-sensitive cortical regions was examined. Schendan and Lucia (2010) thus used this measure to test their two-state interactive account of visual object cognition (Schendan & Kutas, 2007). In this account, the object-sensitive region (that is a region responding more to an object than to its scrambled version) is activated not only by a feed-forward, hierarchical activation, but also by feedback and recurrent processing. This account proposes that object-sensitive areas are activated in functionally different states, and that the time at which the processing in each state occurs is determined by either the activation of object representation or visual knowledge such as category membership. State 1 occurs before 200 ms and State 2 occurs after 200 ms. Taking the results of the studies (Schendan & Kutas, 2007, and Schendan & Lucia 2010) together, Schendan and Lucia proposed that very early figure-ground effects were observed between 95-175 ms, reflected by the P150-N170 complex. This was associated with fast feed-forward lower order image classification, sensitive to global shape but not local contours and influencing perceptual grouping (Schendan & Kutas, 2007).

Schendan and Lucia (2010) also identified an intermediate perceptual grouping stage 200-300 ms, during which the right occipito-temporal P200 was smaller for intact vs. scrambled objects, indicating view-sensitivity for object-sensitive regions. They also identified a fronto-central N3 complex (200-500 ms) implicated in cognitive decisions regarding objects. After 500 ms Schendan and Kutas (2007) identified what they termed a ‘truly’ post-perceptual stage, during a late positive complex (LPC).

Thus, they took these as support for their two-stage model of object-recognition, describing the period between 95-500 ms as displaying a posterior object sensitivity associated with "successively unfolding, temporally overlapping processes from figure-ground segregation to perceptual grouping and cognitive decision-related processes (e.g. object individuation, model selection, decision, naming) that are achieved more for intact known objects than uncategorizable, phase scrambled versions" (Schendan & Lucia, 2010, p. 136).

Itier and Taylor (2004) examined the effect of configural changes to face stimuli on both the amplitude and the latencies of the P1 and N1, using a comparison between upright, inverted and contrast-reversed faces. They found that inverted faces resulted in enhanced and delayed the peaks of the P1, N1 compared to upright faces. However, for contrast-reversed faces, the pattern was different for the P1 and N1. The P1 peak was not delayed with respect to upright faces, whereas the N1 peak was both delayed and enhanced. Itier and Taylor suggested that this demonstrated a very early distinction between types of configural change, with face-processing starting at around 100-120 ms, but that identity processing only started at about 170 ms.

In summary, the earliest view-sensitive components were therefore the P1, and P150-N170. The occipito-temporal N170 (145-195 ms) was enhanced for intact compared to scrambled images. The N170 has been associated with the processing of Stage 1 (of Schendan & Kutas’ model) and figure-ground effects, however the N170 has also been associated with the processing of the identity of faces. The right occipito-temporal P200 (200-300 ms) was also view-sensitive, and was smaller for intact vs. scrambled objects. The P200 was associated with an intermediate perceptual grouping stage.

Effects of Perceptual Load

The effect of perceptual load upon the ERP waveform can inform on the timeline of attentional selection. The studies described below indicate that perceptual load affects the

ERP early in the time windows of the P1 and N1 that were associated with the perceptual processing stage in Schendan and Kutas' (2007) two-stage model described above.

For example, in their ERP study, Handy and Mangun (2000) linked perceptual load to spatial selection. Participants were cued to a location to one side of the display and had to identify a letter ('A' or 'H') subsequently presented at that location. In low load, the identity of the letter was clear, however, in high load, the top arms of the 'A' were separated to make it appear more like an 'H' and those of the 'H' were pulled together to make it appear more like an 'A'. Handy and Mangun found that both the occipito-temporal P1 and N1 were enhanced in amplitude for low vs. high load. The change in P1 was associated with a measure of the suppression of distractor information and in N1 with a measure of the facilitation at the attended location (Luck, 1995).

Handy and Mangun (2000) also suggested that it was not just load that determines early selection, referring specifically to location expectancy as another relevant factor in their study. The influence of stimulus-relevance on the modulation of perceptual load on the P1 and N1 was examined by Rorden, Guerrini, Swainson, Lazzeri and Baylis (2008). In their study, perceptual load was manipulated by the use of a size-judgement task. The perceptual load display was the outline of a diamond shape with gaps in each of the sides. Participants were asked to judge which of the gaps on opposite sides of the diagonal (the comparison gaps were pre-cued by an arrow pointing to those sides) was the larger. Infrequent, irrelevant, distractor coloured circles were presented as interrupting stimuli, which participants were asked to ignore. Effects of load and stimulus relevance (target vs. distractor) were seen at the P1 and N1. The effects on the P1 did not reach statistical significance, although numerically the P1 was enhanced by low vs. high load at the occipital (O1/2) sites, as reported by Handy et al (2001). Therefore, Rorden et al suggested that perceptual load in this case did not result in selective attention. The enhancement of the N1 associated with high vs. low load at parietal (P7/8) and occipito-parietal (PO7/8) sites was modulated by the relevance of the visual information present. That is, the N1 was enhanced for high vs. low load for relevant stimuli, and vice versa for irrelevant stimuli. They concluded that this was as predicted by perceptual load theory and that the amplitude of the N1 indicated the level of perceptual processing. Further, they suggested that as the target and distractors were never shown simultaneously in their study, that inhibition was never necessary and so would not influence their results.

Fu and colleagues who have investigated the effect of perceptual load on voluntary (2008) and involuntary (2009) attention and found effects at different time windows for each. In the study by Fu et al (2008) participants were asked to direct their attention to a target in one visual field and to ignore the distractor in the opposite visual field, thus instigating voluntary attention. Fu et al found that the posterior N1 (190 ms) was enhanced for attended vs. unattended stimuli and that this was modulated by an interaction with load such that the attention effect was greater for high vs. low load. This was localised to the temporo-parietal-occipital gyrus.

In contrast, Fu et al (2009), using similar stimuli to the previous study, but with a location cue that could be valid or invalid (or not followed by a target), observed modulation for the C1 (80ms) and P1m (108-140ms) by involuntary attention. The P1m (greatest at CPz) was enhanced for invalid vs. valid trials and this effect increased with perceptual load. The C1 (greatest at Pz) was enhanced for valid vs. invalid trials for high load, with the difference decreasing with decreasing load. They took this as support for the earlier perceptual gating under high load and that different neural mechanisms underlie voluntary and involuntary attention.

The above studies investigated the effects of perceptual load on the early components C1, P1 and N1. The study of Martinovic, Gruber, Ohla & Müller (2009) also investigated later components in time windows later than 200 ms. In Martinovic et al's study spatial attention was controlled via perceptual load and examined the recognition of objects at the unattended location. It was assumed that familiar objects would elicit recognition in contrast to unfamiliar (nonsense) objects. The study was primarily an investigation of the oscillatory activity of neurons with respect to object recognition[6]. However, Martinovic et al did also derive ERP to examine the effect of attention on the P1 (80-120 ms) and N1

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[6] As EEG measures the synchronous activation of neurons, this can also be interpreted in terms of the frequency of oscillations, in this case in the gamma-band (40 Hz), instead of ERP, which do not take into account this frequency information (Martinovic et al, 2009).
Martinovic et al (2009) examined gamma-band activity (GBA) that was induced (not time- nor phase- locked) and evoked (both time- and phase- locked to stimulus onset). Induced GBA in particular has been linked to the identification of objects and representational processing in visual memory (Gruber & Muller, 2005; Gruber, Malinowski & Muller, 2004).

(130-190 ms) components as well as on two late time windows L1 (200-370 ms) and L2 (480-600 ms). In their experiment a load display was superimposed on an image of either a familiar or unfamiliar (nonsense) picture. The load task comprised a display of three boxes one above the two others in a pyramid configuration. Participants were required to match the contents of the upper box with that shown in one of the two lower boxes. In the low load condition all three boxes contained a line form. In the high load condition, the upper box contained a line form and the lower boxes contained letters. Participants had to match the line form to the letter containing that form. Martinovic et al found that the P1 was maximal for occipital sites and indicated a main effect of familiarity. This familiarity effect implied the recognition of the unattended objects (regardless of load). This is in contrast to the predictions of perceptual load theory in which recognition of irrelevant images only occurs under low load. No effects were found for the N1. Load effects were seen later for the L1 time window, which showed more positive amplitudes for high vs. low load. There was also a significant main effect of familiarity at this time window, showing more positive amplitudes for unfamiliar vs. familiar objects. The factors of load and familiarity did not show a significant interaction. Finally, by the L2 time window, there was only a significant effect of load such that the amplitude was more positive for high vs. low load. There was no significant effect of familiarity at this time window. Taken together, these indicate that the effect of familiarity (seen for the P1 and L1) preceded that of load (seen for the L1 and L2) in the ERP timeline, and that these factors did not significantly interact at any stage.

In summary, the studies above have demonstrated effects of perceptual load on the amplitude of the occipito-temporal P1 and N1 (both enhanced in high vs. low load). These are early ERP components associated with the perceptual stage of Schendan and Kutas’ (2007) two-stage model of object recognition. However, whether load effects are manifested at the P1 or N1 is dependent on a number of factors such as location expectancy, stimulus-relevance, voluntary or involuntary attention. The effect of perceptual load has also been observed at the later time windows of L1 (200-370 ms) at occipital sites and L2 (480-600 ms) at parietal sites in the study of Martinovic et al (2009). For both the L1 and L2 time windows, the amplitudes were more positive for high vs. low load.

Allocation of Spatial Attention: The N2pc component

Although both spatial cuing and perceptual load will be used in the current work in order to control spatial attention, another component, the posterior-contralateral N2pc, will be examined as an indicator of the difference in allocation of spatial attention at the target due to the presentation condition of the distractor image (Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999).

The N2pc is described by an enhanced negativity in the contralateral relative to ipsilateral sites to the visual field at which attention is directed (and the target located). Typically, investigations of the N2pc involve a visual search task in which a target is presented in one visual field amongst an array of non-targets.

Whether the N2pc indexes attentional selectivity or distractor suppression is still not completely resolved. Support for the N2pc indexing the suppression of interfering distractors has been found from studies demonstrating that the N2pc increases with the number of distractors (Luck, 1997), that the N2pc increases with the proximity of non-targets to the target (Luck 1997; Luck, 2005) and that the N2pc is eliminated in a case without any distractors (Luck & Hillyard, 1994). Also, it has been proposed (Duncan & Humphreys, 1989; Humphreys & Muller, 1993) that homogenous distractors can be segmented to a single unit, whereas heterogenous distractors intefere with segmentation and delay target selection. Therefore, under the suppression hypothesis heterogenous displays result in a larger N2pc.

However, other studies have demonstrated results inconsistent with the distractor suppression account. For example, Mazza et al (2009) found although heterogenous displays slowed behavioural RT, such displays did not increase the N2pc with respect to the homogenous displays. Mazza et al proposed that the N2pc is involved in allocating extra resources to the target hemifield in order to enhance feature processing. However, Kiss, van Velzen & Eimer (2008) indicated that the N2pc is not associated with the process of shifting attention and rather is associated with those spatially specific processes enhancing target feature processing. Further support for the attentional selectivity account has been found in the studies demonstrating that the N2pc has also been found not to depend on the number of distractors (Eimer, 1996). Mazza et al (2009) also examined the roles of distractor number, their proximity and homogeneity, arguing that their results support an attentional selectivity view.

Further complications in undertanding the nature of the N2pc come from the study of Eimer and Kiss (2010) who have demonstrated that attentional capture as indexed by the N2pc depends on top-down strategy rather than the bottom-up characteristics of a salient singleton. Therefore, in this thesis, the interest is not in whether the N2pc is elicited by target selection or distractor suppression, but rather its use as an indicator of attentional allocation. Specifically, by the examination of the difference in the size of the N2pc across different prime presentation conditions informs on the possible differences in distractor suppression required of the prime images.

One last study is mentioned here as it highlights that the N2pc is elicited even from involuntary selection of a target location, in a subliminal presentation (Astle, Nobre & Serif, 2010). Astle et al used a priming-type study and suggested that the N2pc was elicited from target location selection from a representation in visual short-term memory (VSTM). The first “memory array” consisted of two shapes in different visual fields. The second “test probe display” included one of the shapes repeated, thus driving involuntary attention to the location of that shape in the original memory array. They found that even subliminal presentation of the memory array elicited an N2pc (although there was no behavioural priming from it). This result supported that a subliminal presentation provided a topographic representation that can capture attention. Similarly, Eimer and Kiss (2010), using a cued visual search task, have also linked the N2pc to retinotopic visual working memory, and again, not just in maintaining the visual information, but also in access to the representations.

In summary, the N2pc has been associated with the allocation of spatial allocation to one or the other visual field (e.g. Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999). Although whether the N2pc indexes target selection or distractor suppression is still under debate, it has been shown that the N2pc indicates attentional capture to a spatial location even under subliminal presentation of the stimuli. The N2pc thus provides a useful test of the allocation of attention that is independent of the control of attention via either a spatial cue or perceptual load as implemented in the experimental studies of this thesis.

2.2.2 ERP Repetition Effects

The previous sections have described how view and load modulate ERP amplitudes. However, key to the research aim of the present thesis is how the factors of view and load modulate ERP repetition effects. Previously, the examination of the view- and load-sensitivity of behavioural priming has been used to test the hybrid model and perceptual load theory. The examination of the view- and load- sensitivity of ERP repetition effects will be used in a similar fashion here. Therefore, it was necessary in the first instance, to establish whether unattended familiar objects elicited ERP repetition effects.
There have not been many ERP studies to date investigating repetition effects from spatially unattended objects. Therefore, the next sub-sections are organised as follows. Firstly, the ERP repetition effects that have been observed from spatially attended objects are discussed in order to provide a guideline for finding repetition effects from unattended objects. The view-sensitivity of the repetition effects at the time windows thus identified is then discussed. This is followed by the discussion of the ERP repetition effects that have been found in masked studies and studies in which spatial attention is controlled via manipulation of perceptual load. These studies indicate that the ERP repetition effects from spatially attended and unattended objects are manifested at similar time windows and electrode sites and with a similar amplitude modulation with repetition. However, the view-sensitivity of the ERP repetition effects from unattended objects that is expected under the hybrid model and perceptual load theory has yet to be tested.

ERP Repetition Effects from Spatially Attended Objects

One ERP study that is of particular relevance to this thesis is the repetition-priming study Henson, Rylands, Ross, Vuilleumier and Rugg (2004). In their combined ERP/fMRI study, the stimuli comprised pictures of everyday objects, and participants performed the semantic task of responding whether the object presented could fit in a shoebox. Henson et al’s study was designed to examine the effect of the lag between prime- and probe-displays. Of particular relevance here are the findings for the immediate repetition condition where the lag between prime and probe was 2.28 s and only these short-lag results follow here. There was a significant repetition effect within the time window of the P120 (110–140 ms) manifested an enhanced P120 for repeated vs. unrepeated objects at occipito-temporal sites. However, Henson et al state that this should be treated as tentative due to the posthoc nature of the tests under which it was revealed. For the time window of the N170 (160-190 ms) the repetition effect was manifested by an enhanced N170 for occipito-temporal sites for repeated vs. unrepeated objects, which was accompanied by a positive deflection for repeated vs. unrepeated objects at left central sites. This effect on the N170 and its topography extended for the time window between 200-300 ms. For the time window between 400-600 ms (N400), repetition effects were observed that were reflected by a more positive amplitude for repeated vs. unrepeated objects, maximal at central sites. These N400 results were consistent with the time window for those found previously, e.g. Rugg and Doyle (1994) and Schweinberger et al (2002) who also observed more positive amplitudes for repeated vs. unrepeated stimuli for parietal sites.

Henson et al (2004) linked their earliest P120 repetition effect with a short-lived visual iconic store. The repetition effects between 160-190 ms (N170) did not differ in topography to those within the 200-300 ms time window. Thus Henson et al suggested that they might share neural generators. The repetition effects within the 200-300 ms time window were similar to those of the N250r. The N250r displays an increased negativity at inferior temporal sites for the immediate repetitions of faces between 180-290 ms, peaking at about 250 ms (Schweinberger, Huddy & Burton, 2004; Schweinberger et al, 2002). Thus, Henson et al considered that their N170 repetition effects reflected the earlier onset of the same neural generators that were involved with the repetition effects seen between 200-300 ms. They also noted that these latter repetition effects were also consistent with the ‘Ncl’, which is the component identified by Doniger et al (2000) described by an increased negativity at occipital sites which onsets at about 230 ms and peaks at about 290 ms.

In Doniger et al’s study, the Ncl was found to be maximal when participants were able to identify gradually less fragmented images and was thus associated with the explicit identification of an object. When objects were repeated across trials in a later study (Doniger et al, 2001), repetition effects were found for the N1 that shared topography with those for the Ncl. This result of shared topography of those repetition effects was similar to those of Henson et al (2004), and Henson et al therefore suggested that repetition produced the earlier recognition of objects than when presented without a prime.

Thus, in Henson et al’s (2004) study of the ERP repetition effects from spatially attended familiar objects, in the short-lag condition of the repetiton-priming paradigm, repetition effects were observed from the time windows of the P1, N1 (N170), N250r and N400. These were observed at posterior occipito-temporal and parietal sites. The tentative P1 was enhanced with repetition. The N1 and N250 were also enhanced by repetition, and shared topography. The N400 had a different topography and the amplitude was more positive for repeated vs. unrepeated stimuli.

There are other studies that have investigated ERP repetition effects from attended objects, however, the Henson et al (2004) is the closest to the paradigms used in this thesis. Studies using long-lag repetition priming have also observed repetition effects at similar time windows, however, these have shown the opposite direction of amplitude modulation to short-lag studies (e.g. Itier & Taylor, 2004). Other short-lag repetition-priming studies on face processing have found different results for the repetition effects on N170 and N250r. For example, in the study of Schweinberger et al (2002), repetition effects were only observed for the inferior-temporal N250r (enhanced for repeated vs. unrepeated faces) and not for the lateral occipito-temporal N170. Further, Schweinberger, Kaufmann, Moratti, Keil and Burton (2007) compared the N170 and N250r with their MEG analogues the M170 (Harris et al., 2005; Itier et al., 2006; Liu et al., 2002) and M250r. The M170 and M250r were localised to different cortical regions (M170 at occipito-temporal regions and the M250r at fusiform gyrus). The results of Schweinberger et al (2002, 2007) therefore make it difficult to predict whether repetition effects will be observed in the time windows of the N170 or the N250r for non-face objects.

The N250r has been observed for studies involving non-face stimuli. For example, Engst et al (2006) found that the N250r was elicited for familiar buildings (although smaller) as well as for faces, and that the associated scalp topography (and thus the neural generators) was not significantly different for the different types of stimuli.

The N250r has also been found for black and white photos of non-face objects and related to the early recognition potential (ERE) and compared to the recognition potential (RP) by Martín-Loeches et al (2005). In their study, the ERE and RP in response to object pictures and names was compared. The ERE/N250r was observed for object pictures, at the right temporo-occipital (PO8), but was not observed for names, and thus Martín-Loeches et al concluded that the component was associated with post-perceptual, but pre-semantic processes. However, the authors also suggested that perceptual processes still influenced the ERE/N250r and associated the component with stored structural representations, as was also suggested by Engst et al (2006) and Pfutze, et al (2002).

In summary, the above studies have demonstrated that ERP repetition effects are observed at a number of time windows ranging from those of the P1, N1 (N170), N250r to the N400. Whether the N170 and N250r are face-specific is still a matter of debate. However, repetition effects have been observed at both the time windows of the N170 and N250r for non-face objects. Therefore, the investigation of repetition effects in this thesis will focus on the time windows of the P1, N1 (N170) and N250r[7]. The study that provides the closest comparison to the short-lag repetition-priming experiments of this thesis is that of Henson et al (2004). Thus, it is expected repetition will result in enhanced amplitudes of the P1, N1 and N250r at posterior parietal, occipito-parietal and occipito-temporal sites.

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[7] The N400 is not examined in this thesis due to the timing of the mask after prime and probe onset which coincides with the time window of this component.

Influence of View on ERP Repetition Effects

As mentioned in Section 1.6, the repetition-priming paradigm is a useful tool in teasing apart perceptual vs. conceptual influences that result in the facilitation (priming) in recognising an object. These influences can be tested by manipulating the view of the prime and probe objects. In this thesis, the interest in the interaction between view and repetition is to test whether holistic or analytic processing is required to elicit a repetition effect, and whether the repetition effects from unattended objects can be associated with access to a stored representation in LTM rather than purely a match of low-level visual features (cf. Thoma et al, 2004).

Some examples of view-changes are those of scrambling an object image either such that it contains the same low-level characteristics but not in a recognisable form, or the object parts can be rearranged (as is the case with split images). Alternatively the image can be kept intact and its orientation changed (e.g. reflection, rotation). Scrambling and orientation changes affect how recognisable an object is. Scrambling an image to the extent of non-recognisability has been used to test whether ERP repetition effects are associated with recognition of objects (e.g. Zhang, Begleiter, Porjesz & Litke, 1997, described below). View-changes such as split images and orientation-changes have been used to test the holistic or analytic processing of objects by Hummel and colleagues.

Zhang et al (1997) linked their ERP repetition effects with the recognition of intact objects. They examined the difference in ERP amplitude between the repetition of line drawings of objects and words that were either presented 'intact' or 'scrambled'. The scrambled images were created by splitting the image into 169 squares and then randomly shuffling those elements. Participants were required to respond to whether they could recognise the stimuli or not ('yes' corresponded to intact objects, 'no' to scrambled, unrecognisable objects). For intact pictures, Zhang et al observed that that there was a positive deflection in the ERP for repeated vs. unrepeated with an onset of around 110 ms and which was maintained for around 600 ms. This was greatest in posterior (temporal and parietal) regions from 240 ms. The authors suggested that as ERP repetition effects were found only for familiar objects in a recognisable visual format, that the repetition effects were linked with recognition.

Components that have been linked to stored structural descriptions (and not purely low-level visual features) are those of the posterior N1 and N250r. For example, Penney, Mecklinger and Nessler (2001) compared the repetition of 2D images of ‘possible’ and ‘impossible’ (structurally unsound) 3D objects. Only the repetition of possible objects resulted in an enhanced N1, implying that access to the low-level information (matching) was not sufficient for repetition effects and that stored structural information was necessary to elicit repetition effects. Further evidence of structural processing during this time window can be seen from studies examining the N170 as an indicator of structural processing in faces (e.g. Eimer & McCarthy, 1999).

The N250 has also been associated with the access to stored representations by Itier and Taylor (2004) who compared learning effects on contrast-reversed, inverted and upright anonymous faces. Participants went through a learning phase in which they were presented with a target face ten times. In the test phase, participants were required to respond to the target face, which was presented 12 times in pseudorandom order amongst a series of 20 nontarget faces. Learning abolished differences in behavioural measures, however, ERP repetition effects were observed both for the N170 and N250. There was a reduced N170 for repeated vs. unrepeated faces, which the authors attributed to perceptual priming. There was also a repetition effect on the N250 such that the amplitude was more negative for repeated vs. unrepeated faces. This amplitude modulation was observed between 250-350 ms for upright faces, between 300-400 ms for inverted faces and between 250-400 ms for contrast-reversed faces. Itier and Taylor suggested that this reflected the increased difficulty in accessing the stored representation when for inverted or contrast-reversed faces compared to upright ones. The N250r has also been associated with the explicit recognition of a face (Gosling & Eimer, 2011) and not just structural encoding prior to recognition.

In a similar time window, the amplitude of the N250r has also been shown to display a degree of view-sensitivity. For example, in their short-lag repetition priming, Schweinberger et al (2002) observed that the N250r was larger for repetition of identical views of a celebrity compared to different pictures of the same celebrity.

Bindemann et al (2008) further investigated the link between the N250r and person identification and the possibility that a face-image might be primed without accessing the identity (FRU) of that person (Bindemann, Burton, & Jenkins, 2007). Therefore, in their (2008) study, they tested repetition effects from faces that had been stretched either horizontally or vertically (cf. behavioural study of Hole et al, 2002). The N250r was sensitive to stretching, but not eliminated by it. Thus Bindemann et al suggested that the N250r is not a direct index of the FRU, rather that it reflects the access to the stored representation to which the percept is compared. They suggested that the mechanism that allows recognition under stretching may be linked with that used to update existing person representations, for example, due to changes in appearance from aging (Burton, 2005). Bindemann et al also speculated that the flexibility in recognition based on information from a stretched face might also be seen in other non-face stimuli.

Zimmerman and Eimer (2013) also investigated the effect of repetitions of view-changed faces (front vs. profile) on the amplitude of the N250r. They also used probes larger than primes to avoid possible effects from visual overlap. It was observed that for trials with the same image, that the N250r was only present between 210-260 ms. However, for those trials in which the faces were repeated in a different view, the N250r was further sustained to 260-310 ms. Similar to Itier and Taylor (2004), Zimmerman and Eimer suggested that this might be due to the increased difficulty in matching faces when they were presented in a different view. Extending their analysis to the progression with time (learning) over the study, they found that the N250r was not found for view-changed repetitions for the first half of the study, but by the second half, the repetition effects appeared to be view-independent. They suggested that this might indicate that structural descriptions may have been acquired at this stage, or that associative links between the two view-specific pictorial representations might have been formed.

The work of Schendan and colleagues has used the interaction between view and repetition to examine the time course of object recognition. For example, Schendan and Kutas (2003) compared the ERP repetition effects from canonical vs. unusual views of everyday objects. The aim of their study was to test view-dependent vs. view-independent theories of object recognition. Participants first completed a study phase in which they were asked to name objects presented in either an unusual or canonical view. The test phase was an indirect memory test where participants were asked to name either previously learnt or different objects and then to discriminate whether they had seen them previously in the same or different view. In the first experiment all the test items were shown in an unusual view. In the second experiment all test items were shown in a canonical view. Taking the results of the experiments together, the first repetition effect observed was a more positive deflection for repeated vs. unrepeated objects for the fronto-central P150 (140-250 ms). This effect was smaller for different views of the same object, and therefore view-specific. The frontal N350 (250-400 ms) showed a less negative deflection for repeated vs. unrepeated objects, here the effect was smaller for the same view of the object, but still view-sensitive. After 700 ms, the repetition effects were no longer modulated by view. Schendan and Kutas (2003) proposed that the results agreed with partially view-invariant models of recognition, predicting larger repetition effects for the same rather than different views in the earlier, rather than later, stages of recognition. They also suggested that there are different networks for early and late repetition effects for different views.

A different view change investigated by Schendan and Kutas (2007) was of fragmented (contour-deleted) images (Gollin, 1960), which allowed the comparison of the effects of global shape to local contour information. Participants were shown the objects in either a fragmented or intact format during a study phase. During the following indirect memory test phase they were shown a fragmented image that was either identical to that previously studied, or its complementary version (Biederman & Cooper, 1991) or an unstudied item. They were asked first to categorise the object and then to rate their confidence for their correct response and finally to name the object. Schendan and Kutas (2007) found that, similar to their earlier study (Schendan & Kutas, 2003) the first repetition effect started at around 150 ms, which, in contrast to their previous findings (Schendan & Kutas, 2003), was associated with a frontocentral N350 that was less positive for unrepeated vs. repeated objects. They thus associated this with processing matching percepts to stored descriptions because the effect was present for objects with the same global, but not local features. Schendan and Kutas also found a repetition effect during the time window of 400-700 ms (N400, P600) taken as a late positive complex (LPC), which they associated with the process of mental rotation to accommodate view-change. Finally, a late slow wave (SW) between 700-850 ms showed a repetition effect that was stronger for different vs. same views of the object. This was linked to a possible organisation of items in working memory.

In summary, the work of Schendan and colleagues has demonstrated view-sensitive ERP repetition effects from the time window of the P150 through to that of the P600. They linked the repetition effects at the P150 with the match of the percepts global (as opposed local) features. Therefore, it is expected that the time windows chosen for the examination of repetition effects in the experiments in this thesis, the P1, N1 (N170) and N250r will be view-sensitive. The repetition effects in the time windows of the N1 (N170) and N250r have been associated with the access to stored structural descriptions. Therefore where repetition effects from unattended objects are observed for these time windows in the present research work, there is thus good support that they are associated with the recognition of unattended objects (as proposed by the hybrid model) rather than the low-level feature matching that could be achieved without recognition or attention.

ERP on Repetition Effects from Unattended Objects

In the above studies, all the stimuli have been attended, however, the aim of this thesis is to examine repetition effects from unattended objects. It is possible that the ERP repetition effects from attended objects would show a qualitative difference to those from unattended objects. In order to show that this is not the case, some studies that have investigated ERP repetition effects from unattended objects are reviewed here.

One method of rendering participants unaware (rather than strictly unattended) of a stimulus is through masking. Eddy, Schmid & Holcomb (2006) used pictures of common objects in a short-lag (50 ms) repetition paradigm, in which the prime images were masked, to examine the effects of feature, object and semantic differences on ERP repetition effects. Participants were required to perform a semantic categorisation task (food vs. non-food) and respond only on non-frequent food items. ERPs were time-locked to non-food items. Eddy et al found a repetition effect between 100-250 ms reflected by an enhanced P190 in the right hemisphere for repeated vs. unrepeated objects. At the occipital electrodes O1 and O2, this effect persisted through to 400 ms.

There was also an associated enhanced anterior negativity N190 for repeated vs. unrepeated objects. Following this (250-350ms) there was an enhanced anterior negativity for repeated vs. unrepeated objects, consistent with the N300. Later, within the 350-650 ms window, there was an enhanced N400 which was more widely distributed, but with a central/parietal focus, for unrepeated vs. repeated objects. Eddy et al suggested that based on previous research, the P/N190 effects could be attributed to feature overlap (Holcomb & Grainger, 2006; Petit et al 2006), the N300 to object-specific processing (McPherson & Holcomb, 1999) and the N400 to semantic processing (Holcomb & Grainger, 2006).

From Eddy et al's study then it would be expected that the ERP repetition effects from unattended objects will be observed in the time windows of the P190, N190, N300 and N400.

Effect of Load on ERP Repetition Effects

The masking of the primes in Eddy et al's (2006) study prevented the further visual processing of the prime images, and the speed of their presentation rendered the participants unaware of the presence of the images. However, the primes were presented at the location of spatial attention and thus it is difficult to class them as spatially unattended. The allocation of spatial attention can also be controlled via the manipulation of perceptual load (as discussed in Section 1.14). Indeed, this manipulation will be used in this thesis. Therefore it is necessary to identify repetition effects that have been observed to be modulated by load.

The ERP studies examining the effects of perceptual load on repetition effects have mainly been those of Schweinberger and colleagues in their investigations of the N250r. In their repetition priming study, Neumann, Mohamed & Schweinberger (2011) compared the effect of perceptual load on the ERP repetition effects for images of faces, houses and hands. A letter search (high or low load) was superimposed on the prime image and participants were required to respond to whether there was a 'X' or 'Z' present in the search array. Following this, the probe image was a repeated (identical) image, a non-repeated image, or an infrequent image of a butterfly. Here, participants were required to respond only to the infrequent images of butterflies. Neumann et al (2011) observed only a marginal effect of load within the time window of N170. Later, in the time window of the N400, robust effects of load were found, but only affecting the face-stimuli. They concluded that the repetition effect on the N250r that was seen for faces, but not modulated by load, indicated a face-specific attention module for the representation of faces.

In summary, ERP repetition effects have been found from 100-400 ms along the waveform for masked objects –thus assumed to be outside of subjective awareness. However, although ERP studies of perceptual load effects on ERP have indicated the load-sensitivity of the P1 and N1, the studies of load on repetition effects indicate that this is manifested later in the waveform at about 400 ms. Due to a lack of previous findings for the elimination of ERP repetition effects under conditions of high perceptual load, the effect of load will be examined at all the chosen time windows for repetition effects, those of the P1, N1 and N250r.

Thus far no known published studies have directly investigated the possible interaction between perceptual load and view on ERP repetition effects. The fMRI study of Bahrami et al (2008) did find orientation-dependence that was only observed under low load conditions for gratings stimuli that participants were unaware of (through the technique of binocular rivalry).

Table 2-1 shows the effects of repetition, view and load and their interactions on the ERP components, which have been selected for examination in this thesis based on the review above.

Table 2-1: Table of ERP components investigated in experiments of this thesis.

	ERP component				
Sensitivity of component	**P1**	**N1**	**N250**	**N2pc**	**N400 and later**
View	√ Schendan & Kutas (2003); Itier & Taylor (2004)	√ Schendan & Kutas (2003); Itier & Taylor (2004)			
Load	√ Handy & Mangun (2000); Fu et al (2009)	√ Handy & Mangun (2000); Fu et al (2008)	√ Martinovic et al (2009)	√ Luck & Hillyard (1994)	
Repetition	√ Henson et al (2004)	√ Henson et al (2004)	√ Henson et al (2004)		√ Henson et al (2004); Rugg & Doyle (2003)
View x Repetition	√ Schendan & Lucia (2010)	√ Schendan & Lucia (2010); Zhang et al (1997); Penney et al (2001)	√ Schendan & Lucia (2010); Bindemann et al (2008); Zimmerman & Eimer (2013)		
Load x Repetition	√ Neumann et al (2011)	√ Neumann et al (2011)			
View x Load x Repetition	No previous literature	No previous literature	No previous literature	No previous literature	No previous literature

2.3. Acquisition of EEG and General Methods for Thesis

2.3.1 Ethics

The University Research Ethics Committee at UEL granted ethical approval for all the experiments reported here. All participants were given an introduction to the experiment and details on participating in an EEG study. All gave written consent to participate in these studies. They were able to withdraw their participation at any time and were given a written debrief upon completion of the experiment. They were encouraged to ask any questions about the experiment at any time during the session and were given the researchers contact details in case questions arose after participation. Example introduction letters, consent forms and debrief are given in Appendix I.

2.3.2 Recording Procedures

ERPs represent a very small change in the recorded signal with respect to the large amount of noise associated with acquisition of the data. Therefore, it is necessary to average across many trials in order to improve the S/N. However, it is just as important to reduce noise during the acquisition of the data itself. Noise artifacts in the EEG signal (i.e. voltage changes that are not relevant to the experimental conditions) can result from the participant themselves, for example, from muscle activity or changes in the skin conductance from sweating, or from the testing environment through electrical interference. Electrical interference may arise from line noise from electrical equipment such as computer presentation monitors. To some extent artifacts can be reduced by instructing participants not to make extraneous movements, and allowing breaks in the experiment for their comfort. The testing environment can also be improved by ensuring it is at a comfortable temperature to prevent sweating, and also electrically insulating electrical cables and other equipment. However, persisting artifacts must be removed during the pre-processing stages of ERP analysis. Guidelines for ERP acquisition and analysis are given in Picton et al (2000); Luck, (2000).

In all of the experiments that required object naming, participants were asked to sub-vocally name the attended object and simultaneously respond with a button-press. This was in order to avoid the contamination of the ERP with the muscle artifacts associated with overt naming. Sub-vocal responses measured in this way have been shown to replicate patterns of behavioural priming (Thoma & Henson, 2011). The details of the acquisition and pre-processing for extraction of ERP specifically relevant for the research presented in this thesis are presented below.

Scalp coverage & Electrodes

EGI dense array Hydrocel Geosensor Nets (HGSN) were used for recording scalp potentials at 128 electrode locations. Each electrode consists of a Ag/AgCl sensor embedded in a sponge (Tucker, 1993) which is then soaked in an electrolyte solution of 1L water mixed with 5cc of Johnson's baby shampoo and 11g of KCl. The electrodes are held together in a net by elastomer threads, which provide an even coverage over the scalp. In order to ensure optimal contact between the electrode and scalp, any hair was moved from below electrodes using a pipette. Such electrodes provide a comfortable and easily administered measure for the participant, however, care must be taken to avoid bridging across electrodes. The impedance of each electrode was checked and ensured to be below 50 kΩ[8] during the testing session. In those cases where the impedance was higher, the hair below these electrodes was rearranged and the electrode sponge re-wetted. This re-wetting was also done at the breaks within the experimental tasks. Luck (2005) notes that skin potentials pose the greatest problem in using this type of electrode, suggesting that the experimental environment be at a comfortable temperature. Ferree suggests the use of a low frequency filter to remove such remaining artifacts. In this way other low frequency drifts such as the drying out of electrodes or slow changes in temperature leading to a change in impedance can also be removed.

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[8] The use of high input impedances in EEG measurement is discussed in Ferree et al (2001).

Amplification and Referencing

The amplifier used was a high impedance NetAmps 200 differential amplifier as described in Tucker (1993). In general, voltage is a potential difference between two sites and therefore voltage measurements are made in comparison to electrical ground. As it is dangerous to connect the participant directly to earth, a virtual ground is created in the amplifier against which a voltage measurement can be made. The active electrode refers to the site at which the measurement is made and the ground electrode is the virtual ground of the amplifier. However, a measurement based just on the difference between these electrodes would include the electrical activity at each location and also the noise inherent in the ground circuit of the amplifier. Therefore, a third reference electrode is required. The voltage between the reference-ground electrodes is subtracted from the voltage between the active-ground electrodes, cancelling the noise from the ground circuit, and it is this resultant difference that is amplified.

The best location of the reference electrode is of some debate (Luck, 2005). It should ideally be placed where there is minimal electrical activity and that serves as an equivalent comparison for the various locations of the active electrodes (e.g. not biased to one hemisphere) and for an equivalent comparison for the ERP from previous studies. Various locations are used for example the mastoid process behind each ear, or the ear lobes. Zhang et al (1997) have suggested that the Cz electrode is a better choice for the reference when testing visual object repetition priming, whereas the nose electrode is preferable for testing visual word priming. In this work, during recording, the relative voltage is measured at each active electrode with respect to a vertex electrode.

For subsequent off-line analyses, an average reference –the average of all electrodes on head- was used. The problems with such a reference are discussed in Luck (2005), one example being that the change in one electrode necessarily affects average and thus voltage at other electrodes. However, the high numbers of electrodes in a high-density array might alleviate reference bias problems (Dien, 1998) and an average reference is less likely to be affected by bias due to a specific location of a reference. Further, the accuracy of voltage measurement increases with number of electrodes and also the average over all electrodes provides a good approximation to the requirement that, by Gauss' law, the average voltage over the entire head should be zero.

Analogue to Digital (A/D) conversion and filtering.

The resolution of the amplifier determines the possible range of voltage changes that can be measured (too low a resolution can saturate if there is too great a change) and Luck recommends 12 bit resolution. The rate of A/D conversion is the 'sampling rate' i.e. how many data samples are recorded per second. In the research studies for this thesis a sampling rate of 500 Hz, was used, which therefore gives a measurement every 2 ms. Some filtering typically occurs on-line and can be set to 'accept' only those frequencies expected to lie within the region of interest for the experiment. In accordance with the guidelines of Picton et al (2000) a band-pass filter accepting only those frequencies between 0.1-200 Hz appropriate for a sampling rate of 500 Hz was used.

2.3.3 ERP Data Pre-Processing

During data acquisition all efforts are made to reduce artifacts from the electromagnetic environment and to some extent from the design of the study. However, unavoidable residual artifacts will remain due to, for example, participants blinking, eye-movements, sweating, moving, and line-noise. These artifacts must be detected and then either those trials removed from further analysis or corrected for in some way. This can be either by trial-by-trial detection in the time domain, or by using a technique such as Independent Components Analysis (ICA) to identify artifactual components, and therefore not lose whole trials. ICA is described in, for example, Makeig et al (1996) and is the method of deriving statistically independent latent components that could result in the measured EEG.

In this thesis, trial-by-trial detection based on automated procedures as outlined below and followed by visual inspection was used. Trials that included artifacts were excluded from further analysis, as were the data of any participants with less than 66% 'good' trials, based on the criteria of Picton et al (2000). Following the removal of artifact-contaminated trials, the trials in each condition were then averaged to further enhance the signal relative to noise (by removing random noise). The basic workflow for ERP extraction used in this thesis is outlined below. The EGI (Eugene, USA) analysis software Netstation (NS) v.4.2.4 was used.

Off-line filtering

ERP frequencies of interest are typically those less than 30 Hz (Luck, 2005). In this thesis a low-pass 30 Hz filter was applied on the raw signal using the EGI NS filter.

Segmentation

For each experimental condition and event to which an ERP was time-locked (the prime or probe onset here), a segment of the EEG recording of 200 ms before the event and 800 ms after the event was determined. The data were thus segmented using the automated procedure provided by the EGI NS software (Segmentation Tool).

Artifact Detection

An automated procedure was implemented to detect eye-movements, blinks and bad channels as provided by the EGI NS software. The ocular artifacts were detected by an amplitude difference of 55 µV for a moving average window of 80ms for an eye-movement and an amplitude difference 140 µV for a moving average window of 80 ms for an eye-blink in the EOG channels. Any segments with more than 10 channels marked as ‘bad’ (amplitude difference of 200 µV for a moving average of 80 ms, or if more than 20% of the recording was marked ‘bad’) were also excluded from subsequent analysis.

Bad channel replacement

The default EGI algorithm (Bad Channel Replacement) was used to replace the signal from bad channels by and interpolation of the signal from neighbouring electrodes to the bad channel was used (as also described in Mercure, Cohen Kadosh & Johnson, 2011).

Averaging

Averaging the trials for each condition will improve the signal to noise ratio, assuming that only the signal is time-locked to the stimulus, whereas the noise will be stochastic. It is also assumed that the signal will be the same across all trials of the same condition, despite differences in, for example, latency jitter. The ratio of signal to noise (S/N) improves as the inverse number of trials squared.

Re-referencing (montage operation)

As mentioned above an average reference was used for the data analysis for this thesis. The voltages at each electrode location was thus calculated and then allocated to the 10-20 standard electrode montage.

Baseline correction

The baseline signal before presentation of the stimulus was calculated from the 100 ms immediately previous to the stimulus onset. The voltage difference from the baseline was then calculated from the point on stimulus onset.

Grand Average

The grand average ERP is the average across all participants for each condition and can be represented graphically by either the waveform at a particular electrode location or as a topographic map over the scalp. It must be noted that specific values taken from the grand average peaks will not match those from the average of the peaks from individual participants due to the way these are calculated. That is, there will be individual variability in the latency of a given peak that is not reflected by the average of those peak measurements. However, the grand averaged waveform reflects the averaged amplitude across participants at each time point. For an extreme example, consider the case of two participants who show the same amplitude positive voltage peak, but with different latencies. The average of their peak measurements will result in a positive voltage. However, if the latency of the positive amplitude peak for one participant is delayed and coincides with the latency of a negative amplitude peak for the other participant, the grand averaged waveform at that time point will show an amplitude that is nearer to zero.

2.3.4 Statistical Analysis

Although there are many ways to interpret EEG/ERP data, the method recommended by Luck (2005) to identify known components that have previously been shown to change with the experimental conditions of interest was used here. Therefore, the change in specific components within a certain time-window and at a particular scalp location previously associated with the effects of repetition, view and load were examined.

Choice of scalp location

The posterior locations, associated with visual processing, and the components of interest that were chosen for analyses were the parietal P7 and P8, occipito-parietal PO7 and PO8 and occipital O1 and O2 locations as defined by the 10-20 system. These are the electrodes numbered 58, 96, 65, 90, 70 and 83 in the 128-channel EGI HGSN net respectively and are shown in Figure 2-5.

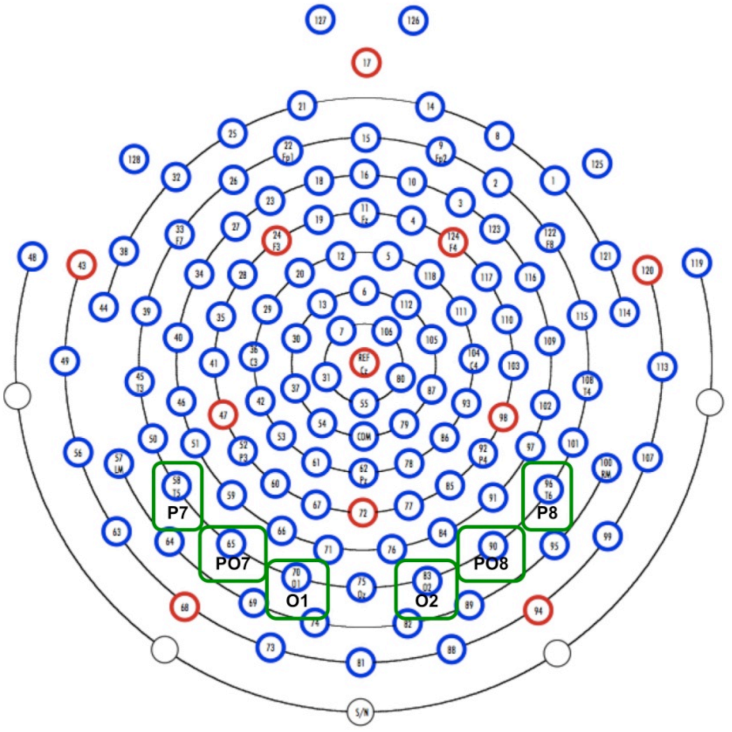

Figure 2-5: The electrode locations of the 128-channel HGSN net and the electrodes chosen for the analyses in this thesis.

Choice of time window

Based on previous research as a guide, the grand-averaged waveform was inspected to choose a time window for each peak for the component of interest, avoiding overlap with other components' peaks. The waveforms of individual participants were then examined to ensure that the time window was appropriate for all participants' data.

Average Peak Measurement

Handy (2004) and Luck (2005) discuss the issues with the choice of a peak measurement, either by the peak voltage value, or by an average of the voltage around the peak over a given time window. Luck (p.52) states that “peaks and components are not the same thing”, peaks possibly comprising many latent components.

Here a ‘peak-picking’ algorithm (‘adaptive peak’ in the ‘statistical extraction’ tool of the NS software) in which the peak voltage was found within a given time-window was used. The average of the voltage within 20 ms either side of that peak was then calculated over all trials for each participant. This allowed both the extraction of the amplitude changes according to condition and also the latency of those peaks, but was not as restrictive as using a single peak voltage value.

Statistical Approach

The data (reaction times, accuracies, ERP amplitudes and eye-fixations) relevant to each experiment were subjected to within-participants ANOVAs as appropriate for each experiment (and described specifically in each experimental chapter). For all ERP experiments, Greenhouse-Geisser corrected *p*-values are reported.

Across experiments, either key main effects and/or interactions are predicted, according to theory or previous observations. In the case of the predicted interactions according to theory between repetition, view and/or load factors (each with 2 levels), simple effect follow-up analyses centred on planned comparisons. Following Howell (2009), an alpha level of .05 (one or two tailed appropriately) was used for planned comparisons, providing these were limited in number. Where an interaction involving the key factors fails to reach conventional levels of significance, Howell has noted that it can still be acceptable to perform key planned comparisons, and hence this approach was adopted. Where significant interactions were revealed that do not involve the key factors of repetition, view or load, but instead only involve hemisphere or electrode site, then the follow up analyses employed a Bonferroni correction.

Chapter 3. Experiment 1: ERP Repetition Effects from Spatially Unattended Objects

3.1. Introduction

Research into whether it is possible to visually recognise an object without paying attention to it has produced mixed results. On one hand, there is evidence for high-level recognition from (response) interference paradigms and positive and negative priming tasks (e.g. de Schepper & Treisman 1996; Tipper 1985, Driver, 2001; Tipper 1985; Tipper & Driver 1988; Leek et al, 2009). On the other hand, it has also been shown that unattended words do not show reliable effects of perceptual implicit memory (Crabb & Dark, 1999), and that unattended objects do not result in either behavioural priming or BOLD repetition suppression (Eger, Henson, Driver & Dolan, 2004). The controversy over whether unattended objects are recognised has been reviewed in Lachter et al (2004, see Section 1.13).

Whether unattended objects are recognised has implications for object recognition models. In such models the way in which an object is internally represented is determined by whether it has been attended to or not (Treisman & Gelade, 1980; Hummel, 2013). The role of attention in a range of influential models for binding an objects component parts and their locations into a description of that object in long-term memory was discussed in Section 1.10. Without attention, an object’s representation is restricted to that using static binding between its component parts and spatial relations, that is, the view of the object is directly encoded all in one (Hummel, 2013). Conversely, with attention, an object’s representation is based upon the dynamic binding between its component parts and spatial relations, that is, the parts and relations are independently encoded in an abstract form. The viewpoint debate has divided theories of object recognition into those that rely on either holistic or analytic representation (Hummel, 2013). However, one resolution to the viewpoint debate is the hybrid model of object recognition (Hummel, 2001), which accommodates both types of representation in parallel routes for recognition modulated by attention. The holistic route of the hybrid model allows object processing without attention, and therefore repetition effects are predicted for unattended objects. Behavioural priming has been previously observed from spatially unattended objects and this has been taken as support that holistic representation that does not require attention, consistent with the hybrid model (e.g. Stankiewicz & Hummel, 1998, 2002; Thoma et al, 2004, 2007).

The aim of Experiment 1 was to establish whether ERP repetition effects from unattended objects are observed in a short-lag repetition-priming paradigm, in line with the findings of behavioural priming from unattended objects reported in the studies of Hummel and colleagues. Experiment 1 thus adapted the repetition paradigm that was originally used by Stankiewicz and Hummel (2002) to test the view-invariance of priming via the holistic route, first to translation (Experiment 1) and then to scale (Experiment 2). Stankiewicz and Hummel (2002) used a spatially cued, short-lag repetition-priming paradigm, and measured the behavioural priming which was operationalised as the difference between naming response time for previously seen, primed, and unseen, unprimed, images. In their Experiment 1, trials began with a central fixation circle, followed by a dot acting as a spatial precue in one of the four quadrants of the screen. The prime presentation followed, comprising two images, one of which was displayed at the same location as the precue (and thus attended). The other image was displayed at the opposite corner (and thus unattended). Participants were required to name the attended object, and the objects were masked. Following that, 3 seconds after the prime display, the probe display was presented, which comprised one image that was either one of the objects shown at the prime display or a different, previously unseen, object. The probe object was shown in one of the four quadrants, and participants were required to name this object. In Stankiewicz and Hummel's (2002) Experiment 1, the primes and probes were identical images. Their results showed priming of the order of 250 ms for both attended-identical and attended-translated conditions and of the order of 50 ms for both unattended-identical and unattended-translated conditions. That is, translation did not have an effect on the amount of priming either from attended or unattended images. In their Experiment 2, the probes were either identical to the primes or scaled to twice the size of the primes. Also, only two possible presentations were used (either to the left or right side of the screen as opposed to the four quadrants used in Experiment 1). Probes were shown at the centre of the screen. They found that not only did spatially attended and unattended primes result in a similar priming pattern as in Experiment 1, but also, importantly there was no effect of scaling: both identical and scaled images produced similar priming within the attended and unattended conditions. Experiment 1 of this thesis adapted the paradigm used in Experiment 2 of Hummel and Stankiewicz's study for an ERP measurement. However, the current study only examined the unattended objects and did not have a factor of attention as did their original study. Here, as in Stankiewicz and Hummel's study, presenting the probe image as twice the size of the original prime image, tested not only that recognition was robust to scale change, but that recognition (here indexed by the ERP repetition effects) reflected the access to representations in LTM and ensured that any effect upon repetition was not solely due to simple low-level visual processing from pixel-to-pixel overlap (this argument for scaled probes has also been given by Bindemann et al., 2008, and Zimmerman & Eimer, 2013).

Repetition effects in ERP from attended objects have been observed previously at a number of time windows, as discussed in Section 2.2.2. These are manifested as amplitude deflections in the time window of the N1 (and N170 for faces Caharel, Jacques, d'Arripe, Raman & Rossion 2009; Kovacs et al, 2006), and such effects have been associated with recognition at the level of the identity of individuals (Itier & Taylor, 2002; 2004; Tanaka, Luu, Weisbrod & Kiefer, 1999). Repetition effects for the N250 have also been associated with identity and access to stored structural descriptions in long-term memory (Martín-Loeches et al, 2005). For short-lags between prime and probe presentation as used in this current study, it has been shown that repetition results in an increased negativity at posterior sites, for both the time windows of the N1 and N250r components (Henson et al, 2004). Repetition effects have also been observed in some studies in the time window of the P1 and these have been associated with low-level visual feature matching (e.g. Eddy et al, 2006; Rossion, 2014; Rossion and Caharel, 2011) and also more holistic, global properties of the image (Boutsen et al, 2006). These time windows of the P1, N1 and N250 guide the choice of time windows for the investigation here.

The two experimental conditions for Experiment 1 were whether the prime image was repeated or unrepeated. The probe image was always scaled to double the size as the prime image. The dependent variables were the ERP amplitude of the probe-locked P1 and N1 components, and the mean amplitude of the N250 component. The naming response times at prime and probe were also recorded.

According to Hummel's hybrid theory of object recognition, short-lag repetition effects are expected for object images even when they are spatially unattended. These are expected to be resistant to a scale-change between prime and probe. In this short-lag repetition priming study, these repetition effects are expected to be manifested in the ERP waveform from the time window of the N1 as a more negative deflection in amplitude for repeated vs. unrepeated objects (as guided by the study by Henson et al, 2004).

3.2. Participants

The 19 right-handed participants tested all reported normal or normal-to-corrected vision and were native English speakers. They received either course credits or £15 worth of high street shopping vouchers for their time. However, due to insufficient numbers of artifact-free trials (less than 60%), three participants' data were excluded from further analysis. The remaining 16 participants (10 female) were aged between 19-41 years (*M* = 22.0 years, *SD* = 6.74).

3.3. Stimuli & Design

The stimuli were 150 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), and Cycowicz, Friedman and Rothstein (1997). The two experimental conditions were (1) repeated and (2) unrepeated. There were 30 trials in each of the repeated and unrepeated conditions, giving a total of 60 trials. Each trial included a prime display, comprising two images, one which was cued and attended and one which was uncued and unattended. This was followed by a probe display comprising one image. For the repeated condition the probe image was the same object as the unattended prime image. For the unrepeated condition the probe image was a different object to both the unattended and attended images in the prime presentation. All of the probes, whether repeated or not, were scaled to twice the size of the prime images. The experimental conditions and corresponding prime and probe presentations are seen in Figure 3-1.

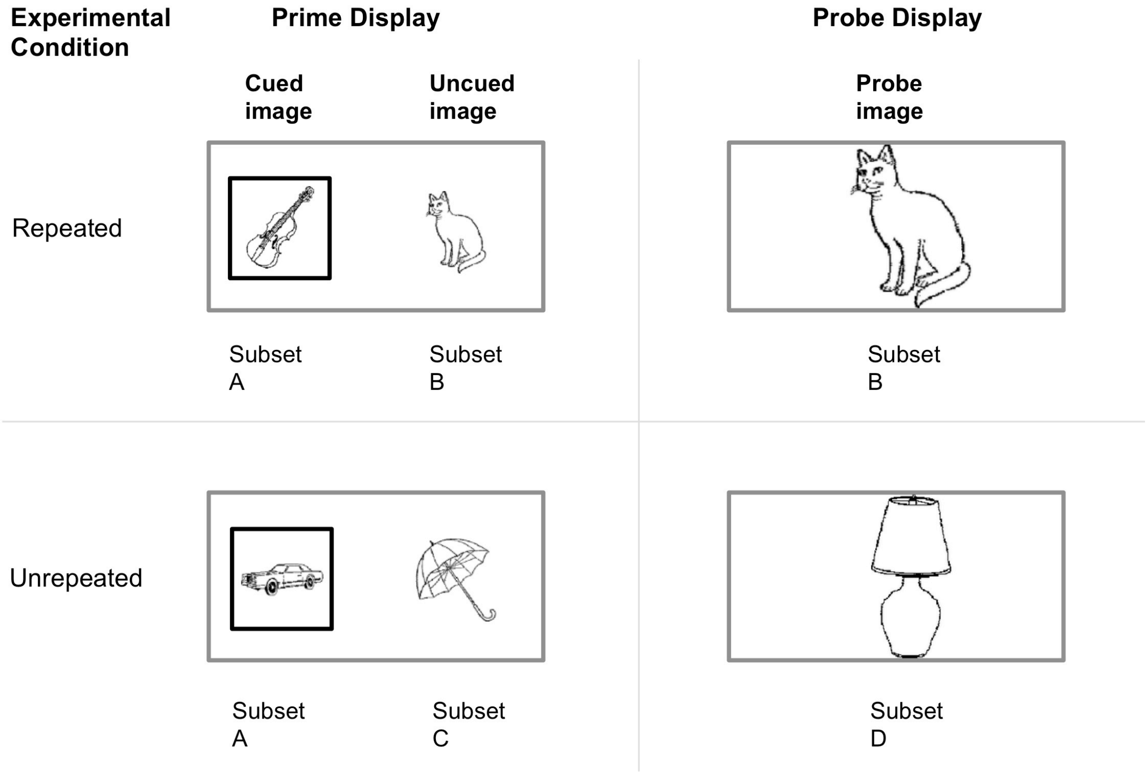

Figure 3-1: Schematic of conditions and stimulus subsets for the first participant in Experiment 1.

Each of the object stimuli was allocated to one of four subsets (A, B, C and D as also shown in Figure 3-1). Subset A contained 60 objects that were presented to all participants as cued (attended) images, i.e. all attended images were the same for all participants, and these occurred as randomly paired to unattended images. To ensure that all objects only appeared once for each participant and that all unattended objects appeared equally often as prime and probe in all conditions across participants, the subsets B, C, and D (each containing 30 objects), were counterbalanced in which condition they appeared across participants as shown in Table 3-1.

Table 3-1: Counterbalancing of object subsets for the first three participants in Experiment 1

Participant	Cued Image	Repeated condition: Object presented as both uncued prime and probe	Unrepeated condition: Object presented as uncued prime only (unprobed prime)	Unrepeated condition: Object presented as probe only (unprimed probe)
1	Subset A	Subset B	Subset C	Subset D
2	Subset A	Subset D	Subset B	Subset C
3	Subset A	Subset C	Subset D	Subset B

All images within each subset were presented in random order. Trials were presented on a 17 inch CRT monitor, and images were standardised to subtend 4.5˚ x 4.5˚ of visual angle at the prime display and 9˚ x 9˚ for the probe display. Stimulus presentation was controlled using a PC running E-prime v.1 (Psychology Software Tools, Pittsburgh, PA).

3.4. Procedure

An example trial sequence is shown in Figure 3-2. Each trial began with a central fixation cross presented for 495 ms, followed by a blank screen for 30 ms. A cuing square (4.57˚ x 4.57˚) was presented at a distance of 4.0˚ either to the left or right of the centre of the screen for 75 ms. Following this, the prime display was presented for 120 ms. This prime display consisted of two images: the attended image within the square and the unattended image equidistant to the other side of the screen. Participants were required to sub-vocally name the attended object and simultaneously respond with a button-press whenever they could name it. Such a sub-vocal response has been shown (Thoma & Henson, 2011) to replicate patterns of behavioural priming, and avoids the contamination of ERP with muscle artifacts associated with overt naming. Sub-vocal naming will be used for all of the repetition-priming experiments in this thesis. A blank screen was then presented for 30 ms followed by a visual random-line pattern mask (15.6˚ x 15.6˚)

covering the entire area of the screen for 495 ms. Following the mask, a blank screen was presented for 1995 ms to allow time for the participants response. This was followed by another central fixation cross presented for 495 ms and then a blank screen was presented for 30 ms. The probe display then followed, which comprised a single image – either the same as the unattended image (repeated) or a completely different image (unrepeated)- that was scaled to twice the size of the prime image, lasting 150 ms. The probe image was then masked (4.57˚ x 4.57˚) by showing a random-line pattern mask for 495 ms. This was followed by another blank screen for 2500 ms during which the participants response of sub-vocally naming the probe image via a button-press was recorded. The subsequent trial was delayed with a random jitter inter-stimulus interval (ISI) of 190, 390, 590 or 790 ms.

The experimental block followed a short practice block of 16 trials using different images to those used in the experimental block. During the practice block three catch-trials were also included at random, in which participants were asked to name the attended target and then the probe out aloud to ensure proper understanding of the task. They were told that this might happen at any time during the experimental block, however, only one catch-trial was actually included: it was always the last trial of the block.

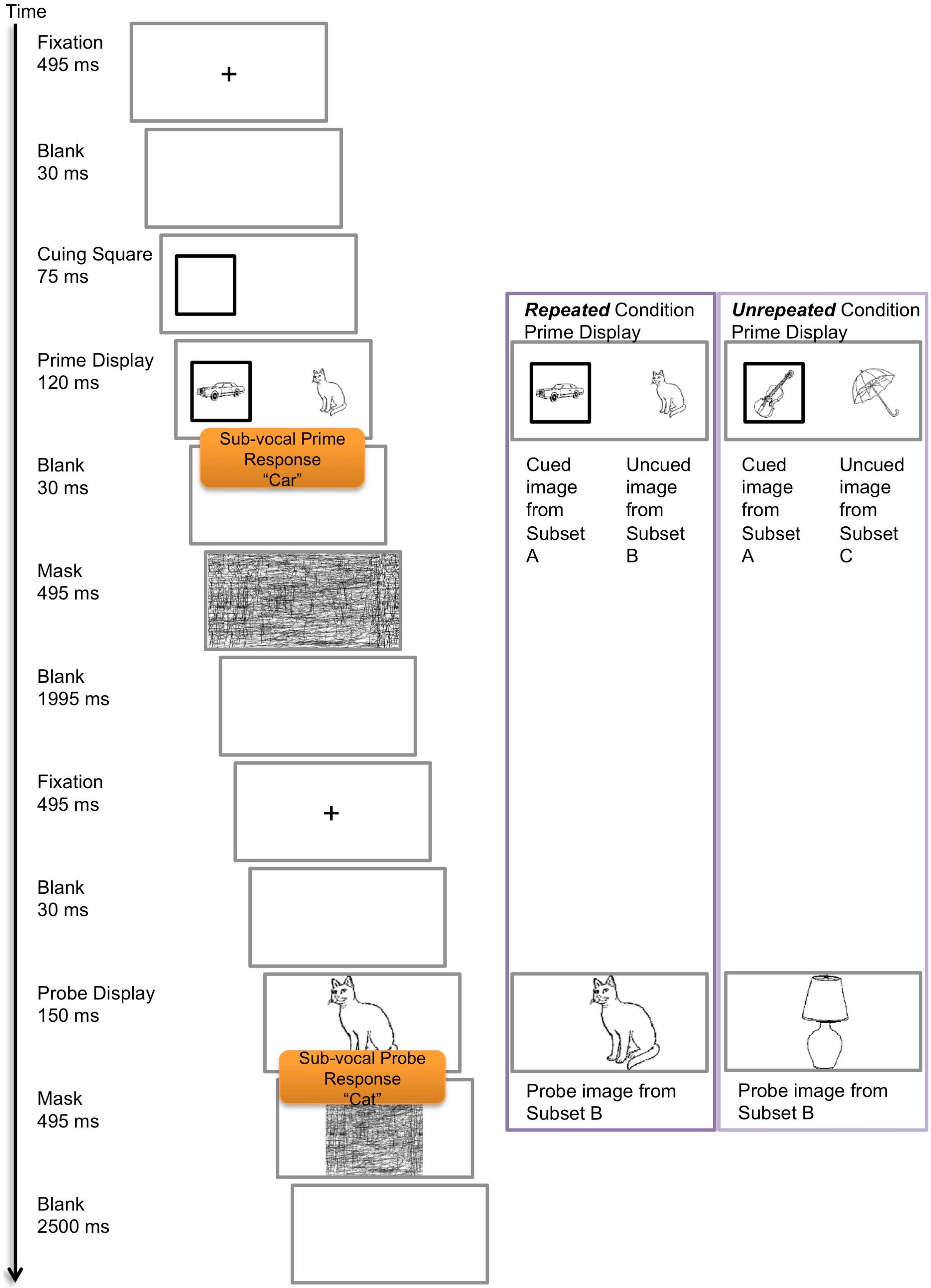

Figure 3-2: Example trial display sequence for Experiment 1. An example of the object allocation to subsets for the first participant is also shown.

3.5. Behavioural Results

All participants were asked on debriefing whether they had noticed the pictures that they had not had to name, and if they had noticed that they had sometimes been repeated. One participant mentioned during debriefing that they were expecting repetitions of objects, therefore their data were excluded from the following analyses.

From the data of the remaining 15 participants, only trials with a response for both prime and probe and a probe response RT between 250-2000 ms were used (87% of trials). Catch-trials were not included in the analyses. There were 100% responses made at the probe and 87% made at the prime.

The paired t-test revealed that repeated objects were responded to (ie. covertly named) significantly faster (*M* = 647.3 ms, *SD* = 355.9) than unrepeated objects (*M* = 677.2 ms, *SD* = 378.8), *t*(14) = 2.37, *p* = .033, *d* = 0.06. This replicates the findings of Stankiewicz and Hummel (2002) for priming from an unattended scaled image[9].

3.6. ERP Results

Pre-processing of the data is described in detail in Section 2.5. Only those responses that were associated with a response both at the prime and probe display were used in these analyses. Catch-trials were not included in the analyses. Data analyses were focused on the electrode sites P7, P8, PO7, PO8. All participants' ERP showed peaks within the time windows of P1: 60-130 ms and N1: 130-190 ms (as confirmed by visual inspection). For N250, the mean amplitude over the time window of 230-310 ms was calculated for each participant. For P1 and N1, a peak-picking algorithm (EGI adaptive mean) was used to calculate the mean amplitudes ± 20 ms around the peak allowing the time window of the mean amplitude calculation to extend out of the nominal time window when necessary. These data were then submitted to a separate 2 x 2 x 2 (Repetition [repeated, unrepeated] x Hemisphere [left, right] x Electrode Site [parietal P7/8, occipito-parietal PO7/8])

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[9] Stankiewicz & Hummel (2002) found behavioural priming of about 50 ms for unattended images.

within-participant ANOVA for each time window of interest. The grand-averaged waveforms for each condition at each electrode site used in the analyses are shown in Figure 3-3.

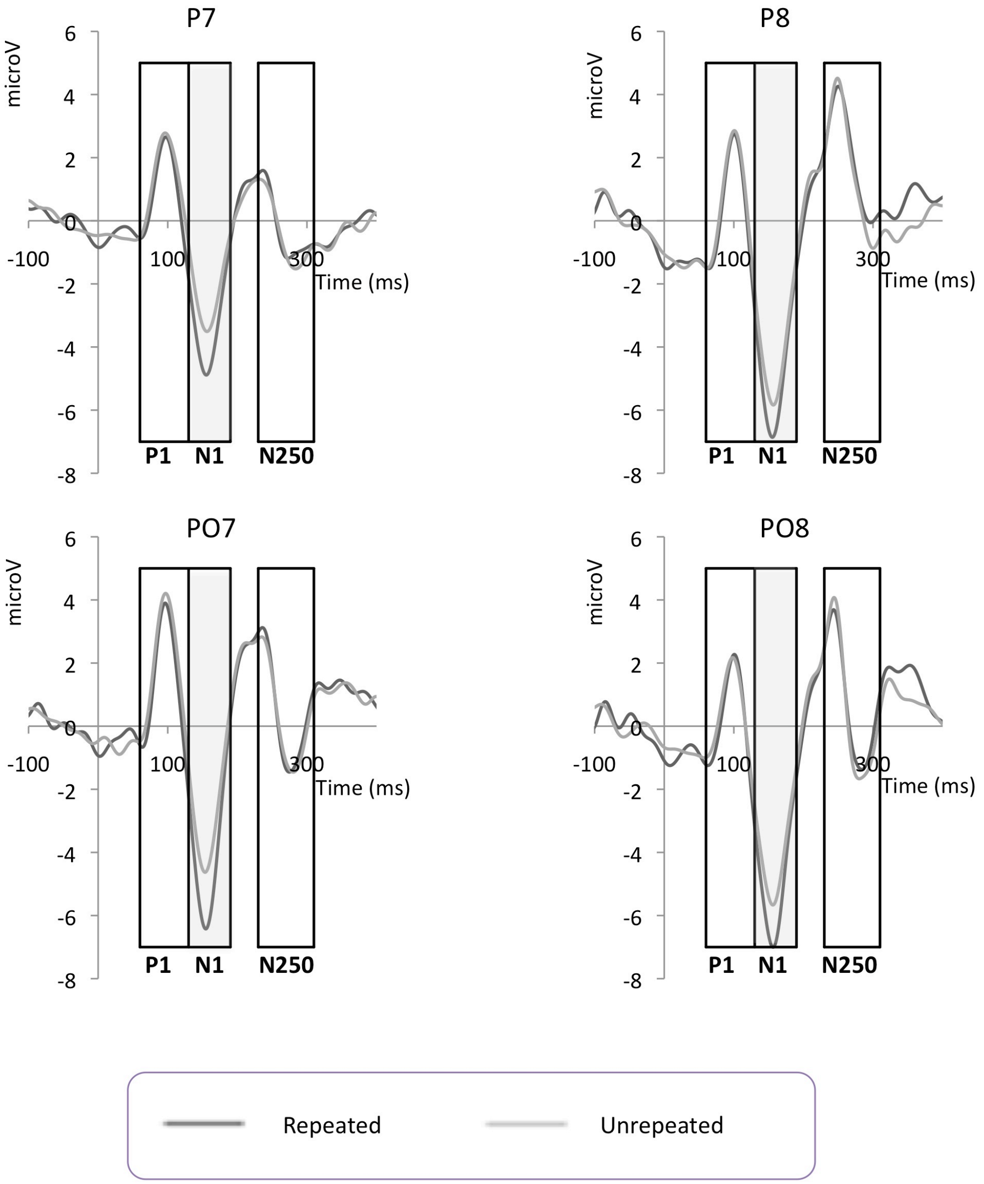

Figure 3-3: Grand-averaged probe-locked ERP waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7 and PO8 for Experiment 1. P1, N1 and N250 time windows are marked, where these boxes are grey indicates that statistically significant repetition effects were observed in these time windows. For those time windows where statistically significant effects were found, bar charts showing mean amplitudes are presented separately below.

3.6.1 Probe-locked P1

The analysis of P1 amplitude revealed a significant interaction between Hemisphere x Electrode Site F(1,15) = 5.02, $p = .041$, $\eta_p^2 = .25$. There were no other significant main effects or interactions in the main ANOVA, *ps* > .12. Follow up paired t-tests for the interaction between Hemisphere x Electrode Site revealed that for the occipito-parietal electrodes, the amplitude for the right PO8 (*M* = 1.62 µV, *SD* = 2.59) was more negative than for the left PO7 (*M* = 3.37 µV, *SD* = 2.30), t(15) = 2.32, $p = .035$, *d* = 0.06. For the left hemisphere, the amplitude for the parietal P7 (*M* = 2.34 µV, *SD* = 2.20) was numerically more negative than for the occipito-parietal PO7, t(15) = 2.05, $p = .059$, *d* = 0.51. However, none of these results held up to Bonferroni correction (criterion value for 4 comparisons, $p < .0125$).

3.6.2 Probe-locked N1

The analysis of N1 amplitude revealed a significant main effect of repetition F(1,15) = 5.45, $p = .034$, $\eta_p^2 = .27$, with a more negative amplitude for repeated images (*M* = -5.5 µV, *SD* = 3.55) compared to unrepeated images (*M* = -4.41µV, *SD* = 2.81). The main effect of hemisphere was not significant F(1,15) = 4.00, $p = .065$. There were no other significant main effects or interactions, *ps* >.15. The mean amplitudes of the N1 peak are shown in Figure 3-4.

The topographic difference map (for unprimed-primed amplitude) shown in Figure 3-5 indicates a posterior difference whereby the amplitude resulting from repeated objects is more negative in amplitude than for unrepeated objects accompanied by a frontal positivity. This onsetted in the left hemisphere at around 110 ms and appearing in both hemispheres until around 190 ms.

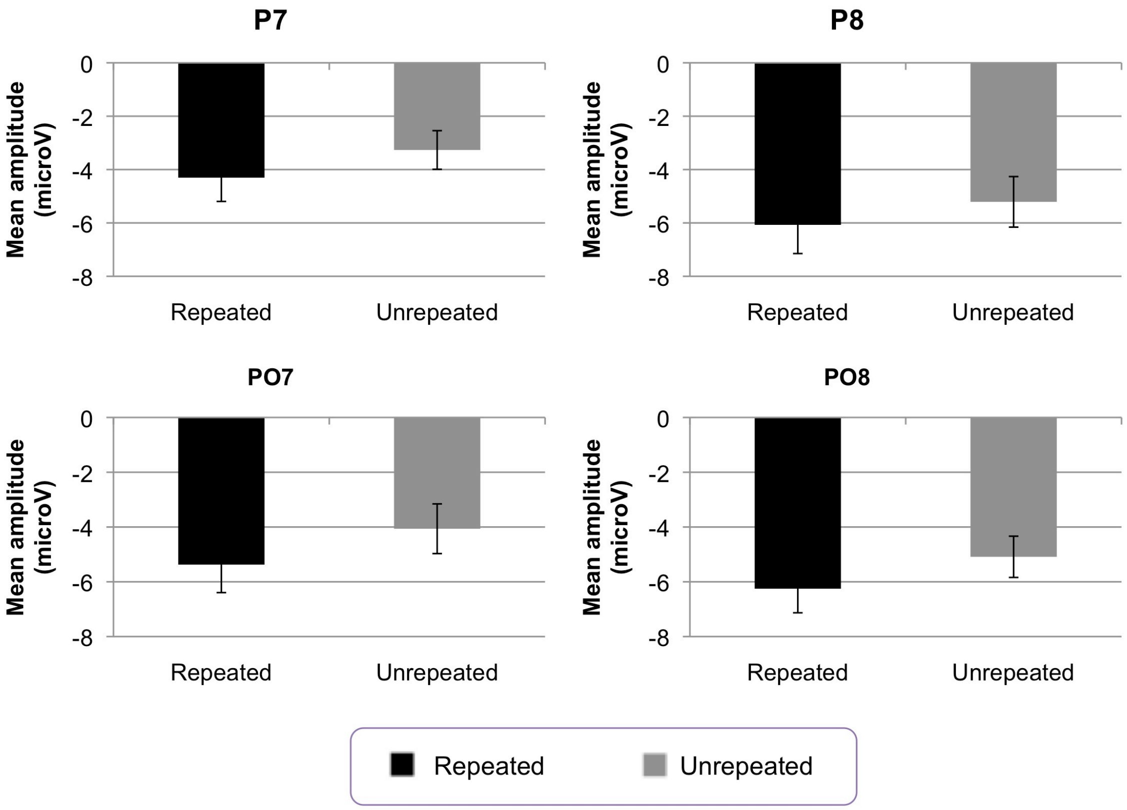

Figure 3-4: Probe-locked N1 mean amplitudes ±1 standard error bars for each electrode analysed for Experiment 1

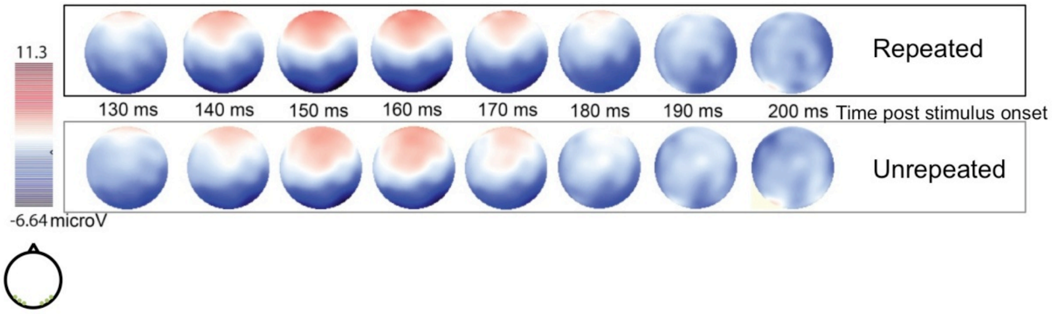

Figure 3-5: Probe-locked difference topomaps between 130–200 ms post-stimulus onset in 10 ms steps for Experiment 1.

3.6.3 Probe-locked N250

The analysis of the amplitude of the N250 revealed a significant interaction between Hemisphere x Electrode Site $F(1,15) = 5.01$, $p = .042$. There were no other significant main effects or interactions in the main ANOVA, *ps* > .22. Follow-up t-tests for the interaction between Hemisphere x Electrode Site revealed that there were no significant differences in electrode site for either hemisphere (*ps* > .14).

3.7. Experiment 1: Summary and Discussion

In Experiment 1 the spatial cuing paradigm, used by Stankiewicz and Hummel (2002) in their tests of behavioural priming, was adapted in order to test for the presence of ERP repetition effects from spatially unattended objects. Under the hybrid model, unattended objects are processed via the holistic route. Therefore the presence of repetition effects in this experiment would add to the support for processing of unattended objects in presumably a format of holistic representations.

Both behavioural priming and ERP repetition effects from spatially unattended objects were observed, indicating that shape recognition proceeds without attention. In terms of the hybrid model of object recognition, the behavioural data show the predicted priming effect from an unattended image of a familiar object in a canonical view. The ERP data indicate a similar story, and a repetition effect was observed that began within the time window of the posterior parietal N1, here peaking between 130-160 ms, with repeated prime images resulting in an enhanced N1 peak compared to unrepeated prime images at posterior parietal and occipito-parietal electrode sites.

Scaling the probe image to twice the size of the prime image ensured that there was no one-to-one visual overlap between the prime and probe images eliminating the possible influences of such low-level feature (picture-to-picture) matching on the repetition effects. Thus, the observed repetition effects are rather associated here with the activation of a holistic representation, as has been argued by Stankiewicz and Hummel, 2002 (also Bindemann et al, 2008; Zimmermann & Eimer, 2013).

The ERP repetition effects in the time window of the N1 were similar to those found in studies examining repetition effects from attended stimuli, e.g the studies of Henson et al (2004) and Soldan et al (2006). However, in contrast to the results of Henson et al (2004) for attended images, and Eddy et al (2006) for masked images, no repetition effects were observed here during neither the time window of the P1 component, nor for that of the N250.

In summary, Experiment 1 confirmed the presence of ERP repetition effects from unattended objects. These were manifested as more negative amplitudes elicited by repeated compared to unrepeated primes in the time window of the N1 at parietal and occipito-parietal electrode sites (P7/8 and PO7/8). The repetition effects were found despite a scale-change between the prime and probe display, which is consistent with the view-sensitivity expected for the holistic route of the hybrid model.

Another prediction from the hybrid model is that recognition via the holistic route is not possible for view changes that alter the locations of the objects parts (as this would result in a different surface map). Experiment 2 therefore tested for the view-sensitivity of the ERP repetition effects for unattended objects under such a view-change.

A second aim for Experiment 2 was to address the potential limitation of Experiment 1 that the repetition effects that were observed here would also be compatible with those predicted had there been any attentional spillage (Lachter et al, 2004) to the uncued objects. Within the hybrid model of object recognition this cannot be discounted by the present results, as an attended image (processed via the analytical route) would also be expected to produce repetition effects irrespective of a scale-change. Therefore, the next experiment included a change of the holistic view property.

Chapter 4. Experiment 2: View-sensitivity of ERP Repetition Effects from Spatially Unattended Objects to Split images

4.1. Introduction

In Experiment 1 ERP repetition effects from spatially unattended objects were observed. These were reflected by an enhanced N1 for repeated vs. unrepeated objects at parietal (P7/8) and occipito-parietal (PO7/8) scalp locations. Such evidence for the processing of unattended objects up to a level sufficient for shape recognition is in contrast to those studies (e.g. Lachter et al, 2004; Lavie et al, 2005) that have indicated that there is no processing of unattended objects beyond simple low-level features. However, the results of Experiment 1 are in agreement with those studies that have indicated the recognition of unattended objects (e.g. Driver, 2001; Stankiewicz & Hummel, 1998; Vuilleumeier et al, 2005).

The ERP repetition effects in Experiment 1 showed repetition effects after scale-change. This is in principle consistent with the scale-invariance that is predicted via the holistic route of the hybrid model for the recognition of unattended objects, and that has been demonstrated through behavioural priming by Stankiewicz and Hummel (2002). They explain how scale-invariance and translational-invariance are specific types of view-invariance that are associated with the 'automatic' holistic route for recognition in the hybrid model. The holistic route relies on representing an image as a 'surface map', as described in Section 1.11, in which part and location information are encoded all-in-one. Stankiewicz and Hummel also describe how, in contrast, recognition is view-sensitive to changes that alter this surface map. Behavioural studies have demonstrated that priming is not found from unattended objects under such view-changes (e.g. Stankiewicz & Hummel, 1998 (mirror-reflection); Thoma et al, 2006 (depth-rotation); Thoma et al, 2007 (plane-rotation)). According to the hybrid model, view-invariant recognition for such view-changes requires the analytic (attended) route.

The aim of Experiment 2 was to test the view-sensitivity of the ERP repetition effects for spatially unattended objects to such a part-location view-change, namely splitting the image vertically in two and swapping the locations of the left/right halves of the image to form a ‘split-image’ (see Figure 4-1).

Figure 4-1: Example of a split image stimulus.

Such split-images have previously been used to test the view-sensitivity of the analytic and holistic routes of the hybrid model both behaviourally (Thoma, Davidoff & Hummel, 2004) and in an fMRI paradigm (Thoma & Henson, 2011). These studies also used a spatially cued short-lag repetition-priming paradigm as used by Stankiewicz and Hummel (1998) and colleagues to test the hybrid model. In both the Thoma and Henson (2011) and Thoma et al (2004) studies, split images only resulted in priming when they had been attended. Intact images resulted in priming whether they had been attended or not. These results are consistent with the analytic processing of attended images, and the holistic processing of unattended images proposed by the hybrid model.

Experiment 3 of Thoma et al (2004) extended these results by testing whether the priming from the unattended intact images truly represented a match to a holistic representation in long-term memory (LTM) rather than the possibility that such priming could be attributed to a visual match of low-level features (picture-to-picture matching). It had previously been indicated (Bar & Biederman 1998; 1999) that the locus of visual priming is at the higher visual areas of the brain and thus reflects access to LTM rather than the perceptual match of features, which would be expected in earlier visual areas (see also Biederman & Cooper, 1991; Stankiewicz et al 1997). In Thoma et al’s Experiment 3 the view of the probe image was matched to the prime image, i.e. the probe image was also intact or split (unlike in previous experiments, where the probe image was always in an intact, canonical view). Thoma et al found that attended split-images did result in priming of the repeated probe split-images. However, there was no priming from unattended split-images, even when the probe was presented in the same split-image view. Thus they concluded that this pattern of view-sensitivity of the priming was good support for the notion of access to a holistic representation in LTM.

Experiment 2 adapted the design used in Thoma et al (2004, Experiment 3) and focused on the effects of repetition and view on unattended (uncued) objects on ERP amplitude. Thus the experimental factors were Repetition (repeated, unrepeated) x View (intact, split). All prime and probe images were matched in view: an intact prime preceded an intact probe and a split-image prime preceded a split-image probe. In contrast to the Thoma et al study, in which the cued (attended) objects were presented either as intact or split images, in the present study the cued (attended) images were all presented as intact images. The independent variables were the view and repetition of the prime image. The dependent variables for the ERP measure were the amplitude of the probe-locked P1 and N1 components, and the mean amplitude of the N250 component. The naming response times at prime and probe were also recorded. Additionally, the N2pc (see Section 2.2.1) locked to the prime onset was also examined to test for possible differences in the allocation of attention (Astle et al, 2010; Eimer, 1996; Luck & Hillyard, 1994) at the target due to the view of the distractor.

According to Hummel's hybrid theory of object recognition, short-lag repetition effects were expected from unattended prime objects only when those prime images were shown intact and not for split images. It was expected that the ERP repetition effects elicited by the intact primes would show a similar amplitude modulation with repetition as those of Experiment 1 (Thoma & Henson, 2011; Thoma et al 2004; Soldan, Mangels & Cooper, 2006). That is a more negative deflection for repeated vs. unrepeated objects in the time window of either the N1 or N250r at posterior parietal and/or occipito-parietal sites. The key theoretical interaction of interest was the prediction of an interaction between the factors View and Repetition.

4.2. Participants

The 18 right-handed participants tested all reported normal or normal-to-corrected vision and were native English speakers. They received either course credits or £15 in high street vouchers for their time. However, due to insufficient numbers of artifact-free trials (less than 60%), four participants' data were excluded from further analysis. The remaining 14 participants (eight female) were aged between 19-26 years (*M* = 20.8 years, *SD* = 2.39).

4.3. Stimuli & Design

The stimuli were 400 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), and Cycowicz, Friedman and Rothstein (1997). The four experimental conditions were (1) intact repeated (2) intact unrepeated (3) split repeated (4) split unrepeated. There were 40 trials in each of the four conditions, giving a total of 160 trials. As in Experiment 1, each trial included a prime presentation (comprising two images, one which was cued and attended and the other which was uncued and unattended), and a probe presentation comprising one image. For the repeated condition the probe image was the same object as the unattended prime image. For the unrepeated condition the probe image was a completely different object to both the unattended and attended images in the prime presentation. The prime objects (and corresponding probe) were shown either as an intact image or a split image. The cued (attended) image was always shown as an intact image. The prime and probe images were the presented in the same size (ie. there was no scaling). The experimental conditions and corresponding prime and probe presentations are seen in Figure 4-2.

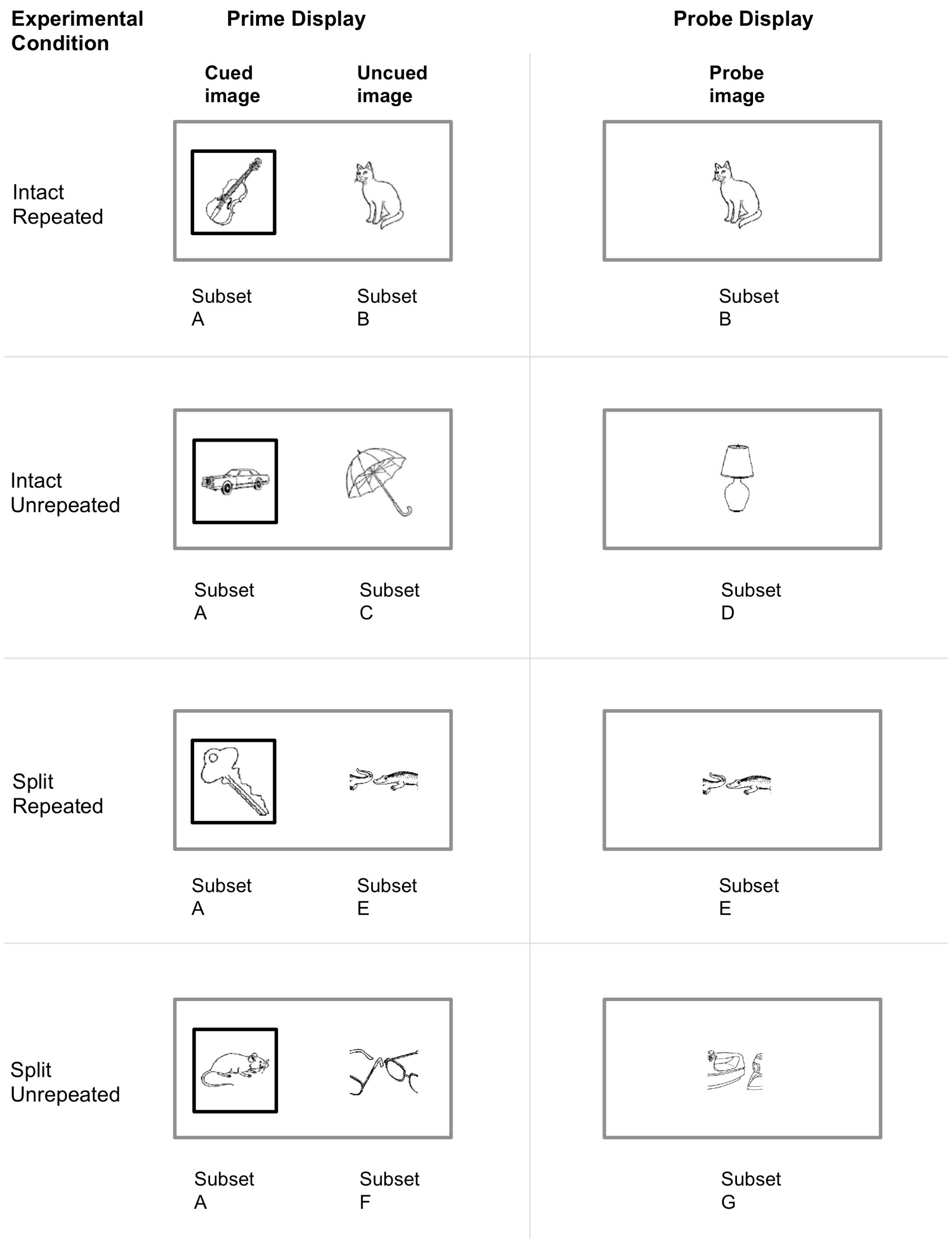

Figure 4-2: Schematic of conditions and stimulus subsets for the first participant (counterbalancing of sets B – G) in Experiment 2.

Each of the object stimuli was allocated to one of seven subsets (A, B, C, D, E, F and G as also shown in Figure 4-2). Subset A contained 160 objects that were presented to all participants as cued (attended) images, i.e. all attended images were the same for all participants, and these were randomly paired with unattended images. To ensure that all objects only appeared once for each participant and that all unattended objects appeared equally often as prime and probe in all conditions across participants, the subsets B, C, D, E, F and G were used in different conditions counterbalanced across participants. Subsets B, C and D each contained 40 objects that for the first participant appeared as intact images in random order as repeated primes and probes (B), unrepeated primes (C) and unrepeated probes (D). The same logic was applied to the subsets E, F and G, also each containing 40 objects, but that appeared as split images. The subsets were counterbalanced across participants, as shown in Table 4-1, which shows the first three participants as an example. All images within each subset were presented in random order. All trials were presented on a 17 inch CRT monitor, and images were standardised to subtend 4.5˚ x 4.5˚ of visual angle. Stimulus presentation was controlled using a PC running E-prime v.1 (Psychology Software Tools, Pittsburgh, PA).

Table 4-1: Counterbalancing of object subsets for the first three participants in Experiment 2

Participant	Cued Image	Intact Repeated condition: Object presented as both uncued prime and probe	Intact Unrepeated condition: Object presented as uncued prime only	Intact Unrepeated condition: Object presented as probe only	Split Repeated condition: Object presented as both uncued prime and probe	Split Unrepeated condition: Object presented as uncued prime only	Split Unrepeated condition: Object presented as probe only
1	Subset A	Subset B	Subset C	Subset D	Subset E	Subset F	Subset G
2	Subset A	Subset G	Subset B	Subset C	Subset D	Subset E	Subset F
3	Subset A	Subset F	Subset G	Subset B	Subset C	Subset D	Subset E

4.4. Procedure

The experimental trial sequence was identical to that of Experiment 1 of this thesis. This also followed a practice session that was the same as that for Experiment 1.

4.5. Behavioural Results

As was the case in the analysis of Experiment 1, only trials with a response for both prime and probe, and with probe RT between 250-2000 ms were included in the analysis. The data from one participant whose RT in each condition was above 2 SD from the mean were excluded from the subsequent behavioural analysis.

There were 100 % responses in each condition for the probe trials and 92 % responses overall for the prime trials. A paired t-test to compare the percentage number of responses to prime responses when intact (unattended) primes were presented vs. split-image primes showed there was no significant difference between these conditions, $p > .21$.

The mean prime RT for each participant were also submitted to a paired t-test which confirmed that there was no effect of the view of the uncued object, $p = .78$.

The mean probe RT for each participant were submitted to a 2 x 2 within-participants ANOVA with factors View (intact, split) and Repetition (repeated, unrepeated). There was a significant main effect of view F(1,12) = 10.34, $p = .007$, $\eta_p^2 = .46$, with the mean RT for naming the probe following intact images ($M = 563.1$ ms, $SD = 196.2$) faster than for split-images ($M = 648.2$ ms, $SD = 262.1$). The interaction between View x Repetition was not significant F(1,12) = 3.67, $p = .079$, $\eta_p^2 = .23$. The mean RT are shown in Figure 4-3.

Although caution is required in interpreting a non-significant interaction (here $p = .079$), and in particular in this case where the main effect of repetition was also not significant, as outlined by the statistical approach in Section 2.3.4, planned comparisons were performed in order to confirm significant priming in each condition. These revealed that there was significant priming of 28.7 ms for intact images t(12) = 1.79, *p* = .0495 (one-tailed), *d* = 0.50, whereas this was not the case for split images, *p* > .3 (one-tailed).

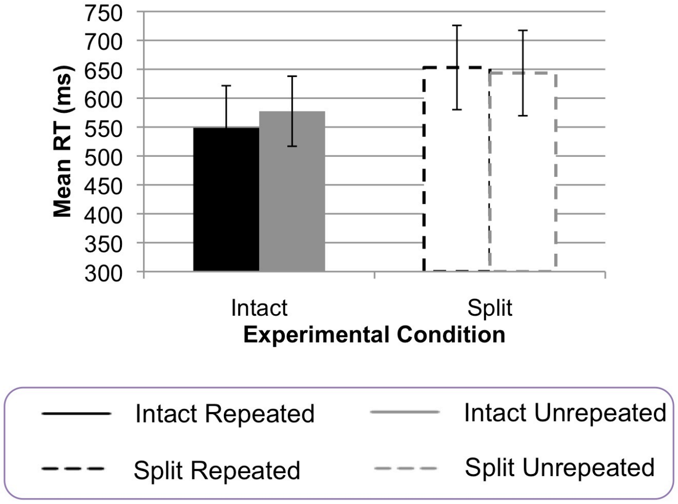

Figure 4-3: Mean probe RT for each condition ±1 standard error bars for Experiment 2

4.6. ERP Results

4.6.1 Probe-locked ERP

Pre-processing of the data is described in detail in Section 2.5, and followed the same workflow using the same parameters as Experiment 1. Data analyses were focused on the electrode sites P7, P8, PO7, PO8. As for Experiment 1, all participants' ERP showed peaks within the time windows of P1: 60-130 ms and N1: 130-190 ms (as confirmed by visual inspection). For N250, the mean amplitude over the time window of 230-310 ms was calculated for each participant. For P1 and N1, a peak-picking algorithm (EGI adaptive mean) was used to calculate the mean amplitudes ± 20 ms around the peak for each participant allowing the time window of the mean amplitude calculation to extend out of the nominal time window if necessary.

These data were then submitted to a 2 x 2 x 2 x 2 (View [intact, split] x Repetition [repeated, unrepeated] x Hemisphere [left, right] x Electrode Site [parietal P7/8, occipito-parietal PO7/8]) within-participant ANOVA for each time window. The grand-averaged probe-locked waveform for each condition at each electrode site used in the analyses are shown in Figure 4-4.

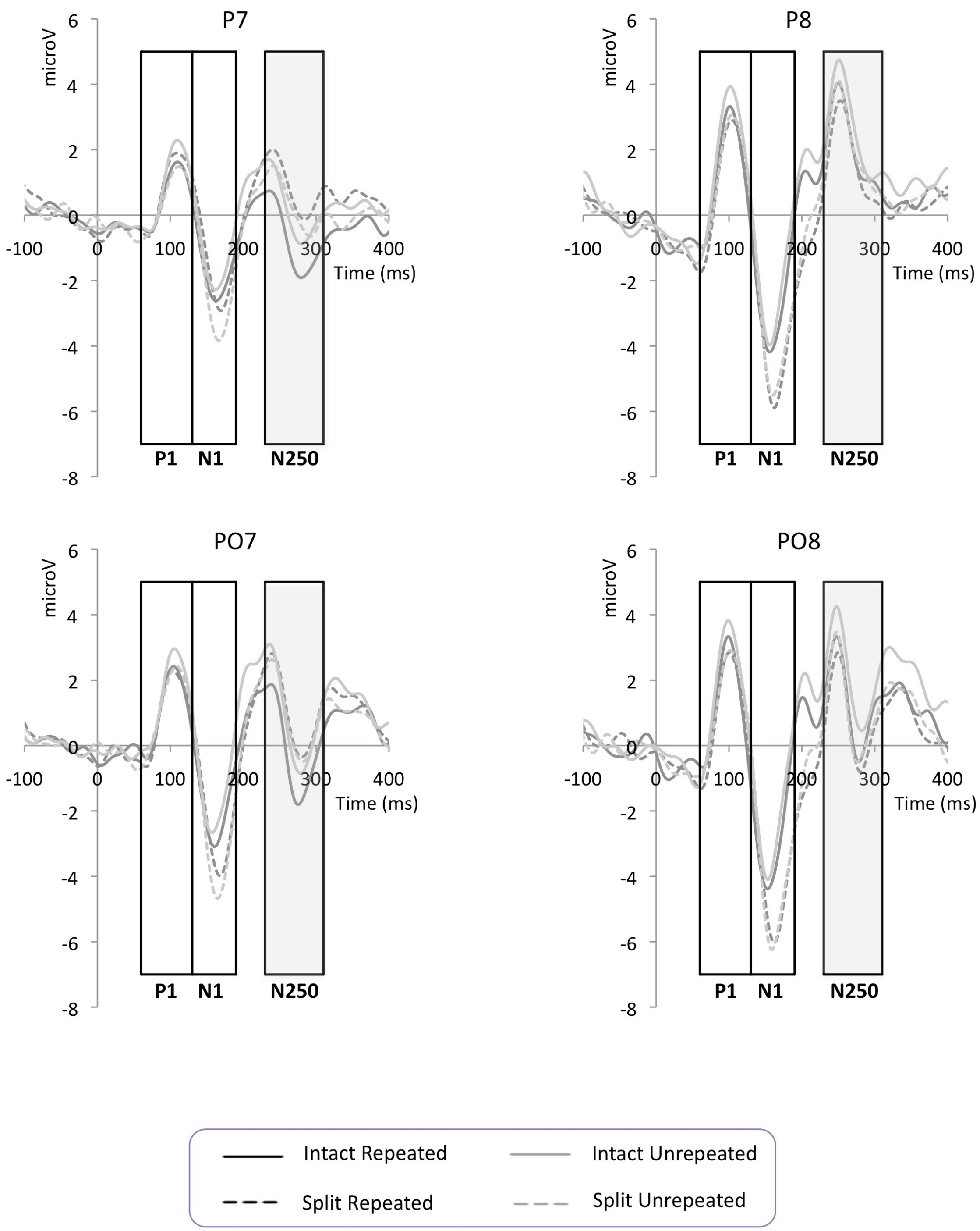

Figure 4-4: Grand-averaged probe-locked ERP waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7 and PO8 for Experiment 2. P1, N1 and N250 time windows are marked, where these boxes are grey indicates that statistically significant repetition effects were observed in these time windows. For those time windows where statistically significant effects were found, bar charts showing mean amplitudes are presented separately below.

Probe-locked P1

The analysis of P1 amplitude revealed no significant main effects or interactions, all *ps* > .17.

Probe-locked N1

The analysis of the N1 amplitude revealed a statistically significant main effect of view F(1,13) = 13.67, $p = .003$, $\eta_p^2 = .51$, with the unattended split conditions revealing a more negative amplitude at the probe ($M = -4.81$ µV, $SD = 2.75$) than intact conditions ($M = -3.63$ µV, $SD = 2.32$). There was also a near significant main effect of electrode site F(1,13) = 4.40, $p = .056$, $\eta_p^2 = .025$. There were no other significant main effects or interactions in the main ANOVA *ps* > .12.

Probe-locked N250

The analysis of the mean amplitude of the N250 revealed a statistically significant interaction between View x Repetition F(1,13) = 7.17, $p = .019$, $\eta_p^2 = .36$. There was also a significant interaction between View x Hemisphere F(1,13) = 10.10, $p = .007$, $\eta_p^2 = .44$. The interaction between Hemisphere x Electrode Site was not significant F(1,13) = 3.93, $p = .069$. There were no other significant main effects or interactions in the main ANOVA, *ps* > .16.

The follow up paired t-tests on the significant interaction between View x Repetition revealed that only probes following intact primes resulted in a significant repetition effect t(13) = 3.03, $p = .005$ (one-tailed). The repeated conditions resulted in a more negative amplitude ($M = -0.51$ µV, $SD = 3.22$) vs. unrepeated ($M = 0.50$ µV, $SD = 3.43$) conditions. For probes following split-image primes there was no difference in amplitude between repeated and unrepeated primes $p > .45$ (one-tailed).

Follow-up paired t-tests for the interaction between View x Hemisphere revealed that in the left hemisphere, probe amplitudes following intact primes were more negative (M = -

1.00 µV, *SD* = 2.67) than following split primes (*M* = -0.16 µV, *SD* = 2.78), t(13) = 2.88, *p* = .013, *d* = 0.77, Bonferroni criterion for 2 comparisons *p* < .025. The mean amplitudes for the N250 at all electrodes are shown in Figure 4-5. The difference topomaps showing the location of the repetition effects are shown in Figure 4-6.

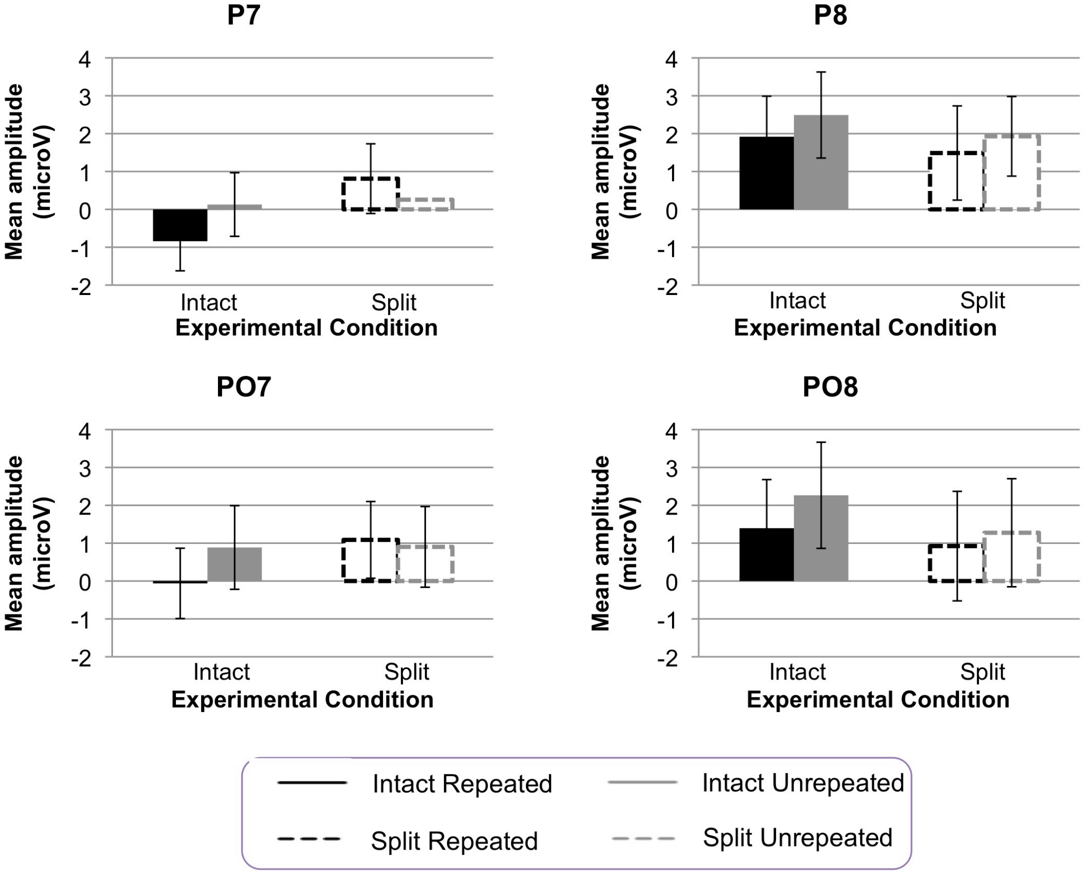

Figure 4-5: Probe-locked N250 mean amplitudes ±1 standard error bars at each electrode for Experiment 2

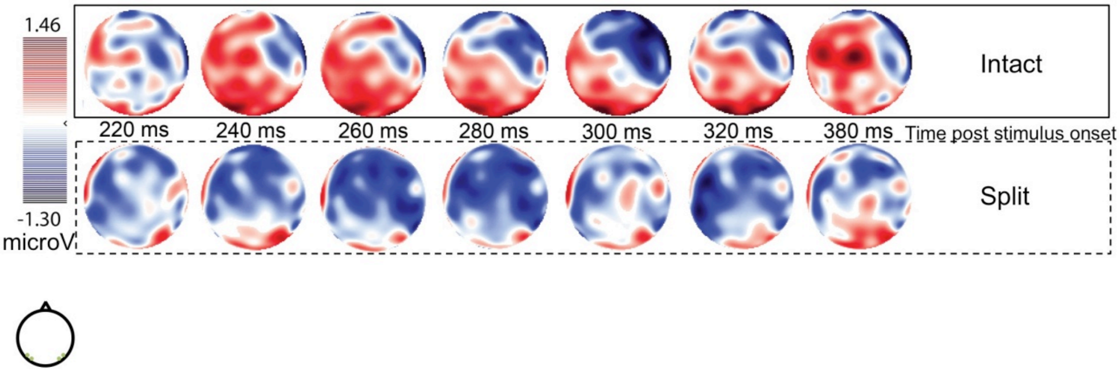

Figure 4-6: Probe-locked difference topomaps between 220-380 ms post-stimulus onset in 20 ms steps for Experiment 2

4.6.2 Comparison of Scalp Topography of Repetition effects for Experiments 1 and 2

In Experiment 1, the ERP repetition effects were found in the time window of the N1 (130-160 ms), whereas here in Experiment 2 they were found in the later time window of the N250 (230-310 ms). As described in Section 2.2.2, Henson et al (2004) observed repetition effects in both early (160-190 ms) and later (200-300ms) time windows, and they found that these did not differ in topography. Here, the topography of the Experiment 1 and Experiment 2 repetition effects were compared in a similar manner. The difference in amplitudes (unrepeated – repeated) for Experiment 1 were compared with those for only the intact image conditions for Experiment 2, at the instance of the maximum difference, found from visual inspection. This time point also corresponded to the middle of the time-windows 160 ms and 270 ms. To reduce the number of contrasts only the 70 HGSN electrodes that best-matched the location of the 10-10 standard electrode sites (Luu & Ferree, 2000; Oostenveld & Praamstra, 2001) were used for the comparison. The procedure for amplitude normalisation by finding the minimum and maximum amplitudes across participants and electrodes, subtracting the minimum amplitude from each individual data-point, and dividing the result by the difference of the maximum and minimum values, described by McCarthy and Wood (1985) and following Henson et al (2004) were used. The normalised amplitudes were then submitted to a mixed-ANOVA with the within-factor of location (70 electrode sites) and between factor of Experiment (1, 2). No significant effects or interactions were found, *ps* > .5. Therefore, following the argument of Henson et al (2004), the repetition effects in Experiments 1 and 2 may be associated with similar neural generators. However, unlike in the Henson et al. study, here the repetition effects were not found at both time windows within each experiment. Further, care must be taken in interpreting such a null result. The topographic maps for each experiment are shown for visual comparison in Figure 4-7.

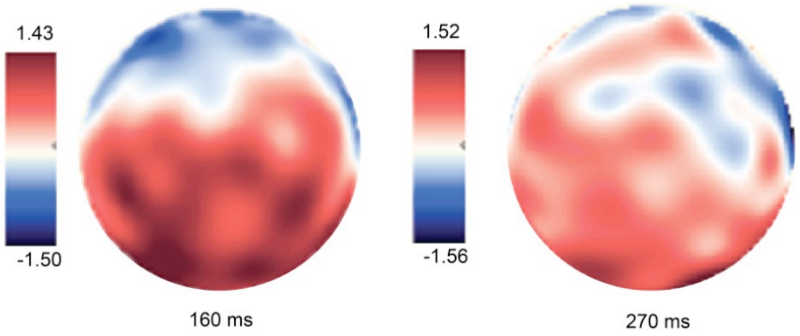

Figure 4-7: Comparison of difference topomaps from (a) Experiment 1 and (b) Experiment 2. Note different scales to maximise appearance of the effect of repetition for comparison of location rather than magnitude.

4.6.3 Prime-locked ERP

The prime presentation in this current study comprised an intact cued image paired with either another intact uncued prime image or an uncued split-image prime. Therefore, the possibility that the lack of repetition effects from split-images was due to uncued intact (salient) objects capturing attention over split (and thus, less salient, e.g. Yantis, 2000) images was tested by examining the N2pc. This is an ERP component indexing the allocation of attention (Astle et al, 2010; Eimer, 1996; Luck & Hillyard, 1994). See

Section 2.2.1 for a description of the properties of the N2pc. Here, an effect of view on the magnitude of the N2pc would indicate that the initial prime presentation conditions were not equivalent for intact vs. split-images and hence present a difficulty in interpreting the results of the repetition effects.

Data analyses were focused on the electrode sites P7, P8, PO7, PO8. For the N2pc analysis, the mean amplitude for the time window of 230-280 ms was chosen (following Astle et al, 2010) and the data submitted to a 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors View (intact, split) x Contralaterality (contralateral, ipsilateral) x Hemisphere (left, right) x Electrode Site (parietal P7/8, occipito-parietal PO7/8). The key interaction of interest was that between View x Contralaterality.

Prime-locked N2pc

The grand-averaged contralateral and ipsilateral prime-locked waveforms are shown in Figure 4-8.

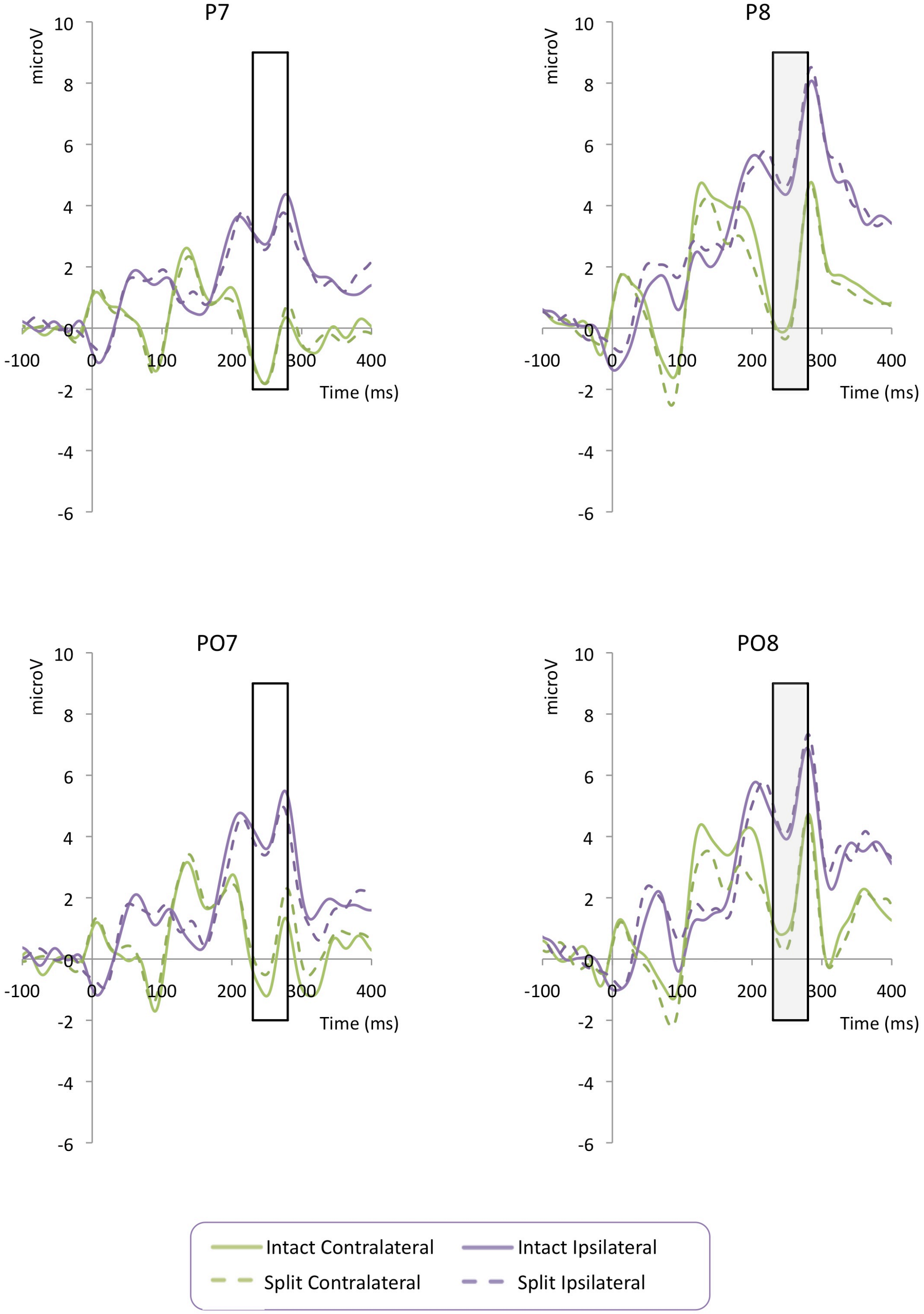

Figure 4-8: Grand-averaged prime-locked contralateral and ipsilateral waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7 and PO8 for Experiment 2. The time window for the N2pc is marked, where this is grey indicates that a statistically significant N2pc was observed.

The analysis of the mean amplitudes revealed a statistically significant three-way interaction of Contralaterality x Hemisphere x Electrode Site F(1,13) = 8.47, $p = .012$, $\eta_p^2 = .39$. There were no other significant main effects or interactions, $ps > .12$.
To follow up the three-way interaction of Contralaterality x Hemisphere x Electrode Site, separate follow-up two-way ANOVAs were performed. The ANOVAs at the levels of right and left hemisphere revealed that in the right hemisphere there was a significant interaction between Contralaterality x Electrode Site F(1,13) = 17.6, $p = .001$, $\eta_p^2 = .58$. Follow up paired t-tests then revealed that for the parietal site P8 the contralateral amplitude (M =1.29 µV, SD = 3.53) was significantly more negative than the ipsilateral (M =5.66 µV, SD = 2.83), t(13) = 6.12, $p <.001$, $d = 1.64$. For occipito-parietal site PO8 the contralateral amplitude (M =1.98 µV, SD = 3.53) was significantly more negative than the ipsilateral (M =5.15 µV, SD = 3.12), t(13) = 5.65, $p < .001$, $d = 1.51$. These comparisons both withstood the Bonferroni criterion for 4 comparisons $p < .0125$.

The important result for this current study was that there was no statistically significant main effect of, nor interaction with, view. Although caution is required in interpreting a null result, this implies that there was no difference in attentional allocation at the target (as indexed by a change in the N2pc) depending on whether the non-target was intact or split. Thus, the observed differences in view conditions cannot simply be attributed to differences in saliency of intact vs split views.

4.7. Experiment 2: Summary and Discussion

Experiment 2 adapted the spatial cuing paradigm used in the behavioural study of Thoma et al (2004) in order to test the view-sensitivity of the ERP repetition effects from spatially unattended objects. As in Experiment 1, the first notable finding of Experiment 2 was of the presence of ERP repetition effects for unattended objects.
Consistent with Experiment 1, the ERP repetition effects were manifested by a more negative amplitude deflection for repeated vs. unrepeated objects at parietal (P7/8) and occipito-parietal (PO7/8) sites. However, here these were found in the time window of the N250. Experiment 2 confirmed that repetition effects were only observed for intact

(and not for split-image) objects as predicted by the hybrid model. The behavioural results showed the same pattern of priming found for the unattended conditions of the original Thoma et al (2004) study. Unattended objects only produced significant priming when they were presented as intact (and not split) images. Although the priming in the intact condition for the present study was only 28.7 ms (compared to the 49.9ms of the Thoma et al study), it was statistically significant. This was in contrast to the split condition in which the amount of priming was not significant. Thus the pattern of behavioural priming for the unattended conditions matches that of the original Thoma et al study.

The probe-locked ERP results showed a significant interaction between View x Repetition for the amplitude of the N250, as was found for the behavioural priming in Thoma et al (2004). For the ERP, there was only a significant effect of repetition from intact primes, consistent with the behavioural data. There was no significant effect of repetition from split-images to their exact probe counterparts, and this (complementary to Experiment 1) provides further evidence that the repetition effects for intact images were not due to the visual overlap of features. If this had been the case the split-image primes should have also resulted in repetition effects for the identical split-image probes.

The lack of repetition effects from the split-images also goes some way to dismiss the argument that the repetition effects were due to the slippage of attention to the uncued objects (Lachter et al., 2004). Under the hybrid model, if attention had slipped, repetition effects would have been expected from the split-images via the analytic route of recognition. Accordingly, in the original Thoma et al (2004) study, under attention (activating the analytic route) split-images were found to prime themselves as much as intact images primed themsleves, whereas without attention (activating the holistic route) only split-images did not prime their split probe. Thus the lack of the split-image repetition effects in Experiment 2 here supports that the uncued objects did not receive attention.

The observation of repetition effects on the amplitude of the N250 and the view-sensitivity of those repetition effects observed in this experiment are consistent with previous work examining the N250r for face processing. Repetition effects for the N250r have also been observed for non-face stimuli such as familiar buildings (Engst et al, 2006), and everyday objects (Martín-Loeches et al, 2005). The amplitude of the N250r has been shown to be image-sensitive (Bindemann et al, 2008) e.g. it is smaller for different images of the same person compared to repeated identical images (Schweinberger et al, 2002), and extinguished for inverted faces (Schweinberger et al, 2004). However, rather analogous to the current findings, it has been seen to be insensitive to scale-changes (Zimmerman & Eimer, 2013; Bindemann et al, 2008). The results of Experiment 2 show that repetition effects on the amplitude of the N250 for unattended objects are sensitive to the configural change of splitting the image. Importantly for the interpretation of the current study's results in terms of the hybrid model, the view of the prime did not appear to affect the attentional allocation to the cued object. The effects on the magnitude of the N2pc served as a measure of the allocation of spatial attention. There was no significant interaction between View x Contralaterality. This implies that there was no difference in attentional allocation depending on whether the uncued image was intact or split. Thus a difference in the capture of attention intact compared to split-images cannot be responsible for the difference in the presence of repetition effects from intact and not split-images.

The repetition effects were manifested at different time windows in Experiment 2 (N250r) and Experiment 1 (N1). The main difference between Experiments 1 and 2 was the types of views presented to participants: Experiment 1 used only intact images and Experiment 2 used both intact and split-images. The only other difference was the number of trials between the experiments.

Visual inspection of the waveforms of Experiment 2 shows a divergence of amplitude (with respect to repetition) already within the time window of the N1, but this difference only reaches statistical significance later. Therefore, a possible explanation of the repetition effects in a later time window in Experiment 2 compared to Experiment 1 is that in Experiment 2, only the onset of processing was seen at the N1, and that recognition was then only completed at the time window of the N250. The accumulation of information leading to identification was demonstrated by Doniger et al (2000) in their ERP study assessing the recognition of progressively less degraded (fragmented) images leading to explicit identification. They found a repetition effect at the Ncl (230 ms onset, 290 ms peak) indicating the point at which the level of fragmentation allowed recognition. This was found to share topography with an earlier repetition effect at the N170 (which was found when the prime and probe levels of degradation were matched). Doniger et al suggested that the repetition effects at both these time windows shared neural generators in the lateral occipital complex. Henson et al (2004) linked the neural generator for the repetition effects they observed between 200-300 ms with that for their early repetition effects between 160-190 ms (although see Schweinberger, Huddy, Burton 2004 and Schweinberger, Pickering, Jentzsch, et al., 2002 for arguments for different generators of N170 and N250r). There is further evidence for the flexibility of the time window of ERP repetition effects that stem from shared neural generators (Morgan et al, 2008).

In the current investigation, the analysis of the scalp topography of the early repetition effect in Experiment 1 and that of the later repetition effect in Experiment 2, found no significant difference between them. Following the argument of Henson et al (2004), this may also indicate similar neural generators (as suggested for the early and late repetition effects but within the same experiment for Henson et al, 2004) but with the caveat of interpretation from a null result.

In summary, Experiment 2, complementary to Experiment 1, has shown that ERP repetition effects were elicited by spatially unattended objects. Experiment 2 has demonstrated the view-sensitivity of these repetition effects to splitting the image, which was as predicted from the assumptions of the holistic route of the hybrid model. Both the reliance of repetition effects from picture-to-picture priming and the possibility of attentional slippage to the uncued prime are rendered highly unlikely, as in both cases split-images would have been expected to prime themselves, and did not. However, the implications of these results as a successful test of the hybrid model are moderated somewhat by the change in the time window for the manifestation of amplitude repetition effects between Experiment 1 and 2. This may be have been due to differences in task-demands and differences in figure-ground and/or configural processing requirements from the images between the experiments.

In Experiments 1 and 2, spatial cuing was used to control the spatial allocation of attention. It was assumed under the paradigm that no attention was allocated to the uncued location, and consequently, that the ERP repetition effects that were observed from these uncued objects were elicited without attention. The presence of such repetition effects is consistent with the assumption of the hybrid model that the holistic route is free of capacity restraints. However, studies testing the capacity-limits of attention have shown that upon exhausting attentional resources at a central task (high perceptual load), the influence from or processing of peripheral ‘unattended’ objects was eliminated (Forster & Lavie, 2008; Lavie et al, 2009). Previous tests of the hybrid model using the spatial cuing paradigm have not included a direct test of capacity-limits. Therefore the following Experiments 3-7 investigated the effect of perceptual load on the recognition of unattended objects. Using perceptual load as an alternative method of manipulating spatial attention in this thesis also serves as a further, independent, test that shape processing (here indexed by ERP repetition effects) of uncued objects can be elicited without attention.

Chapter 5. Experiment 3: The Effect of Perceptual Load on the ERP Repetition Effects from Spatially Uncued Objects.

5.1. Introduction

Experiments 1 and 2 have demonstrated ERP repetition effects that are elicited by spatially unattended objects. These were found after scaling, but eliminated by the configural view-change of splitting the object image. These properties of view-sensitivity match those derived from the holistic route of the hybrid model as described and demonstrated behaviourally by Stankiewicz and Hummel (2002). These Experiments were based on the same spatially cued short-lag repetition-priming studies that have been used to extensively test the hybrid model. Thus far, the tests of the hybrid model have not addressed the issue of capacity limits of attention within this paradigm. The hybrid model is not committed to a particular mechanism of selective attention in its formulation. Previous tests of the hybrid model using a spatial cuing paradigm have relied upon the allocation of all attention to the cued target, and none at the uncued location (Lavie et al, 2009; Stankiewicz et al, 1998). However, the allocation of spatial attention to uncued peripheral objects has also been shown to depend on the perceptual difficulty of the target task, and this has been formalised in the perceptual load theory of Lavie (1995). The aim of Experiment 3 was thus to use the spatial cuing paradigm to test for the effect of perceptual load on the ERP repetition effects for intact objects observed in Experiments 1 and 2.

It has been suggested that the framework of perceptual load theory (Lavie, 1995) has offered an account of the allocation of attention, based on the stimulus properties of the visual display, that is more true to everyday life (Forster & Lavie, 2008). Perceptual load theory is an account of capacity-limited attention. In a task requiring a response to a centrally located target whilst a peripheral task-irrelevant ‘distractor’ is simultaneously shown, the perceptual load at the central task determines the level of distractor influence possible. If the task at the target is not perceptually demanding (low load) there will be sufficient residual resources to allow attentional ‘spillover’ to the distractors, which will then be further visually processed. However, if the target task is sufficiently perceptually demanding (high load) attentional resources are exhausted and this restricts the allocation of attention to the distractor, which then receives no further processing. The effects of perceptual load have been demonstrated in numerous behavioural studies as reviewed in Lavie (2005) and neuroimaging studies as reviewed in Lavie (2010).

Notably, only one of the many studies examining perceptual load theory has compared its predictions regarding non-target recognition with those derived from the hybrid model of object recognition (Lavie et al, 2009). The hybrid model of object recognition predicts the view-dependent recognition of unattended objects via the holistic route, whereas perceptual load theory assumes that attention is required for recognition.

The Lavie et al (2009) study was a behavioural study also using a short-lag repetition-priming paradigm. In a series of experiments participants were asked to name probe objects, that were either new objects (unprimed) or had been previously been presented as distractors (primed), for conditions of high or low perceptual load at the central task in the prime display. Experiments 1 and 2 examined whether there was priming from the distractors under high and low load conditions, as is the aim of this present experiment. Therefore, these experiments will be discussed in this chapter. Lavie et al’s Experiments 4a and 4b tested the view-dependence of distractor priming under low load, and so these studies will be discussed in more detail in the following chapters, in which the effects of both load and view on ERP repetition effects are also investigated in this thesis.

In Lavie et al’s (2009) Experiment 1 the prime display comprised a visual search and a non-target distractor image. Participants were asked to name the only intact object within the centrally presented visual search display. The intact object image was presented either centrally or above or below central fixation and was displayed either with two circular placeholders (low load) or with two scrambled images (high load) at the other two positions. The non-target distractor image was displayed to the left or right of fixation simultaneously to this visual search. This prime display was shown for 500 ms and then masked before the probe display, which was then also masked. Participants were asked to name the probe object, and this was always shown as an intact, upright image. Lavie et al. found that priming from the distractor objects was only present under low, and not under high, load. They also found a similar result from their Experiment 2, in which the prime display comprised a central target object flanked either to the left or right by a distractor prime image. Participants were required to overtly name the target object, which was either presented upright (low load) or inverted, i.e. upside-down, (high load). This prime display was shown for 500 ms and then masked before the probe display, which was then also masked. Prime and probe images were always presented as upright images. As in Lavie et al.'s Experiment 1, priming was only found under low load with this different manipulation of load.

Following the logic of the perceptual load experiments, Experiment 3 tested whether perceptual load affected the ERP repetition effects that were found in Experiments 1 and 2. Experiment 3 used the same spatially cued short-lag repetition-priming paradigm used in Experiments 1 and 2 (and previous tests of the hybrid model), here extended to include the factor of perceptual load. Load was manipulated at the cued target by asking participants to name an object presented within the cuing square that was either presented upright (low load) or rotated by 135° within the picture-plane (high load). The choice of rotation as the manipulation of load relied on a similar argument as used by Lavie et al (2009, Experiment 2) for using inverted images for their condition of high load. That is, that the recognition of a severely rotated object is considerably more perceptually demanding than for an upright object. It has been shown that unfamiliar views reduce naming performance (e.g. Jolicoeur, McMullen, & Ingleton, 1993; McMullen & Jolicoeur, 1990, 1992; Murray, 1999). The reduced naming efficiency for in-plane rotations has been demonstrated by Thoma et al (2007).

As discussed in Section 2.2.1, the effect of perceptual load has been associated with both the early P1 and N1 components as well later in the ERP waveform. For example, the P1 has been shown to be enhanced for low vs. high load and has thus been associated with the early suppression of distractors (Rorden et al, 2008; Handy & Mangun, 2000). The N1 has been shown to be enhanced for high vs. low load in a manipulation requiring voluntary attention (Fu et al, 2008).

In a later time window, Neumann et al (2010) found that there was a more negative deflection in amplitude, for high compared to low load, starting from the time window of the N170. However, they found that this effect was only statistically significant for the time window of the N400. Martinovic et al (2009) also found load effects in the time windows of 200-370 ms and 480-600 ms. The effects of perceptual load have also been found at occipital O1/2 (Handy & Mangun, 2000), and at the parietal/occipito-parietal (P7/8, PO7/8) electrode sites (Neumann et al, 2010; Martinovic et al, 2009).

Thus, Experiment 3 crossed the factors of Repetition (repeated, unrepeated) x Load (high, low). The independent variables were repetition and load. The dependent variables for the ERP measure were the amplitudes of the probe-locked P1 and N1 peaks, and the mean amplitude of the N250 component. The prime-locked N2pc amplitudes were also derived. The behavioural measures of the naming response times at prime and probe were also recorded. The choice of electrode sites was expanded to include occipital O1/2 as well as the parietal/occipito-parietal (P7/8, PO7/8) electrode sites used in Experiments 1 and 2 of this thesis.

Under the hybrid model, repetition effects from the spatially unattended (uncued) objects are predicted under both conditions of low and high load. That is, it was expected that there would be no effect of load and that there would only be a main effect of repetition. As in Experiments 1 and 2, the effect of repetition was expected to be that of more negative amplitudes for repeated compared to unrepeated objects. The modulation of the waveform by perceptual load should indicate that the manipulation was successfully reflected in ERP. If, as assumed under perceptual load theory, high load exhausts attentional capacity and attention is required for the recognition of the uncued object, then a Load x Repetition interaction would result (see Lavie et al., 2009).

5.2. Participants

The 18 right-handed participants all reported normal or normal-to-corrected vision and were native English speakers. They received either course credits or £15 of high street vouchers for their time. However, due to insufficient numbers of artifact-free trials (less than 60%), four participants' data were excluded from further analysis. The remaining fourteen participants (11 female) were aged between 19-35 years (*M* = 23.0 years, *SD* = 4.13).

5.3. Stimuli & Design

The stimuli were 240 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), and Cycowicz, Friedman and Rothstein (1997). The four experimental conditions were (1) low load repeated (2) low load unrepeated (3) high load repeated (4) high load unrepeated. There were 48 trials in each of the four conditions, giving a total of 192 trials. As in Experiments 1 and 2, each trial included a prime presentation, comprising two images, one which was cued and attended and the other which was uncued and unattended, and a probe presentation comprising one image. For the low load condition, the attended image was shown upright and for the high load condition, the attended image was shown rotated 135° in the picture-plane. For the repeated condition the probe image was the same object as the unattended prime image. For the unrepeated condition the probe image was a completely different object to both the unattended and attended. In the current study all primes and probe images were the presented as the same size (no scaling), and probe objects were shown as upright images. The experimental conditions and corresponding prime and probe presentations are seen in Figure 5-1.

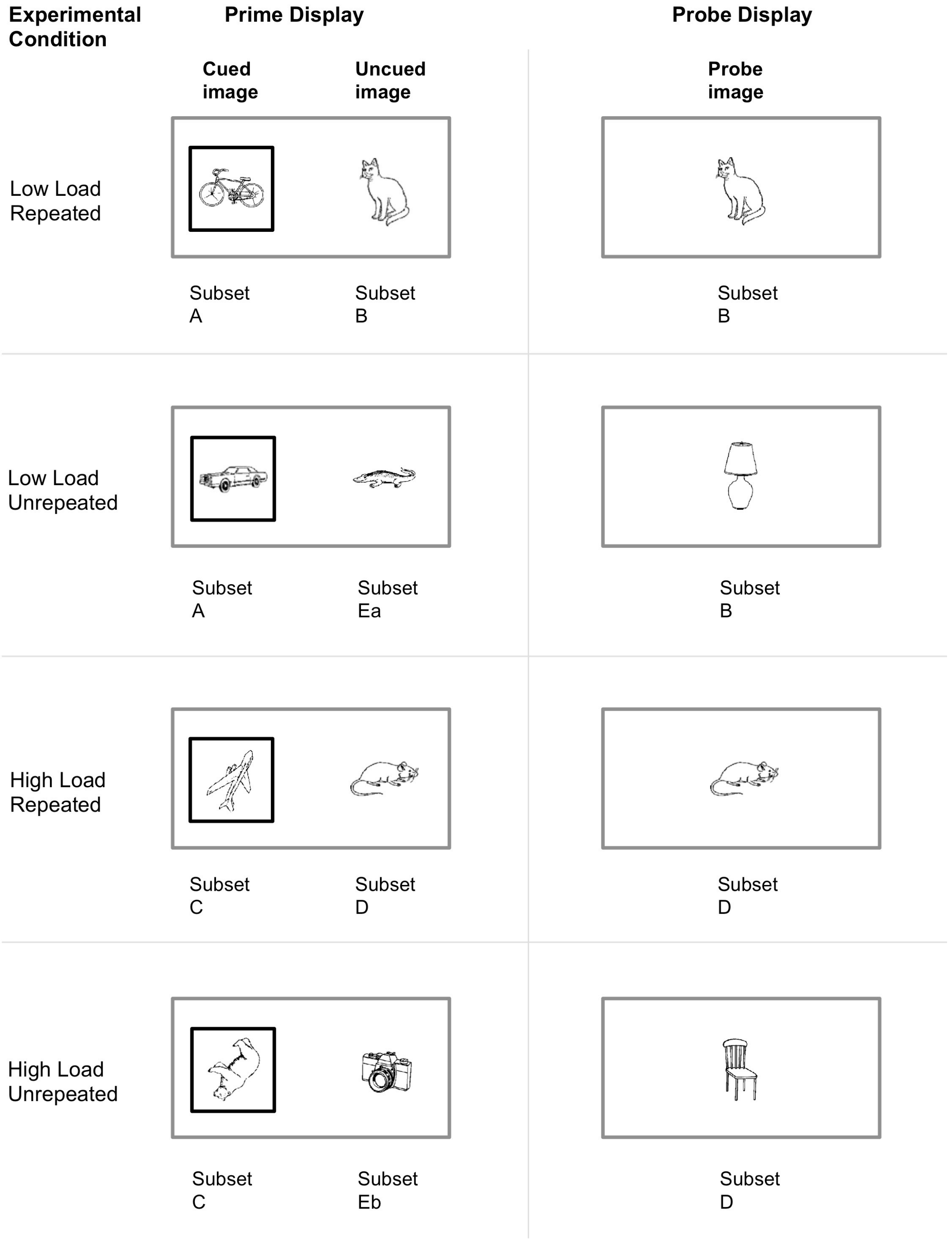

Figure 5-1: Schematic of conditions and stimulus subsets (counterbalanced) for the first participant in Experiment 3.

Each of the object stimuli was allocated to one of five subsets (A, B, C, D and E) containing 48 objects, as shown in Figure 5-1. Subset E contained objects that were presented to all participants as unrepeated primes randomly paired with cued (attended) images and probes. Half of the objects in this subset were presented in high load and the other half in low load conditions, counterbalanced across participants. To ensure that all objects only appeared once for each participant equally often as cued images and repeated primes and probes over all conditions across participants, the subsets B, C, D and E were counterbalanced across participants. For the first participant, the objects in subsets A and B appeared as cued images in high (A) and low (B) load. The objects in subsets C and D appeared as repeated primes and probes in high (C) and low (D) load. The subsets were counterbalanced across participants, as shown in Table 5-1. All trials were presented on a 17 inch CRT monitor, and images were standardised to subtend 4.5˚ x 4.5˚ at the prime and for the probe display. Stimulus presentation was controlled using a PC running E-prime v.1 (Psychology Software Tools, Pittsburgh, PA).

Table 5-1: Counterbalancing of object subsets for the first three participants in Experiment 3

Participant	Cued High Load Objects	Cued Low Load Objects	Repeated High load condition: Objects Presented both at prime and probe	Repeated Low load condition: Objects Presented both at prime and probe	Unprobed prime objects
1	Subset A	Subset B	Subset C	Subset D	High load: Subset Ea Low load: Subset Eb
2	Subset D	Subset A	Subset B	Subset C	High load: Subset Eb Low load: Subset Ea
3	Subset C	Subset D	Subset A	Subset B	High load: Subset Ea Low load: Subset Eb

5.4. Procedure

The timings of the events for each experimental trial were the same as for Experiments 1 and 2. There were 192 experimental trials in total, and this followed a short practice block of trials using different images.[10]

5.5. Behavioural Results

Only the RT associated with correct responses at both prime and probe and for probe RT between 250-2000 ms were included in the following analyses (86% trials). There were 100% probe responses in each condition. The percentage number of prime responses in high and low load were submitted to a paired t-test. This revealed that there were significantly more correct responses in low load (*M* = 92.6%, *SD* = 6.93) vs. high load (*M* = 78.7%, *SD* = 14.9%), t(13) = 5.17, $p < .001$, $d = 1.39$.

The mean prime RT for each participant were submitted to a paired t-test to compare high vs. low load. This confirmed that the mean RT for high load (*M* = 772.0 ms, *SD* = 248.4) was significantly slower than for low load (*M* = 681.3 ms, *SD* = 183.8), t(13) = 3.72, $p = .003$, $d = 0.99$.

The mean probe RTs were submitted to a 2 x 2 ANOVA on Load x Repetition. Here no significant main effects or interactions were found, with the only significance value of less than .1 being that of the interaction between Load x Repetition F(1,13) = 3.33, $p = .093$, all other *ps* > .26. The mean probe RT data are shown in Figure 5-2.

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[10] In the following experiments of this thesis a set of individual differences measures were also added: 2D/4D digit ratio, Broadbent's cognitive failures, Edinburgh handedness, WTAR. These were intended as pilot data for possible indications of individual differences relating to repetition effects. However, due to the small sample numbers the results will not be presented here.

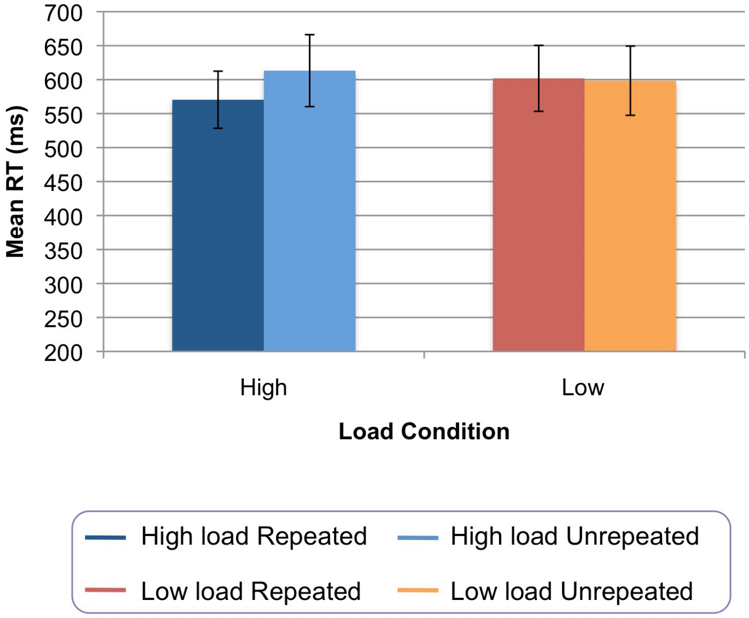

Figure 5-2: Mean probe RT ±1 standard error bars for each condition in Experiment 3.

5.6. ERP Results

5.6.1 Probe-locked ERP

Pre-processing of the data is described in detail in Section 2.5 and was the same for all ERP Experiments in this thesis. Only those trials with correct responses at both prime and probe were included in these analyses. Data analyses were extended to include the electrode sites O1 and O2 as well as P7, P8, PO7 and PO8.

All participants' ERP showed peaks within the time windows of P1: 60-130 ms and N1: 130-190 ms (as confirmed by visual inspection). For the N250, the mean amplitude over the time window of 190-260 ms was calculated for each participant. For the P1 and N1, a peak-picking algorithm (EGI adaptive mean) was used to calculate the mean amplitudes

± 20 ms around the peak for each participant allowing the time window of the mean amplitude calculation to extend out of the nominal time window if necessary.

For electrode sites P7/8, PO7/8, these data were then submitted to a 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x Repetition (repeated, unrepeated) x Hemisphere (left, right) x Electrode Site (parietal P7/8, occipito-parietal PO7/8). For electrode sites O1/2, they were submitted to a 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x Repetition (repeated, unrepeated) x Hemisphere (left, right). The grand-averaged waveform for each condition at each electrode site used in the analyses are shown in Figure 3-3.

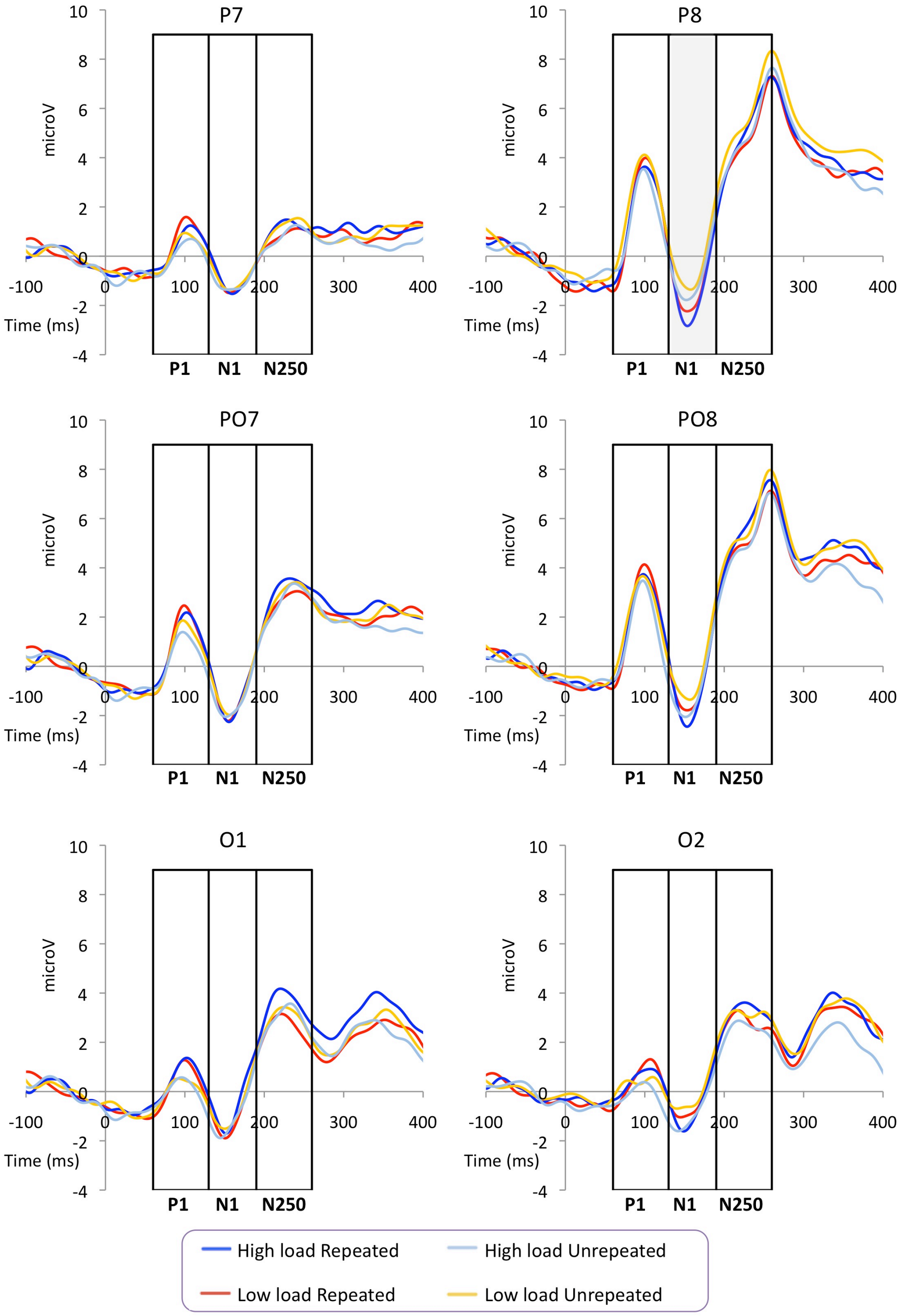

Figure 5-3: Grand-averaged probe-locked ERP waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7, PO8, O1 and O2 for Experiment 3. P1, N1 and N250 time windows are marked, where these boxes are grey indicates that statistically significant repetition effects were observed in these time windows. For those time windows where statistically significant effects were found, bar charts showing mean amplitudes are presented separately below.

Probe-locked P1

The analysis of the P1 amplitude at the P7/8, PO7/8 electrodes revealed a significant main effect of hemisphere F(1,13) = 8.00, p = .014, η_p^2 = .38, with the right hemisphere amplitude more positive (*M* = 3.42 μV, *SD* = .73) than the left hemisphere (*M* = 1.59 μV, *SD* = .48). The main effect of load was not significant F(1,13) = 3.61, p = .080, and neither was the main effect of electrode site, F(1,13) = 3.56, p = .082. There were no other significant main effects or interactions, *ps* > .19.

In the analysis of the P1 amplitude at the O1/2 electrodes, the only effect showing a significance value less than .1 was that of the interaction between Load x Hemisphere F(1,13) = 3.85, p = .072. There were no other significant main effects or interactions, *ps* > .30.

Probe-locked N1

The analysis of the N1 amplitude at the P7/8, PO7/8 electrodes revealed a significant three-way interaction between Repetition x Hemisphere x Electrode Site F(1,13) = 6.27, p = .026, η_p^2 = .33. The main effect of load was not significant, F(1,13) = 3.36, p = .09. There were no other main effects or interactions in the main ANOVA, *ps* > .11.

In order to follow up the three way interaction between Repetition x Hemisphere x Electrode Site, follow-up two-way ANOVAs were performed at each level of hemisphere. For the left hemisphere, no significant main effects or interactions were found, *ps* >.17. For the right hemisphere, the interaction between Repetition x Electrode Site was marginally significant F(1.1, 14.2) = 4.31, p = .054 , η_p^2 = 25. In the right hemisphere, only at the parietal P8 was the mean amplitude for repeated conditions (*M* = -2.22 μV, *SD* = 2.37) more negative than for unrepeated conditions (*M* = -1.66 μV, *SD* = 2.18). A paired t-test revealed that this difference was marginally significant, t(13) = 1.67, p = .055 (one-tailed), *d* = 0.45. For PO8, the amplitude modulation with repetition was in the opposite direction, and did not show a significant difference, p > .24.

In the analysis of the N1 amplitude at the O1/2 electrodes, the only significance value that was less than .1 was that of the interaction between Load x Hemisphere F(1,13) = 3.28, *p* = .093 (all other *ps* > .15). The mean amplitudes of the probe-locked N1 are shown in Figure 5-4.

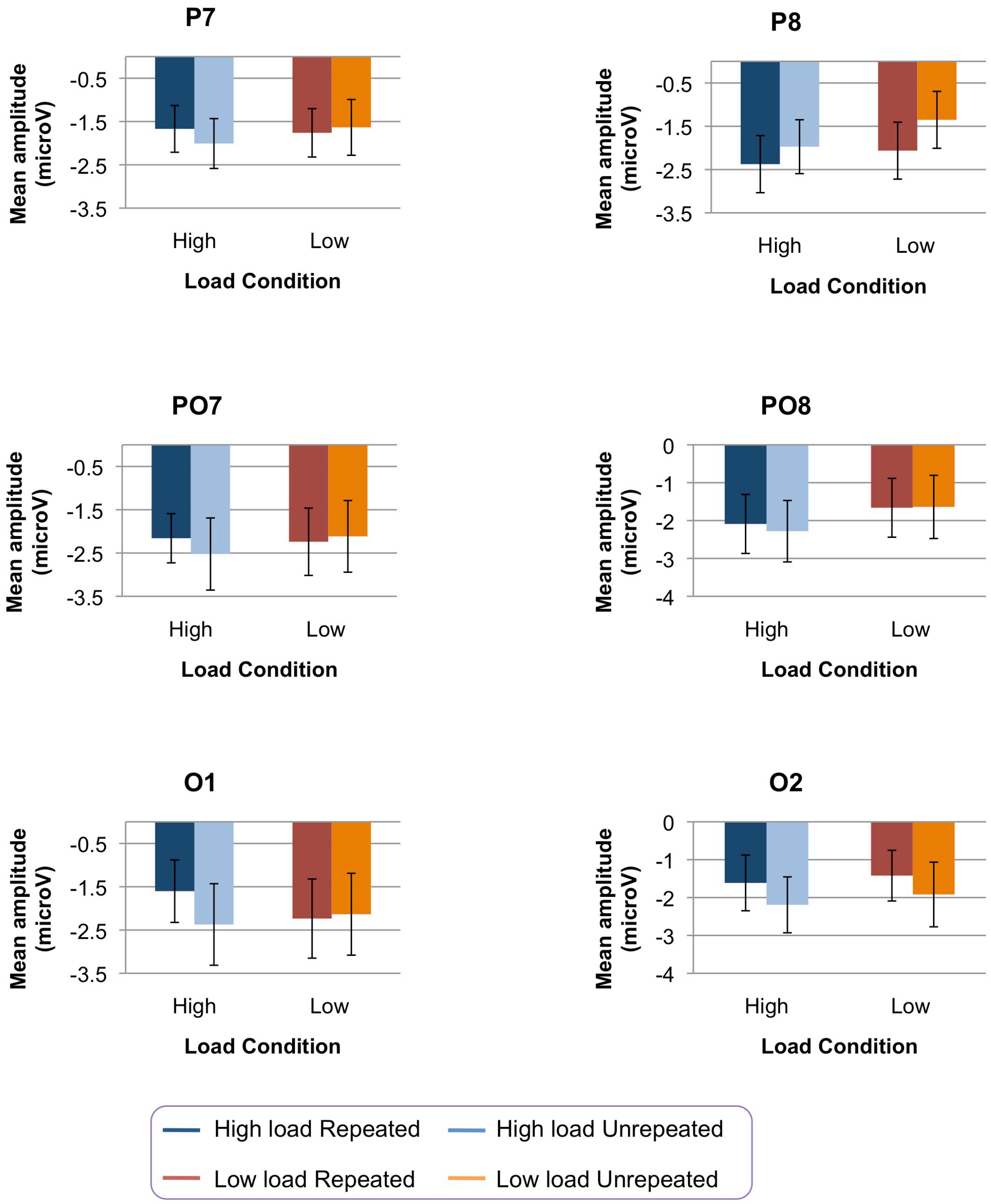

Figure 5-4: Probe-locked N1 mean amplitudes, ±1 standard error bars for Experiment 3.

Probe-locked N250

The analysis of the N250 amplitude at the P7/8, PO7/8 electrodes revealed a significant main effect of hemisphere F(1,13) = 18.55, p = .001, and of electrode site F(1,13) = 8.22, p = .013. These factors also showed a significant interaction of Hemisphere x Electrode Site F(1,13) = 9.63, p = .008, η_p^2 = .43. There was also a significant interaction between Repetition x Electrode Site F(1,13) = 5.53, p = .035, η_p^2 = .30. There were no other significant main effects or interactions in the main ANOVA, *ps* > .17.

Paired t-tests were performed in order to follow up the interaction between Hemisphere x Electrode Site. These revealed that the left hemisphere sites showed a more negative amplitude than their right hemisphere counterparts (P78: t(13) = 4.82, p < .001; PO78: t(13) = 3.30, p = .006) and parietal P7 showed a more negative amplitude than occipito-parietal PO7 t(13) = 4.28, p = .001 (Bonferroni criterion for 4 comparisons p < .0125).

Paired t-tests to follow up the Repetition x Electrode Site interaction revealed that for the parietal electrodes the amplitude for repeated conditions (*M* = 2.91 μV, *SD* = 3.09) was numerically more negative than for unrepeated (*M* = 3.35 μV, *SD* = 3.23), but that this was not significant, t(13) = 1.52, p = .075, *d* = 0.41. For the occipito-parietal electrodes there was no significant difference in amplitudes p > .45.

The analysis of the N250 amplitude at the O1/2 electrodes revealed a significant interaction between Load x Hemisphere F(1,13) = 5.73, p = .033. There were no other significant main effects or interactions, *ps* > .29. The paired t-tests to follow up the interaction between Load x Hemisphere revealed that there were no significant differences in amplitude between load conditions in either hemisphere (*ps* > .19) or between hemisphere in either load condition (*ps* > .67).

5.6.2 Prime-locked ERP

Data analyses were focused on the electrode sites P7, P8, PO7, PO8, O1 and O2. For the N2pc analysis, the mean amplitude for the time window of 230-280 ms was chosen (following Astle et al, 2010) and the data submitted to a 2 x 2 x 2 x 2 within-participant

ANOVA for each component, with factors Load (high, low) x Contralaterality (contralateral, ipsilateral) x Hemisphere (left, right) x Electrode Site (parietal P7/8, occipito-parietal PO7/8) and for electrode sites O1/2 a separate 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x Contralaterality (contralateral, ipsilateral) x Hemisphere (left, right).

Prime-locked N2pc

The prime display consisted of two peripheral images, either both were shown upright (low load) or the target was shown plane-rotated and the uncued prime image upright (high load). Therefore, the possibility that the upright (salient) prime image affected the allocation of attention at the target when presented alongside the rotated (non-salient) image was tested by examination of the N2pc, an indicator of the spatial attention allocated at the target. If attentional allocation was affected by upright prime distractors in high load in this way it would be difficult to argue for the presence of repetition effects under high load that were equivalent to those under low load in terms of attentional demands. The grand-averaged contralateral and ipsilateral waveforms at each electrode for each experimental condition are shown in Figure 5-5.

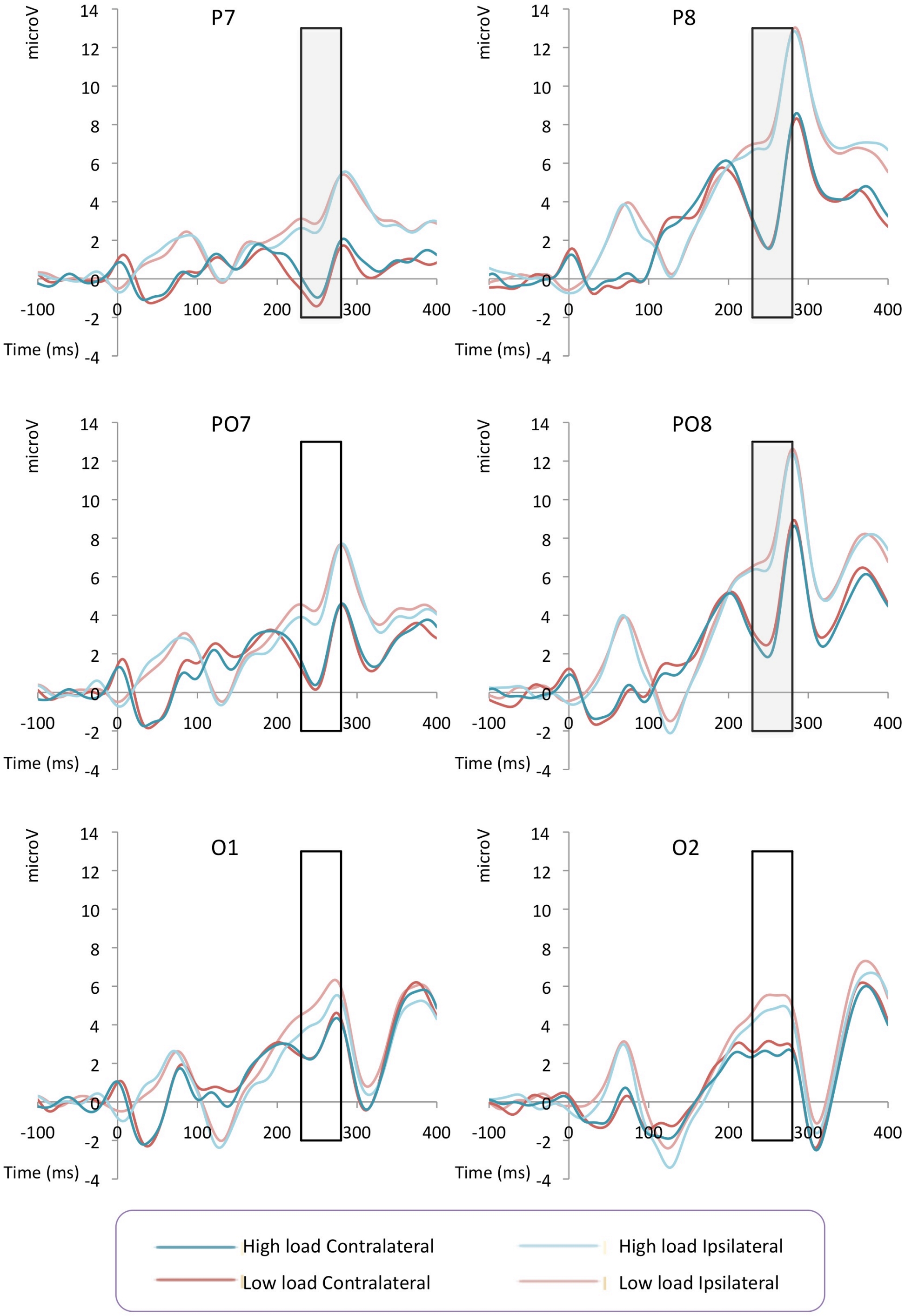

Figure 5-5: Grand-averaged prime-locked contralateral and ipsilateral waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7, PO8, O1 and O2 for Experiment 3. The time window for the N2pc is marked, where this is grey indicates that a statistically significant N2pc was observed.

The analysis of the N2pc revealed significant main effects of contralaterality to the visual field of the cued image F(1,13) = 30.43, *p* < .001 and electrode site F(1.5, 19.5) = 6.46, *p* = .011, and an interaction between Contralaterality x Electrode Site F(1.5, 19.8) = 8.14, *p* = .005. These were qualified by a significant three-way interaction between Contralaterality x Hemisphere x Electrode Site F(1.5, 20.1) = 7.03, *p* = .008, η_p^2 = .35. There were no other significant main effects or interactions, *ps* > .33.

The two-way ANOVAs and corresponding paired t tests performed to follow up the three-way interaction indicated that the contralateral amplitude was always significantly more negative than the ipsilateral amplitude for parietal and occipito-parietal electrode sites in the right hemisphere (P8: t(13) = 5.47, *p* < .001, *d* = 1.29, and PO8: t(13) = 4.86, *p* < .001, *d* = 1.47. However, in the left hemisphere, only the parietal P7 showed a significantly more negative contralateral compared to ipsilateral amplitude t(13) = 3.24, *p* = .007, *d* = 0.86, (Bonferroni criterion for 4 comparisons *p* < .0125).

Importantly, there was no significant interaction between Load x Contralaterality in this time window of 230-280 ms. This would imply that the attentional allocation was the same at the target regardless of the orientation (load) of the image within the cuing square.

5.7. Experiment 3: Summary and Discussion

In Experiment 3 the spatial cuing paradigm of Experiments 1 and 2 was adapted to include a manipulation of perceptual load at the target. This involved using either an upright target (low load) or a rotated target (high load). The aim was to test whether the ERP repetition effects for unattended objects found in Experiments 1 and 2 were modulated by perceptual load.

The behavioural data for the prime display indicated that the effect of rotating the target image did produce the expected delay in naming times compared to upright images. However, unexpectedly for the probe display, naming times for high load were faster than for low load. Further, there was no significant effect of repetition and this did not interact reliably with load.

The ERP results, however, did indicate near significant repetition effects in amplitude differences that were present in the N1 time window. This difference in amplitude carried through to that of the N250. This effect was especially apparent at the right hemisphere parietal site P8, which numerically showed enhanced negativity for repeated vs. unrepeated images. These repetition effects were consistent with those found in Experiments 1 and 2.

The effect of load appeared only as a trend early in the waveform (P1 and N1) both at parietal/occipito-parietal electrode sites. This effect only reached significance by the time window of the N250 component both at parietal/occipito-parietal electrode sites. However, importantly, these load effects did not significantly interact with repetition over the course of the waveform.

Therefore, these ERP findings lend support to the suggestion that the repetition effects from unattended objects are robust to the perceptual load at the target. No significant interaction between Load x Repetition was found, and this is in contrast to the predictions - derived from perceptual load theory - for an interaction such that repetition effects would only be present under low load conditions.

The difference in attentional allocation at the prime display was tested by the examination of the N2pc, and here there was no significant interaction between Load x Contralaterality. This strongly indicated that in both conditions of load, attention was directed to the cued target equivalently. The results for the N2pc are also compatible with there being too small a load effect between the load conditions for an effect to be revealed. However, the choice of load manipulation was guided by that of Lavie et al (2009) who used inverted images for their condition of high load, and indeed the behavioral results indicate a substantial effect of load, as it was indeed harder to name rotated objects than upright ones during the prime display. The mean RT under high load was 90.1 ms slower than under low load. This was comparable to the difference in mean RT between load conditions of 107 ms that was found by Lavie et al. Further, the ERP results indicated that load effects did manifest along both the probe-locked and prime-locked waveforms, but that for the probe-locked ERP load effects did not interact with repetition at any point.

In Experiment 3 – for the first time - both spatial cuing and perceptual load have been used to manipulate spatial attention. Lavie et al (2009) suggested a “profound difference” (p1354) between the effects of cuing and load: that cuing may restrict analytic processing, whereas load may restrict both holistic and analytic processes. The spatial cuing experiments thus far in this thesis have indicated that analytic processing was indeed eliminated for uncued objects. The restriction on holistic processing expected from the high load condition for this experiment under perceptual load theory has not been borne out. However, it is possible that there is a problem in interpreting the results from such an experiment, which combines both cuing and load in one paradigm. Therefore, Experiments 4-7 used a different load manipulation that is often used in tests of perceptual load, and indeed was also used in the behavioural study of Lavie et al (2009). This was a letter search load task in which the central task for participants consists of a visual search among a letter array whilst flanking distractor objects are shown simultaneously. Importantly, in that paradigm, spatial attention is controlled only by the load of the letter search task and is not cued.

5.8. Summary of Experiments 1-3

Experiments 1-3 used spatially cued short-lag repetition-priming paradigms and aimed to investigate the ERP repetition effects elicited by spatially unattended objects. In the prime display two images were presented simultaneously on either side of fixation, and shown to briefly to allow eye movements. Attention was directed to one of the images by the cuing square and the other image was thus assumed to be unattended (Stankiewicz et al, 1998).

Experiments 1 and 2 established the presence, and tested the view-sensitivity to configural and scale changes, of the ERP repetition effects. Experiment 1 confirmed the presence of ERP repetition effects for probe images that were twice the size of those presented at the prime display. The probe image was presented centrally and the prime image always to one or other side of the screen, and so this demonstrated that the repetition effects were found after scale and translational changes.

Experiment 2 confirmed that only intact-image primes (and not split-image primes) elicited ERP repetition effects. Taken together, these experiments demonstrate ERP repetition effects whose properties of view-sensitivity are consistent with those predicted for unattended objects that are recognised via the holistic route of the hybrid model. Experiment 3 investigated the effect of perceptual load on the ERP repetition effects for spatially unattended objects established in Experiments 1 and 2. The hybrid model assumes that the holistic route does not require any attention to proceed. However, studies have shown that under high perceptual load at the target, the influence of peripheral images is eliminated (Lavie, 2005; Forster & Lavie, 2008). Experiment 3 thus extended the spatial cuing paradigm to also include the factor of perceptual load. This was achieved by presenting the cued image either upright (low load) or rotated to 135° in the picture plane (high load). The uncued images were presented upright and intact, thus under the hybrid model these images were predicted to elicit ERP repetition effects in both load conditions. Under perceptual load theory these repetition effects were predicted to be eliminated under high perceptual load (i.e. a Load x Repetition interaction). Experiment 3 confirmed ERP repetition effects from the unattended objects. Although these only reached near significance, they were consistent in the amplitude modulation and time window with the previous Experiments 1 and 2 that did show statistically robust repetition effects. Importantly, and key to the aim of Experiment 3 was that although the interaction between Repetition x Hemisphere x Electrode was significant, the Load x Repetition interaction was not ($p > .45$). This implies that the observed repetition effects were not modulated by either manipulation of attention - spatial cuing or perceptual load. Taken together, the three experiments provide good evidence for the presence of ERP repetition effects elicited by unattended objects. These were manifested at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes such that repeated images elicited a more negative amplitude than for unrepeated images. These repetition effects were found either in the time window of the N1 (130-190 ms) for Experiments 1 and 3, or the N250 (230-310 ms) for Experiment 2.

What are the reasons for the discrepancies between the current findings of no load modulation for repetition effects in Experiment 3 and typical findings from load research? Although Experiment 3 was directly based on a study used in Lavie et al.

(2009, Experiment 2) most perceptual load studies manipulate load via a central visual search task. Lavie et al (2009) suggested that discrepant findings regarding the processing of ‘unattended’ objects between studies supporting perceptual load theory and those supporting the hybrid model may lie in the difference between the way in which attention that is manipulated by perceptual load or spatial cuing affects object representations. In the Lavie et al (2009) experiments no spatial cue was used and only attention was manipulated via perceptual load. Therefore, in Experiments 4-7 used a more traditional perceptual load paradigm to further investigate the effects of capacity restrictions on the ERP repetition effects from peripheral irrelevant images. This paradigm will be described in more detail in the relevant experimental chapters to follow.

Chapter 6. Experiment 4: The Effect of Perceptual Load and View (split images) from Task-irrelevant Peripheral Images on Behavioural Priming Using a Letter Search Task

6.1. Introduction

Experiments 1-3 have demonstrated ERP repetition effects elicited by unattended objects within a spatial cuing paradigm. In combination, the repetition effects observed in Experiments 1 and 2 demonstrated view-sensitivity consistent with that expected for the holistic route of the hybrid model. The holistic route is also thought to be automatic and relatively capacity-free (Hummel, 2001). The results of Experiment 3 indicated that the ERP repetition effects from uncued objects were not modulated by high load, supporting capacity-free processing via the holistic route. However, the results of Experiment 3 were inconsistent with those of Lavie et al (2009) who demonstrated that behavioural priming was eliminated under high perceptual load. It is difficult to directly compare the results as in Experiment 3 attention was controlled via both a spatial cue and perceptual load, whereas in the Lavie et al study, attention was only controlled via perceptual load, without a spatial cue.

Indeed, Lavie et al suggested that a possible explanation of the discrepancy between their results and those of Hummel and colleagues was due to the difference in the action of attention manipulated by perceptual load compared to spatial cuing. They suggested that the effect of attention manipulated via perceptual load may apply to both holistic and analytic processing, whereas that of spatial attention (manipulated by a cue) may affect only analytic processing. Lavie and colleagues have not used spatial cuing in their tests of perceptual load theory; Hummel and colleagues have not included perceptual load in their tests of the hybrid model. Experiment 3 of this thesis combined spatial cuing with perceptual load and therefore it is not straightforward to disentangle their different influences.

Therefore the main aim of Experiment 4 was to examine the ERP repetition effects from peripheral, task-irrelevant images in a paradigm in which the only manipulation of spatial attention was via the perceptual load at a central letter search task (i.e. no spatial cue was used). This was the task that was used in Experiments 3, 4a and 4b of the Lavie et al (2009) study.

The experiments (3, 4a and 4b) of Lavie et al (2009) used a short-lag repetition-priming paradigm using a prime display with an attended target letter search array and flanking task-irrelevant distractor image. Participants were asked to respond to seeing either the letter ‘X’ or ‘N’ amongst 5 other letters in the search array that were either all ‘O’ (low load) or ‘K’, ‘R’, ‘V’, ‘S’ or ‘L’ (high load). The prime display was presented for 195 ms, as was the following probe display, which comprised a single, centrally located image that was either identical to the prime (repeated) or a completely different object (unrepeated).

Having shown that priming from the task-irrelevant distractors was extinguished under high load using this letter search manipulation of perceptual load, Lavie et al (2009) went on to use this task to test the view-sensitivity of the priming in Experiments 4a (mirror-reflection), 4b and 5b (depth-rotation) under low load only. They found equivalent priming for identical and view-changed objects under low load. Overall, their results differed from those of the present Experiments 1-3 in two respects. Firstly, Lavie et al found that priming was extinguished under high load conditions. Secondly, Lavie et al observed view-independent priming under low load conditions. The first aim of Experiment 4 was therefore to behaviourally replicate these results from Lavie et al (2009) in order to examine whether the differences may be due to the use of different manipulations of attention. Experiment 4 therefore tested whether behavioural priming was both extinguished under high load and view-independent under low load when using a paradigm without a spatial cue (the letter search task). It follows from Lavie et al’s suggestion for the difference in the restriction of processing due to perceptual load (analytic and holistic) or spatial cuing (analytic) that view-dependent priming only arises in spatial cuing paradigms.

Another possible explanation for the Lavie et al.’s (2009) result that priming was only found in low load is that they were due to covert eye-movements during the letter search task, although the prime display presentation time was short (195 ms) and should have prevented saccades to the prime-images. The second aim of Experiment 4 was therefore to use eye-tracking during the letter search prime presentation to test for this alternative explnation of Lavie's results.

Therefore, Experiment 4 was adapted from the letter search repetition-priming Experiment 4a of the Lavie et al. (2009) study, here extended to manipulate both factors of perceptual load (high, low) and view (intact, split) in one experiment in order to examine their effects on behavioural priming. The independent variables were the factors perceptual load and view configuration. The dependent variables were the naming response times at of the probe image and eye fixations during the prime display, so Experiment 4 was a purely behavioural study.

According to the hybrid model of object recognition, attention to one object (the letter search array) precludes attention falling on another object (Lavie et al, 2009; Stankiewicz, et al 1998). Therefore in the current paradigm it is expected that only the letter search array will be attended, provided that presentation times for the prime display containing the search array are kept very brief. As familiar views of intact images can be recognised via the holistic route of the hybrid model, which is posited to be automatic and capacity-free, it was expected that intact primes would result in ERP repetition effects. However, as split images require analytic processing for recognition, ERP repetition effects were not expected for split image primes. That is, a View x Repetition interaction was predicted whereby only intact primes would result in repetition effects. However, according to perceptual load theory, repetition effects are only expected under low load. That is, an interaction between Load x Repetition is predicted, whereby only low load primes would result in repetition effects. The key interactions of theoretical interest were therefore those of View x Repetition, Load x Repetition and Load x View x Repetition.

6.2. Participants

The 20 participants tested all reported normal or corrected-to-normal vision and were native English speakers. The data from 15 participants were analysed, the others being excluded due to problems with tracking or calibration of the eye-tracker. These participants were aged between 19-36 years (*M* = 24.2 years, *SD* = 5.10), and 10 were female. All were recruited from the UEL psychology undergraduates in return for course credit.

6.3. Stimuli & Design

The stimuli were 144 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), and Cycowicz, Friedman and Rothstein (1997) and some copyright-free images available from the internet. An additional 22 images were used for practice trials. The eight experimental conditions were (1) low load intact repeated (2) low load intact unrepeated (3) high load intact repeated (4) high load intact unrepeated (5) low load split repeated (6) low load split unrepeated (7) high load split repeated (8) high load split unrepeated. There were 12 trials in each of the eight conditions, giving a total of 96 trials. Each trial included a prime display, comprising the letter search array and a flanking (either to the left or right) prime-image. The prime object was either presented as an intact or split image. For split prime images, the image was split vertically in half and the sides of the two halves swapped over. The probe display comprised one intact image that was either the same object as the previously encountered prime object or a completely different object. All images were standardised to subtend 3.8˚ x 3.8˚ of visual angle.

The letter search array consisted of a circular arrangement of 6 letters. One of the letters was a target that participants had to look for either the letter ‘X’ or ‘Z’. In the low load condition, the 5 other letters (‘nontargets’) were ‘O’s, in the high load condition the non-target letters were ‘J’, ‘L’, ‘R’, ‘S’ and ‘V’. The experimental conditions and corresponding prime and probe presentations are seen in Figure 6-1.

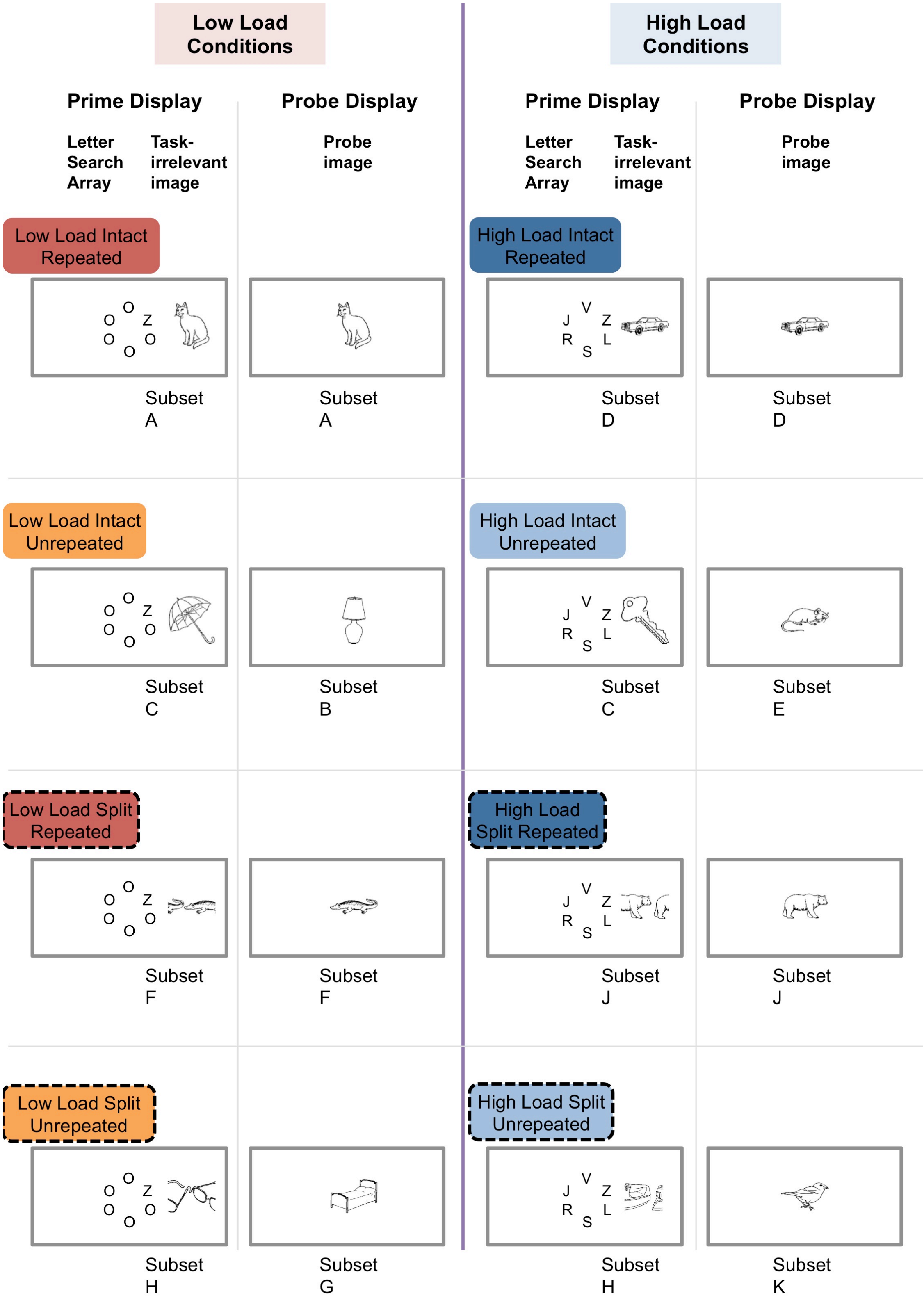

Figure 6-1: Schematic of conditions and stimulus subsets for the first participant in Experiment 4

Each of the object stimuli was allocated to one of 10 subsets (A, B, C, D, E, F, G, H, J and K as also shown in Figure 6-1). Subsets C and H contained 24 objects that appeared as unrepeated primes as intact images (C) and split images (H). Half of the objects in subsets C and D appeared under high load, the other half appeared under low load and this was counterbalanced across participants. To ensure that all objects only appeared once for each participant and that all objects in the repeated conditions appeared equally often in all conditions across participants, the subsets A, B, D, E, F, G, J and K, each containing 12 objects, were counterbalanced across participants. For the first participant, subsets A, B, D and E each contained objects that appeared in random order as intact images in low load conditions as repeated primes and probes (A), unrepeated probes (B) and similarly under high load (D) and (E) under high load. The same logic was applied to the subsets F, G, J and K for split objects under load (F, G) and high load (J, K). The subsets were counterbalanced across participants. Stimulus presentation was controlled using a PC running E-prime v.1. (Psychology Software Tools, Pittsburgh, PA) and displayed on a 19” monitor at a viewing distance of 60 cm.

6.4. Procedure

An example trial sequence is shown in Figure 6-2. Each trial began with a central fixation cross (490 ms) after which the prime display was presented (190 ms). The prime display consisted of central letter search array (low or high load) of diameter 5.7°, flanked either to its left or right at a distance of 8^o by the prime object which was either displayed as an intact or a split image. This was followed by a random-line mask (450 ms) and a blank-screen (1490 ms) whilst participants were required to respond whether they had seen an ‘X’ or ‘Z’ in the letter search array with an appropriate button press. Participants heard a beep on an incorrect response. This was followed by another central fixation cross (495 ms) and then by the presentation of the probe display (190 ms). The probe display comprised either the same object as the prime (repeated) or a completely different object (unrepeated). All probe objects were shown as intact images. A random line mask was then presented (490 ms). This was followed by a blank-screen (1990 ms) whilst participants were asked to sub-vocally name (and simultaneously respond by button-press) the probe object. They were asked to use the same button as they had used to respond to the letter search task. In the event that they had responded incorrectly to the letter search (and had heard a beep) they were asked to use the other button to the one that they had just pressed for the letter search. This ensured that all trials consisting of both correct letter search and probe response could be determined. All participants repeated these instructions back in their own words and found the task straightforward on completion of the practice. At the end of each trial there was a variable randomised jitter of 190, 390, 590 or 790 ms to reduce expectancy effects.

Prior to the experimental trials, participants completed a practice session, which gradually built-up the elements of the task. They first completed 18 trials of the letter search (responding to the ‘X’ or ‘Z’) all in the condition of low load with no flanking non-targets. Then a similar 18 trials were completed in the condition of high load. Then they completed 24 mixed-load trials randomised for low and high load. Finally, they completed 14 mixed-load trials, but with the additional non-target images and naming of the probe image (all images different from those used in the test-trials).

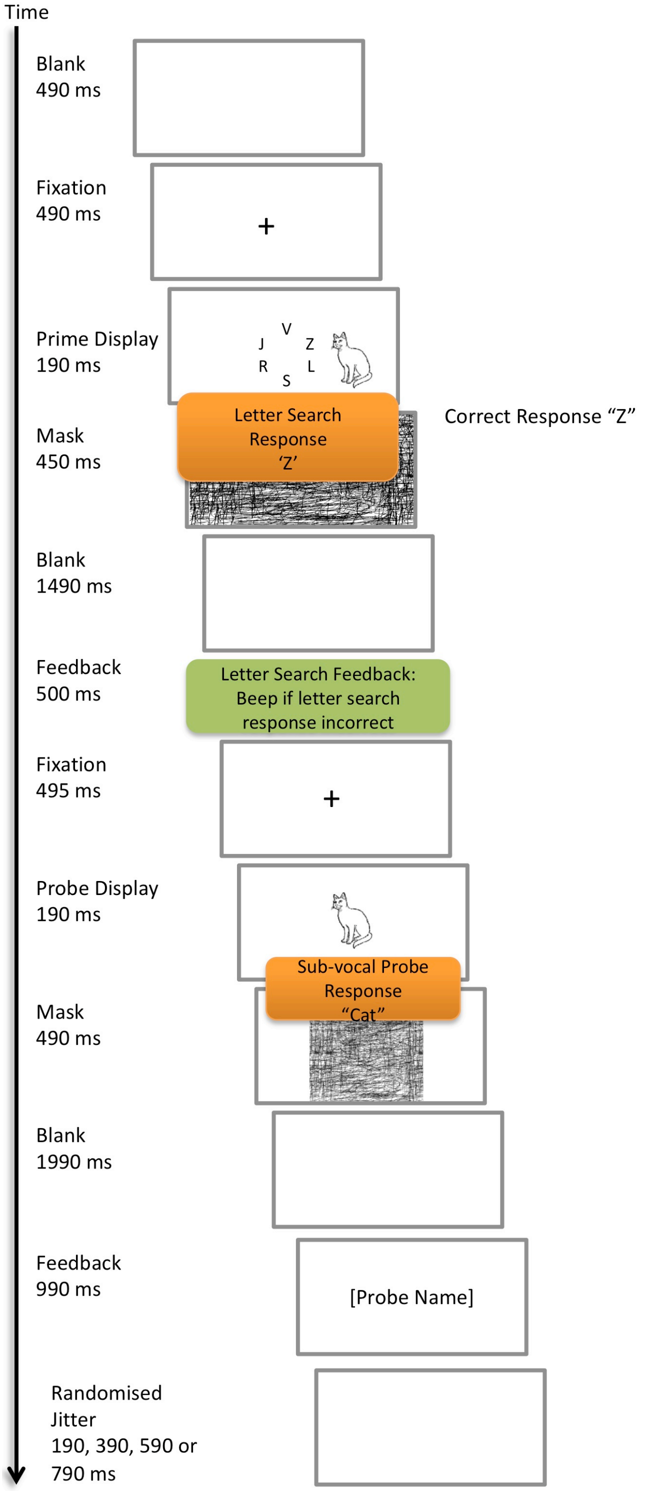

Figure 6-2: Example trial display sequence for Experiment 4.

An Applied Science Laboratories (ASL, Waltham, MA) model 504 remote eye tracking system was used to track the movements of participants' dominant eye during the experimental trials. The sampling rate was set to 60 Hz. Participants used a chinrest during the study to minimise head movements.

6.5. Behavioural Results

Only trials with correct responses for the letter search task and those with a probe RT between 300 ms and 2000 ms were included in the following analyses (61% of all trials). The percentage number of correct prime responses were submitted to a 2 x 2 within participants ANOVA with factors Load (high, low) x View (intact, split). This revealed a significant main effect of load F(1,14) = 14.5, $p = .002$, $\eta_p^2 = .51$. The percentage number of correct responses under high load (M = 79.5%, SD = 3.53) was lower than for low load (M = 93.0%, SD = 4.50) as was expected. There was no other significant main effect nor an interaction between the factors, *ps* > .56.

The percentage number of probe responses were submitted to a 2 x 2 x 2 within-participants ANOVA with factors Load (high, low) x View (intact, split) x Repetition (repeated, unrepeated) and this revealed no significant main effects or interaction *ps* > .13.

The mean prime RT for each participant were entered into a 2 x 2 within participants ANOVA with the factors Load (high, low) x View (intact, split). This ANOVA revealed a significant main effect of load F(1,14) = 34.8, $p < .001$, $\eta_p^2 = .71$. The RT for high load (M = 848.2 ms, SD = 133.9) was slower than for low load (M = 693.0 ms, SD = 164.2) as was expected. There was no significant main effect of view or interaction between Load x View, *ps* > .42.

The mean probe RT for each participant were entered into a 2 x 2 x 2 within-participants ANOVA with factors Load (high, low) x View (intact, split) x Repetition (repeated, unrepeated). This ANOVA revealed that the main effect of view was significant F(1,14) = 6.88, $p = .020$, and that this was modified by a significant interaction between View x Load, F(1,14) = 10.50, $p = .006$, $\eta_p^2 = .43$. The interaction between View x Repetition was also significant, F(1,14) = 4.70, p = .048, η_p^2 = .25. There were no other significant main effects or interactions, *ps* > .18. Follow-up paired t-tests for the View x Repetition interaction showed that the effect of repetition was only significant for intact primes, such that repeated images were named faster (*M* = 633.0 ms, *SD* = 49.1) than unrepeated images (*M* = 692.2 ms, *SD* = 63.9), t(14) = 2.34, p = .035, d = 0.60. For split primes there was no significant priming, p > .6. This result is in support of the prediction from the hybrid model that intact objects should result in priming regardless of the level of load, and is in contrast to the findings of the Lavie et al (2009) study, which showed that there was no priming for high load, and further that both views resulted in priming in low load. The mean probe RT data are shown in Figure 6-3.

Although caution is required in interpreting the non-significant three-way interaction (here p > .18), as outlined by the statistical approach in Section 2.3.4, planned comparisons were performed in order to confirm significant priming in each condition. These revealed that only the low load intact images showed a robust repetition effect (RT for repeated images (*M* =651.5 ms, *SD* = 184.9) faster than unrepeated (*M* = 720.5 ms, *SD* = 283.3), t(14) = 1.91, p = .038 (one-tailed), d = 0.49, other *ps* > .06.

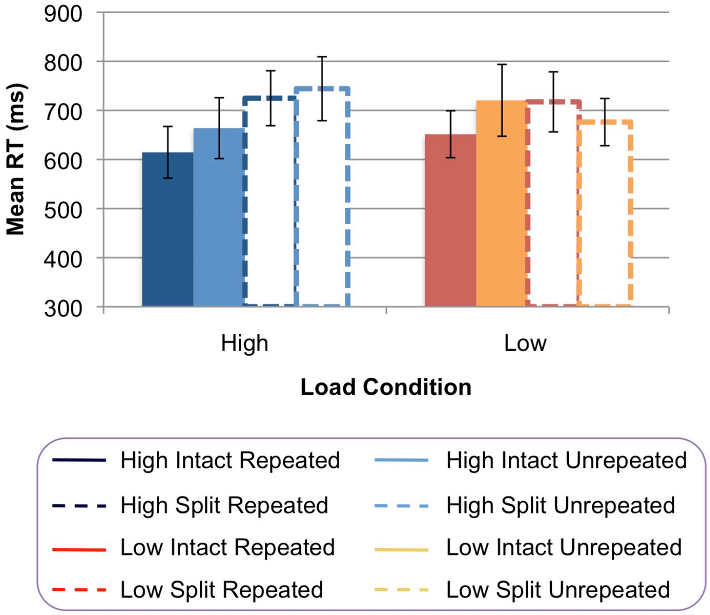

Figure 6-3: Mean probe RT for each condition ±1 standard error bars for Experiment 4.

6.6. Eye tracking Results

Figure 6-4 shows the location and duration of fixations from all participants during the prime display. The areas of interest for analysis of fixations were defined by a square around the extent of each component of the presentation display, that is the letter search array (5.7° x 5.7°) and the area of the flanking image (3.8° x 3.8°) which was centred 8° to the left or right of the array. Only those fixations with duration of 50 ms or longer were included in the analyses. Most fixations were restricted to the area around the letter search array (*M* = 80.9 %, *SD* = 19.4) and there were no fixations found within the area of interest of the distractor images either to the left or right of the display (0% for both cases). There were some (*M* = 19.1 %, *SD* = 19.4) fixations made to areas outside of either of these areas of interest of the letter search array or distractor image. Figure 6-5 shows the percentage number of fixations lasting longer than 50 ms in each area of interest, which were defined as the area of the letter search array, that of the left flanker, that of the right flanker and outside of either of those areas of interest (‘off’).

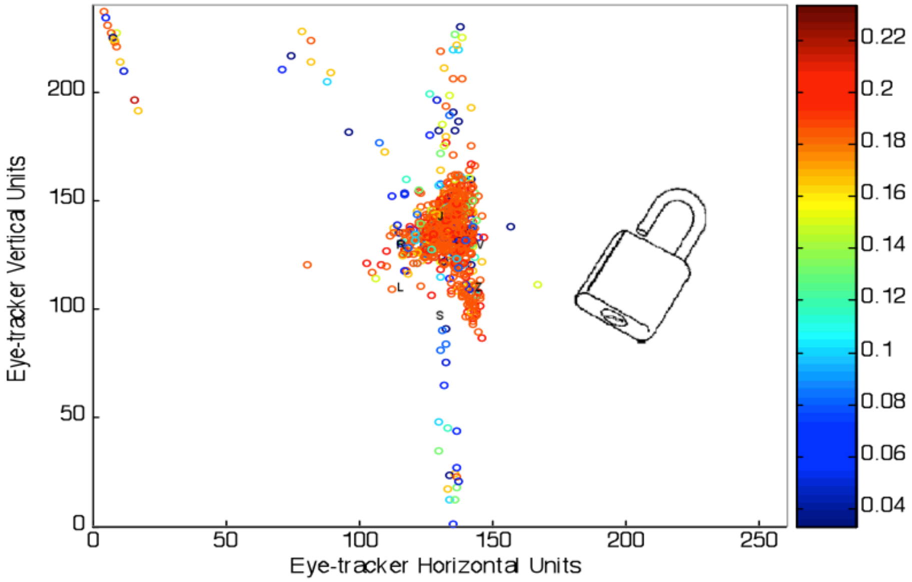

Figure 6-4: Location and duration of fixations from all participants overlaid on prime presentation display for Experiment 4. The colour represents the duration (sec) of each fixation and the location is given in eye-tracker horizontal (x-axis) and vertical (y-axis) units

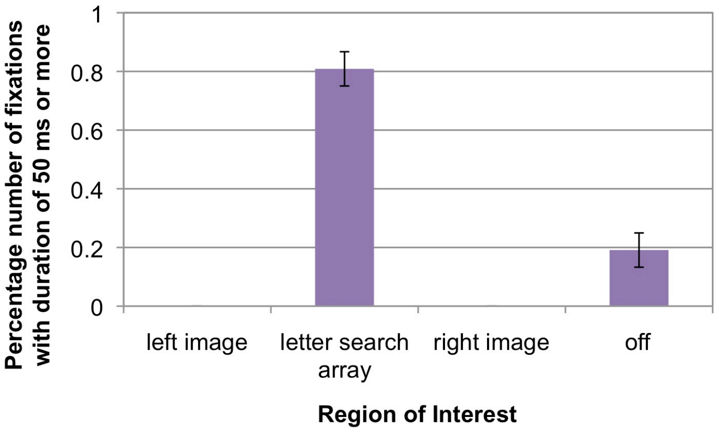

Figure 6-5: Percentage number of all fixations (over 50 ms) for all participants in each defined area of interest of the prime presentation display for Experiment 4. NB for the areas of interest of left and right images there were no fixations.

6.7. Experiment 4: Summary and Discussion

Experiment 4 was a behavioural study adapted from the short-lag repetition-priming paradigm of Experiment 4a of Lavie et al (2009). Here, both the factors of perceptual load and view change (split images) were included. In this present Experiment 4, priming from the task-irrelevant peripheral objects was observed from intact, and not split, images. The eye-tracking data confirmed that the priming observed cannot be attributed to overt fixations to the peripheral object images. The repetition priming for flanker objects was not found under high load. Therefore, the results are partly different to those of Experiment 3 or Lavie et al (2009) and are difficult to explain in terms of either the hybrid model or perceptual load theory.

The present experiment found view-dependent priming under low load, consistent with the holistic route of the hybrid model, and the previous spatial cuing results (even though here there was no cue). This suggests that it was not merely the use of a spatial cue that resulted in the view-sensitivity of priming previously (as argued by Lavie et al., 2009), but rather that the result can be taken to support the notion of an automatic holistic representation across different manipulations of spatial attention.

Experiment 4 indicated that by using a view manipulation of splitting images rather than mirror-reflection (as in Lavie et al., 2009) that priming was view-dependent (see also Thoma et al, 2004; Thoma & Henson, 2011, for the theoretical merits of using split images rather than a mirror image manipulation of view). This suggests that the view-invariance found by Lavie et al. may have been due to the specific view-manipulation they used. According to perceptual load theory, under low load a spillover of attention to the peripheral object results is expected to result in priming that is resilient to view-changes (as they are in effect under attention). This was supported by the results of Lavie et al’s (2009) study in which view-invariant priming for mirror-reflected and depth-rotated 3D images under low load was observed. However, in this current experiment priming from split images was eliminated even under low load. Taken together with the results of Thoma et al (2004), which showed that only attended split images can prime themselves, this lack of priming from the peripheral task-irrelevant split images also indicates that spatial attention was not allocated to them. This is consistent with the assumptions of Stankiewicz et al (1998) that if one object is selected in a visual display of two objects, that the other is effectively ignored.

Under the hybrid model, the holistic route acts without restriction of capacity-restraints on attention, and so the intact primes would have been expected to result in priming even under high load. However, this was not found to be the case, and there was only priming under low load. The elimination of priming under high load would fit with the predictions from perceptual load theory. However, inconsistent with perceptual load theory, under low load the priming was only observed for intact images. The present results are therefore difficult to reconcile with either the hybrid model or perceptual load theory.

One key difference is whether task-irrelevant flanker images are processed at all under high load. In Experiment 4, the observation of priming under low load is a good indication that the processing of the prime objects was sufficient to result in facilitation in naming upon its repeated presentation (Eddy, Schmid, & Holcomb, 2006). However, from the behavioural results alone it is difficult to say whether the lack of priming under high load can be attributed to a lack of processing or whether they have undergone automatic processing, but that it was not sufficient to result in priming. Experiment 5 directly examined whether task-irrelevant flankers were processed under conditions of high perceptual load at the letter search array.

Chapter 7. Experiment 5: The Influence of Perceptual Load in a Letter Search Task on the Processing of Task-irrelevant Peripheral Images

7.1. Introduction

In Chapter 6, Experiment 4 used a letter search task as a manipulation of perceptual load (without cuing). Behavioural priming was only observed for intact and not split images, consistent with the predictions from the hybrid model for the holistic recognition of unattended objects. However, unlike the ERP repetition effects in Experiment 3, for which there was no interaction with load, for Experiment 4 the priming was only significant under low load. It is not clear from these results alone whether the lack of behavioural priming from high load intact objects reflected the lack of their processing under high load, or a difference in sensitivity between behavioural measurements compared to that of ERP. Guillame et al (2009) have argued that ERP effects have consistently been found where behavioural ones have not.

One of the mechanisms for selective attention proposed by Lavie et al (2004, p.339) is “a rather passive mechanism, whereby irrelevant distractor interference is prevented simply because the distractors are not perceived when there is insufficient capacity for their processing”. In this case, it would be predicted that under high load conditions, task-irrelevant distractor objects would not be perceived, that is processed, at all. This is in contrast to the predictions of the hybrid model for the automatic processing of the intact objects (that is, regardless of load). Thus, the aim of Experiment 5 was to investigate the effects of the perceptual load on the processing of task-irrelevant distractor images in the letter search paradigm using ERP.

The first aim of Experiment 5 was to test whether, at the time of encoding, the processing of distractor images was eliminated completely under conditions of high perceptual load (Lavie et al, 2004). This was achieved by using the same comparison as used by Forster and Lavie (2008 a, b) of a distractor present compared to absent. In their studies, Forster and Lavie examined the effect on response time of a letter search task when task-irrelevant images of well-known cartoon characters were shown flanking the central letter search array. Forster and Lavie (2008a) compared the presence (or not) of the flanking distractor images and found that both load and distractor presence showed independent effects. Upon timing the presentation display such that saccades were not possible and adding an element of time pressure for responses, Forster and Lavie (2008b) found that there was a significant interaction between load and distractor presence. High load eliminated the effect of distractor presence. Forster and Lavie argued that this demonstrated attentional capture by the images, which was eliminated under high perceptual load.

The possibility of attentional capture by task-irrelevant, but salient images is also relevant to the work in this thesis. All of the experiments reported here use images of everyday objects. Therefore, it must be considered that there is a possibility that the images themselves draw attention (e.g. from familiarity of everyday objects, or their uniqueness in visual array, Yantis, 2000). Therefore, the second aim of Experiment 5 was to investigate the effect of the presence of distractor images on the allocation of spatial attention at the target in the letter search array, and whether this was eliminated under high load conditions. This was achieved by examining the effects of distractor presence and load on the amplitudes of the N1 and N2pc, which have been demonstrated to be indicators of the allocation of spatial attention (Eimer, 1996; Handy & Mangun, 2000; Luck & Hillyard, 1994).

An advantage of the letter search task is that it provides a similar display to those visual search tasks used in ERP studies of attentional allocation as indexed by the N1 (e.g. Handy & Mangun, 2000) and N2pc (Astle et al, 2010; Eimer, 1996; Luck & Hillyard, 1994). For both the N1 and N2pc the effect of attentional allocation to a target in one visual field is reflected by an enhanced negativity in the amplitude of the contralateral compared to ipsilateral electrode sites. The size of the N2pc (the difference between amplitudes at contralateral and ipsilateral electrodes) is also enhanced by attentional allocation to the target, although there is some debate as to whether it indexes target selection (Eimer, 1996) or distractor inhibition (Luck & Hillyard, 1994). This ambiguity makes it difficult to interpret changes in the magnitude of the N1 or N2pc with attentional capture by the distractors directly. For example, it has been shown that the N2pc is larger for increasing numbers of non-targets in a visual array and their visual similarity to the target, and N2pc is not elicited when a target is presented alone (Luck & Hillyard, 1994). This has been taken to support that the N2pc indexes greater attentional demand at the target, and that this demand is greater with the need to suppress more interfering non-targets. Here this distractor influence on the attentional demands at the target is taken as an indicator of distractor processing[11]. Therefore, in this experiment, if a difference in the size of the N2pc is observed for the conditions of distractor presence vs. its absence, then this will indicate that the distractor has received processing (as an absent distractor can not be processed). If high load eliminates distractor processing, but low load does not, then under high load there will be no difference in the size of the N2pc between when a distractor is present or absent (neither receive processing), but under load load there will be a difference (greater N2pc for distractor present). Distractor influence was taken to indicate attentional capture in the studies of Forster and Lavie.

Related to the possibility that the distractor images may be processed independently of the letter search task is the possibility that the likelihood of the processing of distractors depend upon their proximity to the target letter in the search array. The attentional window allocated around a target may allow distractor influence, but upon becoming narrowed under high load (Caparos & Linnell, 2010) then exclude distractor influence. Therefore, the third aim of Experiment 5 was to examine the effect of distractor proximity with respect to the target position in the letter search array, under high and low load.

Experiment 5 thus adapted the design used in the prime display of Experiment 4 for ERP measurement but removed the probe displays. That is, Experiment 5 was not a repetition-priming study and the distractor objects were never repeated. This rendered the distractors completely task-irrelevant and there was no incentive for participants to pay attention to them. Similar to the Experiments 5a and b of Lavie et al (2009), this design removed the possibility that the nature of a repetition-priming task itself may have caused participants to pay attention to the distractor images. In the Lavie et al Experiments 5a

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[11] An alternative account of the N2pc is that it indexes target selection, and studies supporting this account have demonstrated that the size of the N2pc does not increase with the number of non-targets (Eimer, 1996). Differences across conditions will not be expected under such an account and would be harder to interpret in terms of distractor processing.

and b, priming was tested only after all of the prime trials had been completed. Priming in these experiments was subsequently measured by a surprise memory test, in which participants were presented with the same images mixed with unseen images and asked whether they had seen them before or not. Lavie et al found that object recognition rates were higher in low as compared to high load conditions, thus implying that the priming observed in their previous experiments was not due to the nature of the repetition-priming task.

The conditions of the present Experiment 5 were defined by the crossed factors of Perceptual Load (low, high) and Target-Distractor Proximity (near, far, not present). The independent variables were load and target-distractor proximity. The dependent variables for the ERP measure were the amplitudes of the N1 and N2pc. The response times and accuracies for the letter search task were also recorded. The choice of electrode sites was the parietal (P7/8), occipito-parietal (PO7/8) and occipital (O1/2).

7.2. Participants

The 16 right-handed participants tested all reported normal or normal-to-corrected vision and were native English speakers. They received either course credits or £15 of high street vouchers for their time. However, due to insufficient numbers of artifact-free trials (less than 60%), three participants' data were excluded from further analysis. The remaining thirteen participants (11 female) were aged between 21-40 years (*M* = 25.8 years, *SD* = 6.69).

7.3. Stimuli & Design

The stimuli were 96 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), and Cycowicz, Friedman and Rothstein (1997). The six experimental conditions for the present study were: (1) low load distractor near, (2) low load distractor far, (3) low load distractor not present, (4) high load distractor near, (5) high load distractor far, (6) high load distractor not present. There were 24 trials in each of the six conditions, giving a total of 144 trials. The experimental conditions and corresponding load and distractor presentations are shown in Figure 7-1. Each of the object stimuli was randomly allocated to each of the conditions that included a distractor. All trials were presented on a 17 inch CRT monitor, and images were standardised to subtend 3.8˚ x 3.8˚ of visual angle. Stimulus presentation was controlled using a PC running E-prime v.1 (Psychology Software Tools, Pittsburgh, PA).

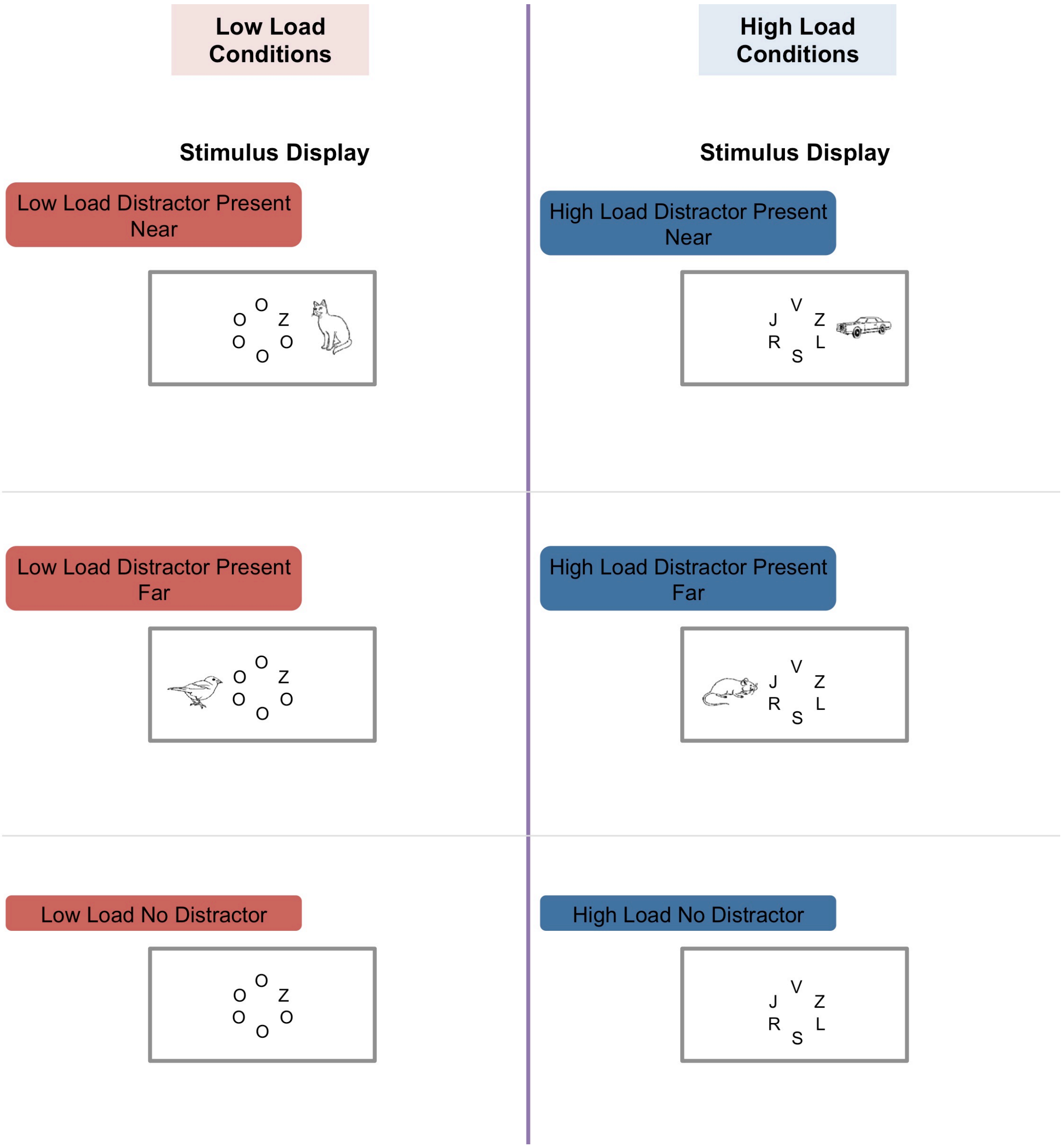


Figure 7-1: Schematic of conditions and stimulus subsets for Experiment 5.

7.4. Procedure

Each of the trials was the same as for Experiment 4, but with the components associated with the probe display removed. An example trial display sequence is shown in Figure 7-2. Each trial began with a central fixation cross (490 ms) after which the letter search and flanking distractor were presented (190 ms). The central letter search array (diameter

5.7°) in either low or high load was either presented alone (distractor not present) or presented simultaneously flanked either to its left or right at a distance of 8° by a distractor-image. There then followed a random-line mask (450 ms). This was followed by a blank-screen (1490 ms) whilst participants were required to respond whether they had seen an ‘X’ or ‘Z’ in the letter search array with an appropriate button press. Participants heard a beep on an incorrect response. At the end of each trial there was a variable randomised jitter of 190, 390, 590 or 790 ms to reduce expectancy effects. Before commencing EEG recording, participants completed a practice session, in which they first completed 18 trials of the letter search (responding to the ‘X’ or ‘Z’) all in the condition of low load with no flanking non-targets. Then a similar 18 trials were completed in the condition of high load. Then they completed 24 mixed-load trials randomised for low and high load.

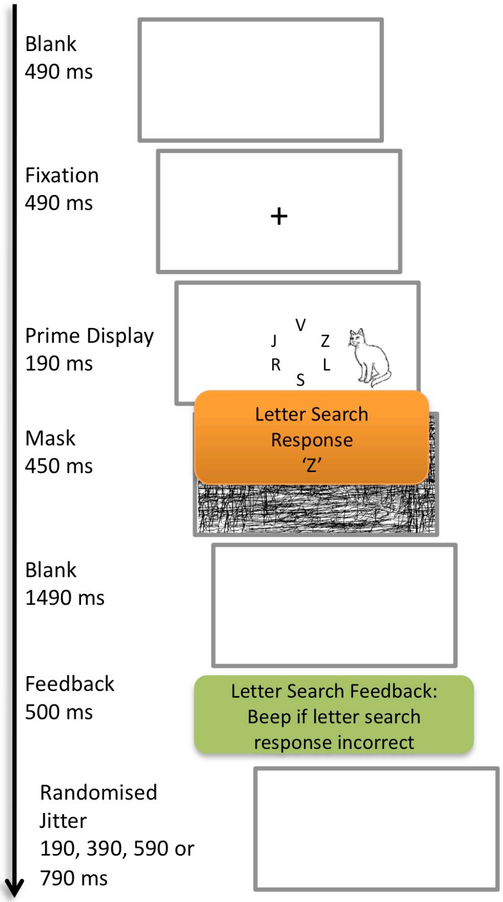


Figure 7-2: Example trial display sequence for Experiment 5.

7.5. Behavioural Results

Only the correct responses that corresponded to RT between 150-1200 ms (representing 2 SD from the grand mean) were included in the following analyses (84% trials included). The mean percentage number of correct responses for each participant was entered into a 2 x 3 within participants ANOVA with factors Load (low, high) x Target-Distractor Proximity (near, far, not present). This revealed a significant main effect of load F(1, 12) = 14.0, $p = .003$, $\eta_p^2 = .54$. The percentage of correct responses in high load (*M* = 83.2%, *SD* = 10.4) was lower than for low load (*M* = 93.3%, *SD* = 5.46) as expected from previous results with this load task. There was no other significant main effect or interaction between the factors, *ps* > .36.

The mean RT for each participant was entered was entered into a 2 x 3 within participants ANOVA with factors Load (low, high) and Target-Distractor Proximity (near, far, not present). There were significant main effects of load F(1,12) = 135.1, $p < .001$, $\eta_p^2 = .92$, and distractor location F(2.0, 23.5) = 3.70, $p = .045$, $\eta_p^2 = .23$, but no significant interaction between these factors $p > .6$. These mean RT data are shown in Figure 7-3. As expected, the RT were slower in high (*M* = 793.8 ms, *SD* = 95.4) compared to low (*M* = 586.6 ms, *SD* = 108.7) load. Paired t-tests revealed that the RT for distractor objects near to the target objects (*M* = 710.9 ms, *SD* = 97.4) was significantly slower than for those far from them (*M* = 680.2 ms, *SD* = 105.4), t(12) = 2.32, $p = .039$, *d* = 0.64, and for when distractors were not present (*M* = 679.3 ms, *SD* = 100.2), t(12) = 2.20, $p = .048$, *d* = 0.61. These latter two conditions did not differ from each other, $p > .9$.

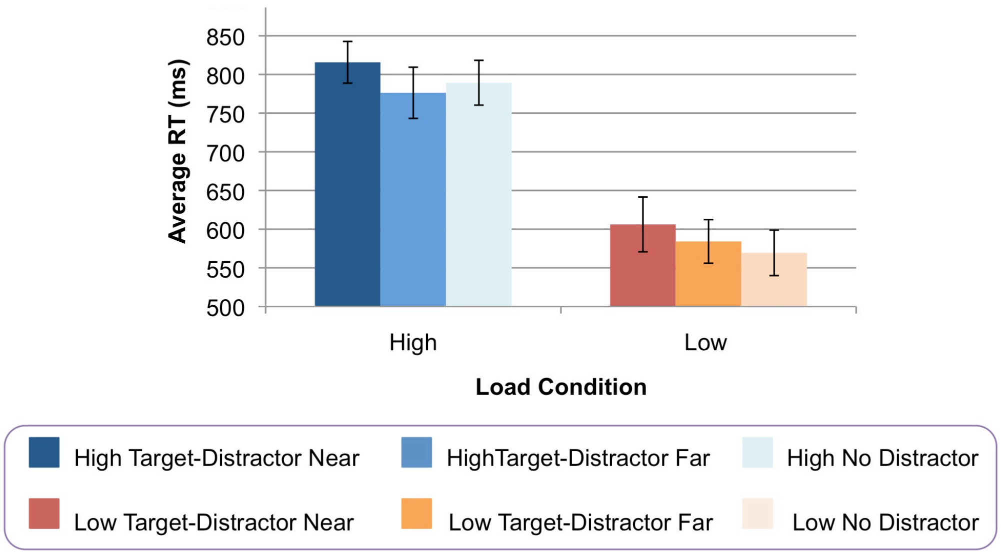


Figure 7-3: Mean RT for each condition ±1 standard error bars for Experiment 5.

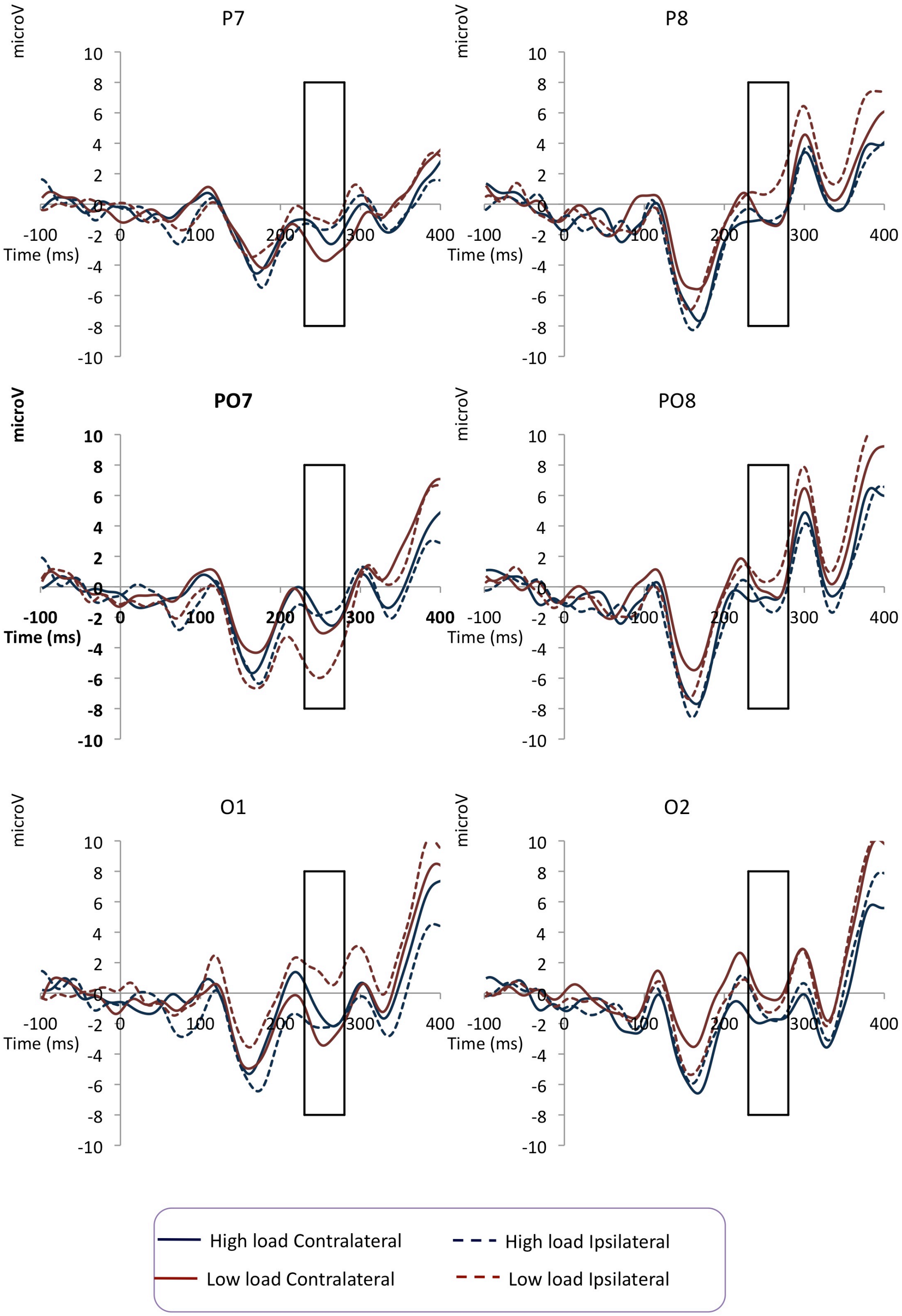
7.6. ERP Results

Pre-processing of the data is described in detail in Section 2.5 and was the same as for the other experiments reported here. Only those responses that were associated with a correct response to the letter search task were used in these analyses. Also, trials in which the target letter appeared at the central vertical positions (top and bottom of array) were not used as these did not correspond to the left or right visual field. Data analyses were focused on the electrode sites P7, P8, PO7, PO8, O1 & O2. All participants' ERP showed peaks within the time windows of N1: 130-190 ms (as confirmed by visual inspection). For N1, a peak-picking algorithm (EGI adaptive mean) was used to calculate the mean amplitudes ± 20 ms around the peak for each participant, allowing the time window to extend out of the nominal time window when necessary. For the N2pc, mean amplitude over the time window of 230-280 ms was calculated for each participant (following Astle et al, 2010).

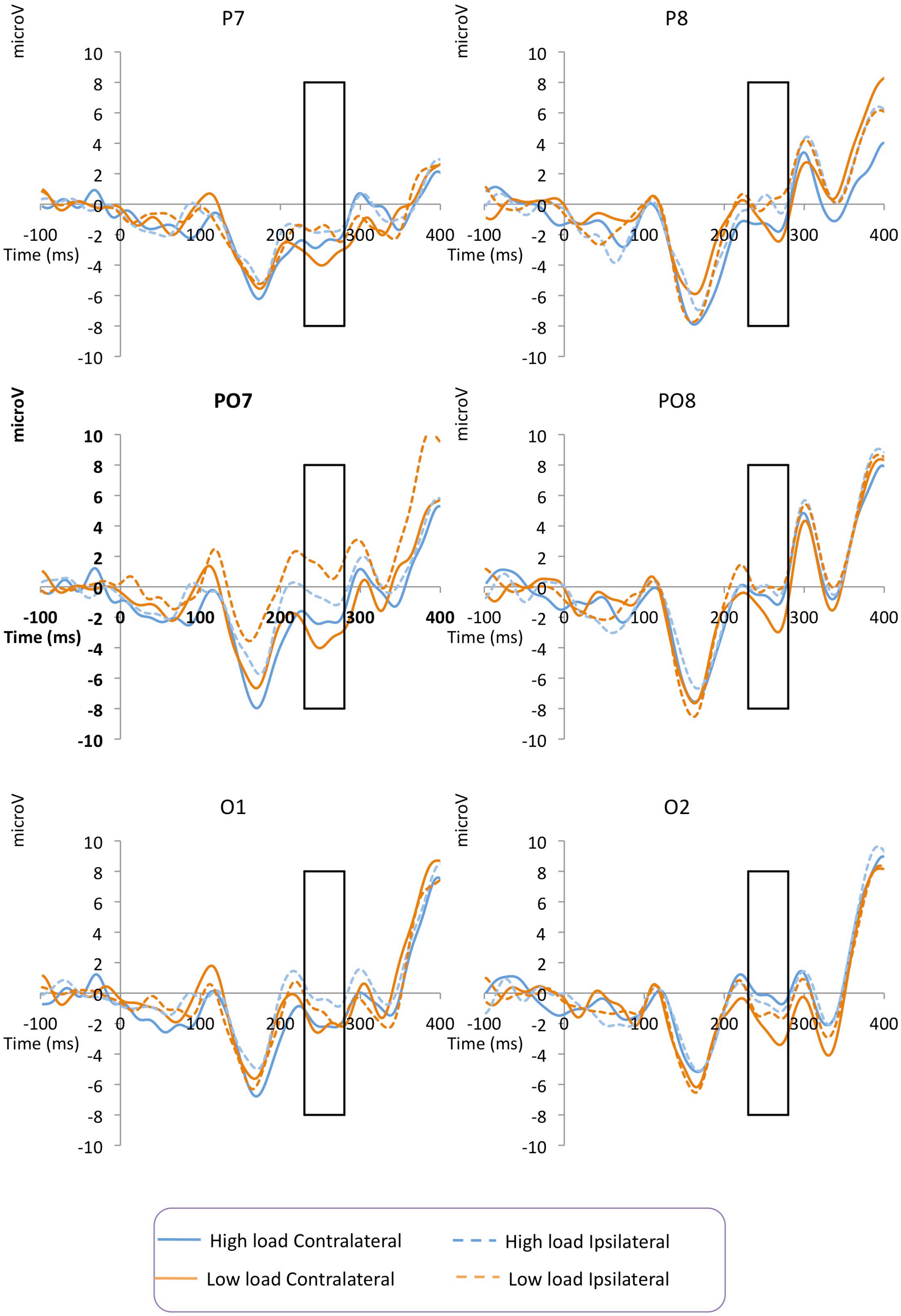
Here the data were entered into separate ANOVAS for the amplitude analyses of the N1 and N2pc, both were analysed under a 2 x 3 x 2 x 2 x 2 within-participants ANOVA with factors Load (low, high), Target-Distractor Proximity (near, far, not present), Contralaterality (ipsilateral, contralateral), Hemisphere (left, right) and Electrode Location (parietal, occipito-parietal) for the P7/8, PO7/8 electrode sites. For the occipital electrode sites, the data were entered into a 2 x 3 x 2 x 2 within-participants ANOVA with factors Load (low, high), Target-Distractor Proximity (near, far, not present), Contralaterality (ipsilateral, contralateral) and Hemisphere (left, right).

The grand-averaged waveform locked to the stimulus display onset for each condition at each electrode site used in the analyses are shown in Figure 7-4.

(a)


P7
P8
PO7
PO8
O1
O2
microV
10
8
6
4
2
0
-2
-4
-6
-8
-10
-100
0
100
200
300
400
Time (ms)
High load Contralateral
High load Ipsilateral
Low load Contralateral
Low load Ipsilateral

(b)


P7
P8
PO7
PO8
O1
O2
microV
Time (ms)
10
8
6
4
2
0
-2
-4
-6
-8
-10
-100
0
100
200
300
400
High load Contralateral
High load Ipsilateral
Low load Contralateral
Low load Ipsilateral

(c)

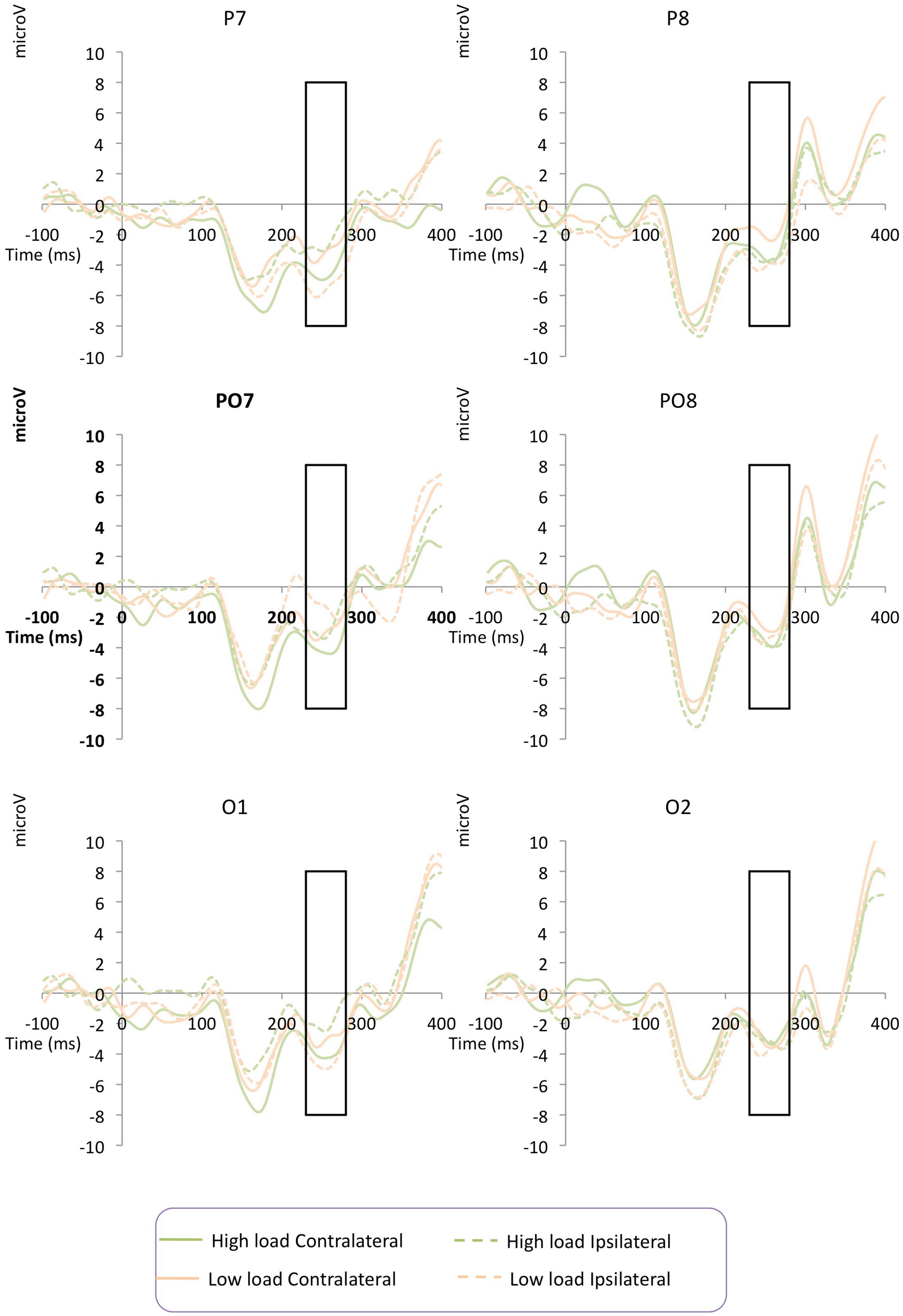


Figure 7-4: Grand averaged ERP contralateral and ipsilateral waveforms locked to stimulus onset for each condition of load for 30 Hz low-pass filtered data for (a) target and distractor near (b) target and distractor far (c) no distractor present for P7, P8, PO7, PO8, O1 and O2 for Experiment 5. The time window for the N2pc is indicated.

7.6.1 N1 Amplitude

The analysis of the amplitudes of the N1 at parietal and occipito-parietal electrodes (P7/8, PO7/8) revealed a significant main effect of load F(1,12) = 5.81, *p* = .033, for which the amplitude for high load was more negative (*M* = -7.23 μV, *SD* = 3.50) vs. low load (*M* = -6.57 μV, *SD* = 3.31). There were also significant main effects of target-distractor proximity F(1.7, 20.2) = 7.25, *p* = .006 (near *M* = -6.16 μV, *SD* = 3.18, far *M* = -6.91 μV, *SD* = 3.94, no distractor *M* = -7.73 μV, *SD* = 3.22) and hemisphere F(1,12) = 511.7, *p* = .020, which showed a more negative amplitude for the right (*M* = -7.80 μV, *SD* = 3.78) vs. left hemisphere (*M* = -5.99 μV, *SD* = 3.38) hemisphere. The four-way interaction between Load x Contralaterality x Target-Distractor Proximity x Hemisphere was not significant F(1.6, 19.2) = 3.16, *p* = .075. There were no other significant main effects or interactions in the main ANOVA, *ps* > .12.

The analysis of the amplitudes of the N1 at occipital electrodes (O1/2) revealed that although the main effect of distractor location was not significant F(1.5, 18.5) = 3.35, *p* = .068, it was qualified by a significant interaction between Load x Contralaterality x Target-Distractor Proximity F(1.6, 19.5) = 4.89, *p* = .024. The interaction between Contralaterality x Hemisphere was nonsignificant F(1, 12) = 3.99, *p* = .069, and neither was the four-way interaction between Load x Contralaterality x Target-Distractor Proximity x Hemisphere F(1.76, 21.7) = 3.30, *p* = .062. There were no other significant main effects or interactions in the main ANOVA, *ps* >.13.
In order to follow-up the interaction between Load x Contralaterality x Target-Distractor Proximity separate ANOVAs were performed on high and low load. These revealed that the only significant effect was that of distractor proximity for low load F(1.9, 23.2) = 5.39, *p* = .013. Paired t-tests then revealed a less negative N1 amplitude for the distractor on the near to the target (*M* = -4.71 μV, *SD* = 2.42) than for the distractor far from the target (*M* = -6.09 μV, *SD* = 3.21), t(12) = 2.57, *p* = .025, and for no distractor (*M* = -6.61 μV, *SD* = 2.81) t(12) = 2.99, *p* = .011.

In summary, for parietal and occipito-parietal electrodes significant main effects of load and distractor proximity were found, but these did not interact. There was also no significant main effect or interaction with contralaterality at these electrodes. However, at the occipital electrodes there was a significant interaction between Load x Target-Distractor Proximity x Contralaterality. Follow up tests revealed that only in low load was there a significant effect of target-distractor proximity, therefore high load did restrict distractor influence at these electrodes.

7.6.2 N2pc

The topomaps showing the difference between (left-right) visual fields for the time window of the N2pc are shown in Figure 7-5. The modulation of the N2pc due to load and target-distractor proximity was investigated in order to test for the processing of the distractor images.

The analysis of the amplitudes of the N2pc at parietal and occipito-parietal electrodes (P7/8, PO7/8) revealed that there was a nonsignificant main effect of load, F(1,12) = 3.79, $p = .075$, but the main effects of target-distractor proximity F(1.9, 22.7) = 14.29, $p < .001$, contralaterality F(1,12) = 6.10, $p = .029$ and hemisphere F(1,12) = 6.11, $p = .029$ were significant. These were qualified by significant interactions between Target-Distractor Proximity x Contralaterality F(1.8, 21.4) = 7.78, $p = .004$, $\eta_p^2 = .39$, Load x Hemisphere F(1,12) = 4.87, $p = .048$, $\eta_p^2 = .29$, Load x Target-Distractor Proximity x Hemisphere F(2.0, 24.0) = 3.51, $p = .046$, $\eta_p^2 = .23$ and Target-Distractor Proximity x Contralaterality x Electrode Site F(1.5, 18.0) = 4.03, $p = .046$, $\eta_p^2 = .25$. There were no other significant main effects or interactions in the ANOVA for these electrodes, *ps* > .15.

In order to follow up the significant interaction between Load x Target-Proximity x Hemisphere at these (P7/8, PO7/8) electrodes, separate ANOVAs were first performed at each level of hemisphere. For the right hemisphere, only the main effect of target-distractor proximity F(1.9, 22.6) = 11.68, $p < .001$, $\eta_p^2 = .49$, was significant. Follow up paired t-tests revealed that the amplitude for no distractor present (M = -2.67 µV, SD =

3.06) was significantly more negative than for when the distractor was present, both when it was near to the target (*M* = .29 µV, *SD* = 4.17), t(12) = 4.57, *p* = .001, *d* = 1.27, and when it was far from the target (*M* = -0.73 µV, SD = 4.18), t(12) = 2.89, *p* = .013, *d* = 0.80, Bonferroni criterion for 3 comparisons $p < .017$. There was no significant difference between whether the distractor was near or far from the target ($p > .8$).
For the left hemisphere there was a significant main effect of load F(1,12) = 6.12, *p* = .029, η_p^2 = .34, which showed the amplitude for high load (M = -2.13 µV, SD = 3.06) was more negative than for low load (M = -1.49 µV, SD = 3.08). There was also a significant main effect of target-distractor proximity F(1.8, 21.8) = 9.44, *p* = .001, η_p^2 = .44, for which the most negative amplitude was for the case of no distractor present (*M* = -3.15 µV *SD* = 2.91), becoming more positive with distractor proximity to the target, far (*M* = -1.45 µV, *SD* = 3.59), near (*M* = -0.73 µV, *SD* = 2.99). The interaction between Load x Target-Distractor Proximity was not significant F(1.5, 18.3) = 3.54, *p* = .061.
The significant interaction between Target-Distractor Proximity x Contralaterality x Electrode Site was followed up by first performing separate two-factor ANOVAs for the parietal and occipito-parietal electrode locations. For both electrode locations, there was a significant interaction between Target-Distractor Proximity x Contralaterality (for parietal F(1.9, 23.2) = 9.77, *p* = .001, for occipito-parietal F(1.9, 22.5) = 4.24, *p* = .029). For the parietal sites, a Tukey HSD on the difference in amplitude (ipsilateral – contralateral) revealed that for no distractor present the difference was significantly smaller to both when the distractor was near to the target (*p* = .002) and when it was far from (*p* = .004), but that these latter conditions did not differ from each other ($p > .9$). For the occipito-parietal electrode sites the Tukey HSD revealed that the when the target was far from the target the N2pc was significantly larger than when there was no distractor (*p* = .025), the difference between the distractor near to the target and there being no distractor was not significant (*p* = .057).

The analysis of the N2pc amplitudes at the occipital electrodes (O1/2), revealed a significant main effect of distractor proximity F(1.8, 21.3) = 9.64, *p* = .001, and a near significant main effect of contralaterality F(1,12) = 4.47, *p* = .056. There was a significant interaction between Load x Target-Distractor Proximity F(1.6, 19.3) = 4.72, *p*

= .028, and these were qualified by a significant four way interaction between Load x Target-Distractor Proximity x Contralaterality x Hemisphere F(2.0, 23.6) = 8.20, p = .002, η_p^2 = .41. There were no other significant main effects or interactions for the ANOVA for these electrodes, *ps* > .10.

In order to follow up the four-way interaction, separate ANOVAs were first performed at each level of Hemisphere. The left hemisphere revealed a significant interaction between Load x Target- Proximity x Contralaterality F(1.7, 20.0) = 3.83, p = .046, η_p^2 = .24, which was not significant for the right hemisphere F(1.5, 17.6) = 3.64, p = .059. In order to follow up the significant three-way interaction that was found in the left hemisphere, two separate two-way ANOVAs were performed at each level of load. For low load, there was a significant interaction between Target-Distractor Proximity x Contralaterality F(1.8, 21.8) = 8.88, p =.002, η_p^2 = .43. Paired t-tests revealed that there was only a significant N2pc elicited when the distractor was near to the target with the contralateral amplitude (*M* = -2.66 µV, *SD* = 3.85) more negative than the ipsilateral (*M* = 1.24 µV, *SD* = 6.24), t(12) = 2.28, p = .042, d = 0.63 (other *ps* >.56). For the ANOVA at the level of high load, no significant main effects or interaction were found, *ps* > .22.

In summary, at the parietal and occipito-parietal electrode sites, a significant interaction between Target-Distractor Proximity x Contralaterality x Electrode Site was found. Analysing this interaction further revealed that although target-proximity affected the size of the N2pc. That is, the N2pc was larger for a distractor present compared to when it was absent. The lack of a significant interaction with load implies that distractor images were processed, at both levels of load.

For the occipital sites (O1/2), the main ANOVA revealed a significant four-way interaction between Load x Target-Distractor Proximity x Contralaterality x Hemisphere. Analysing this interaction further revealed that, in contrast to the P7/8 and PO7/8 sites, load did significantly interact with target-distractor proximity upon the size of the N2pc, in this case in the left hemisphere (O1). At this electrode, a significant N2pc was elicited only when the distractor was near to the target and under low load. This implies that at this electrode site, high load did restrict the processing of distractor images.

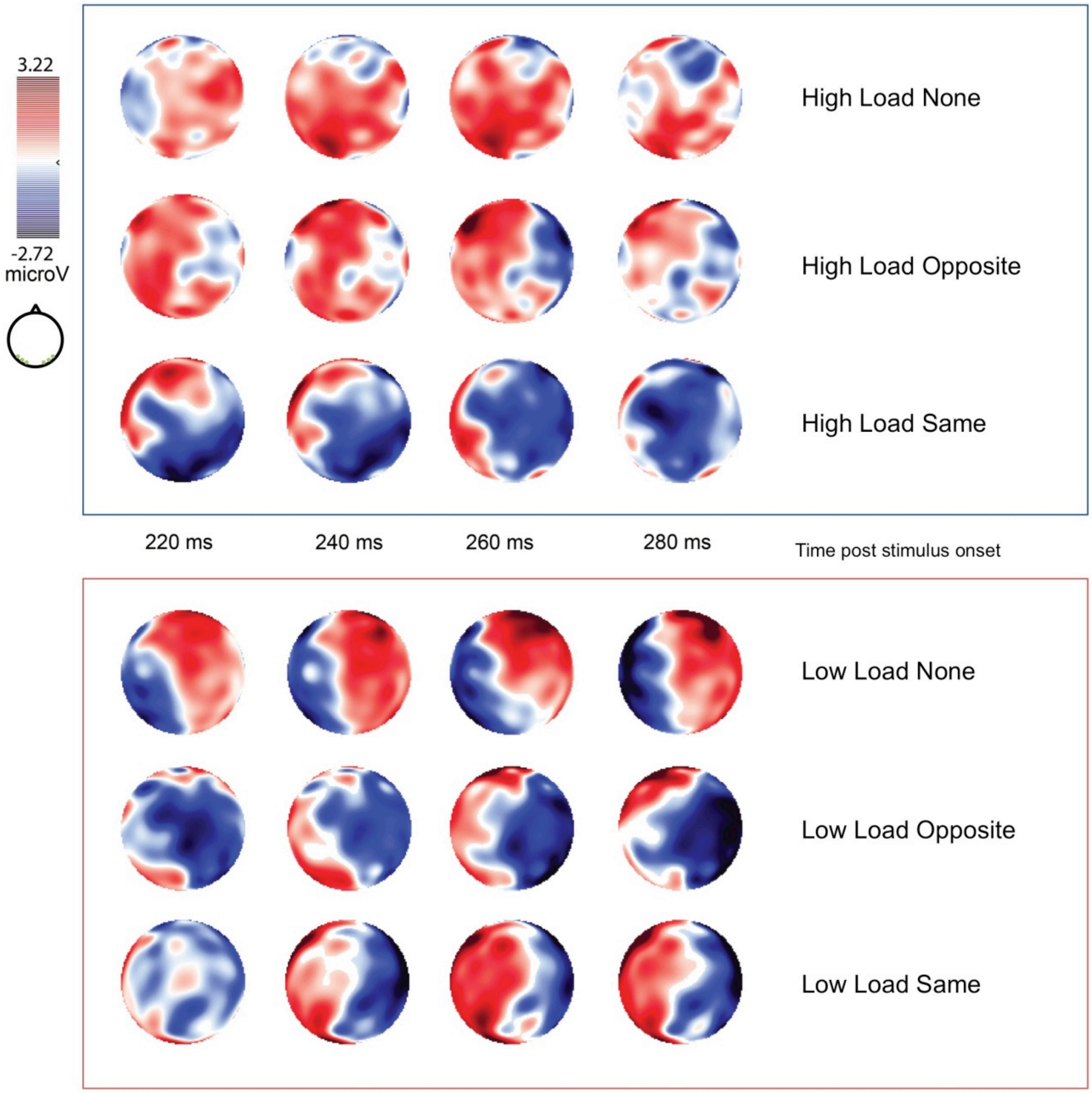


Figure 7-5: Difference topomaps for left-right visual field between 220-280 ms post-stimulus onset in 20 ms steps for each condition for Experiment 5.

7.7. Experiment 5: Summary & Discussion

Experiment 5 was an ERP study to investigate the effects on the amplitude of the N1 and N2pc by the presence of distractor images and perceptual load in a letter search task.

The behavioural data showed that although there were significant main effects of load and target-distractor proximity, that these did not interact. That is, high load did not eliminate distractor influence. There was some indication that when distractor objects were near to the target in the letter search array, that the RT were slowed compared to when distractor and target were presented far from each other. This behavioural measure was similar to that was used by Forster and Lavie (2008a, b) to imply the attentional capture by distractor images. They also used a similar letter search load task with flanking distractors that were either present or absent. In Experiment 5, the timing of the display was controlled such that saccades were prevented to the distractor images (confirmed by the eye-tracking results of Experiment 4). When Forster and Lavie also controlled presentation time to prevent saccades, they found that high perceptual load at the letter search eliminated distractor influence, and so suggested that attentional capture by the distractors had been eliminated. In the present experiment, this argument would lead to the suggestion that distractors captured attention, especially when close to the target letter, and in both cases of load.

The ERP data showed that the N1 amplitude was more negative for high compared to low load, as was expected from the requirement for greater attentional demands in locating the target letter in the high load condition, and consistent with the finding that the N1 amplitude is enhanced with spatial attention (Luck & Hillyard, 1994; Handy & Mangun, 2000). The present results also showed that the most negative N1 amplitude was elicited when there was no distractor present, becoming less negative when there was a distractor far from the target and the smallest N1 elicited by the distractor near to the target (rather analogous to the pattern seen in the behavioural RT). Therefore, this implies that the spatial attention at the target was maximal when no distractor was present, decreasing with proximity of the distractor image to the target. For the occipital sites, this effect of distractor proximity was only only significant under low load, implying that high load did eliminate distractor influence on the amplitude at these electrodes.

Therefore, the current results for the amplitude of the N1 at occipital electrode sites (O1/2), were consistent with the proposal of Lavie et al (2004) that there is no processing of the distractors in the high load condition, particularly as here there was not even a difference in the N1 amplitude between whether the distractor was present or not.

The time window of the N2pc showed a similar story. The parietal and occipito-parietal electrode sites did not show a significant interaction between Load x Contralaterality. At these electrodes, there was, however, a significant interaction between Target-Distractor Proximity x Contralaterality, which showed that there was a larger N2pc elicited when a distractor was present than when there was none present. This suggests that distractor images were processed, at both levels of load. Somewhat similar to the pattern of results at the N1, load and target-distractor proximity were found to significantly interact at the occipital (O1/2) electrodes, here revealed by a significant interaction between Load x Target-Distractor Proximity x Contralaterality x Hemisphere. A significant N2pc was only found at the left hemisphere (O1) site, for the case of distractor and target near to each other and under low load. Therefore, similar to the result of the N1, at this occipital electrode, high load did appear to restrict the influence of the distractor images, but in the case of the N2pc this did affect the allocation of attention at the target.

The size of the N2pc was greatest when a distractor was present than when it was absent. Under the distractor inhibition account, the change in size of the N2pc with distractor presence would imply that the attentional demands at the target was greater when a distractor was present and had to be inhibited, than when the distractor was absent. Therefore, rather than being influenced by the number of non-targets in the letter search array (load), attentional allocation to the target letter was influenced by the presence of a meaningful distractor image.

Overall, the present results indicated that distractor images were perceived (N1) and affected the allocation of attention (N2pc) under both conditions of high and low load. This was apparent at the parietal (P7/8) and occipito-parietal (PO7/8) electrode sites, but not at the occipital (O1/2) sites, where high load did restrict distractor influence on the ERP amplitude.

The results of Experiment 5 indicate that intact distractor objects receive processing resources even under conditions of high perceptual load. Therefore, it is asked whether intact objects will also elicit ERP repetition effects under high load conditions, similar to Experiment 3, or be extinguished under high load, similar to the behavioural priming of Experiment 4. The present results also indicate that the presence of distractors affect attentional allocation. Whether this automatic (observed under high load) processing of distractors is restricted to intact objects as would be predicted for the holistic route of the hybrid model was tested in Experiment 6. In Experiment 5, the differences in distractor processing may only reflect the clear low-level difference between a distractor that is present vs. absent. Therefore the test of the view-sensitivity of ERP repetition effects is required to understand whether the further processing associated with shape recognition also occurs. This was addressed by Experiment 6, which adapted the behavioural Experiment 4 for ERP measurement, and examined the effects of load and view-sensitivity on ERP repetition effects.

Chapter 8. Experiment 6: The Effects of Perceptual Load and View (split images) on ERP Repetition Effects from Task-irrelevant Peripheral Images Using a Letter Search Task.

8.1. Introduction

The aim of Experiment 6 was to test the view and load sensitivity of ERP repetition effects in the letter search paradigm. The results of Experiment 5 indicated that in the letter search paradigm, distractor images received some processing resources, even under conditions of high perceptual load. However, from those results it was not clear whether the processing of the distractors remained at the low-level or whether it would be sufficient to elicit the shape recognition that would be predicted for intact objects under the holistic route of the hybrid model. Under the hybrid model, only intact, upright objects are predicted to elicit repetition effects via the holistic route. The results of the behavioural Experiment 4 showed only significant priming from intact objects under low load conditions, and this was difficult to interpret with either the hybrid model or perceptual load theory. Therefore, Experiment 6 adapted the behavioural Experiment 4 for ERP measurement to examine whether a similar pattern of load and view sensitivity found behaviourally in Experiment 4 would be found for the ERP repetition effects in Experiment 6. The only other change between Experiments 4 and 6 was to include more trials per condition.

Therefore, the experimental conditions for Experiment 6 were the same as for Experiment 4, crossing factors of Load (low, high), View (intact, split) and Repetition (repeated, unrepeated). The dependent variables for the ERP measure were the amplitudes of the probe-locked P1 and N1 peaks, and the mean amplitude of the N250 component. The prime-locked N2pc amplitudes were also derived (following Astle et al, 2010). The naming response times at prime and probe were also recorded. The choice of electrode sites was the occipital O1/2 as well as the parietal/occipito-parietal (P7/8, PO7/8) sites.

According to the hybrid model only intact objects would be expected to elicit ERP repetition effects. These would be expected under both conditions of load. Therefore a significant interaction between View x Repetition would be expected. In contrast, according to perceptual load theory only the distractor images presented under low load would be expected to elicit repetition effects. Here, the spillover of attention to the distractor images would then result in view-independent repetition effects, resulting in a significant interaction between Load x Repetition (Lavie et al., 2009).

ERP repetition effects have been found in the time windows of the P1, N1 and N250, as have effects of load on ERP amplitude, and these time windows were chosen again for investigation here. In the research work presented in this thesis so far ERP repetition effects have been found for the parietal (P7/8) and occipito-parietal (PO7/8) electrode sites in the time windows of the N1 and the N250, showing more negative amplitudes for repeated compared to unrepeated objects. This was the direction of amplitude modulation with repetition that was therefore also expected in this Experiment 6.

8.2. Participants

The 16 right-handed participants that were tested reported normal or normal-to-corrected vision and were native English speakers. They received either course credits or £15 of high street vouchers for their time. However, as three of the participants were over 40 years old (Grady et al, 2006), their data were excluded from the subsequent analyses, as was one participant due to insufficient numbers of artifact-free trials (less than 60%). The remaining twelve participants (eight female) were aged between 21-36 years (*M* = 26.8 years, *SD* = 4.35).

8.3. Stimuli & Design

The stimuli were the same as those used in Experiment 4 with the addition of extra images such that there were in total 576 line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), Cycowicz, Friedman and Rothstein (1997) and some copyright-free images available from the internet. An additional 22 images were used for practice trials. The eight experimental conditions were (1) low load intact repeated (2) low load intact unrepeated (3) high load intact repeated (4) high load intact unrepeated (5) low load split repeated (6) low load split unrepeated (7) high load split repeated (8) high load split unrepeated. There were 48 trials in each of the eight conditions, giving a total of 384 trials. Each trial consisted of a prime display comprising a letter search task with a flanking non-target image of an everyday object, and a probe display consisting of one object image. The probe image was either the same object as presented at the prime, or a different object. All probe objects were presented as intact images. The experimental conditions and corresponding prime and probe presentations are seen in Figure 8-1.

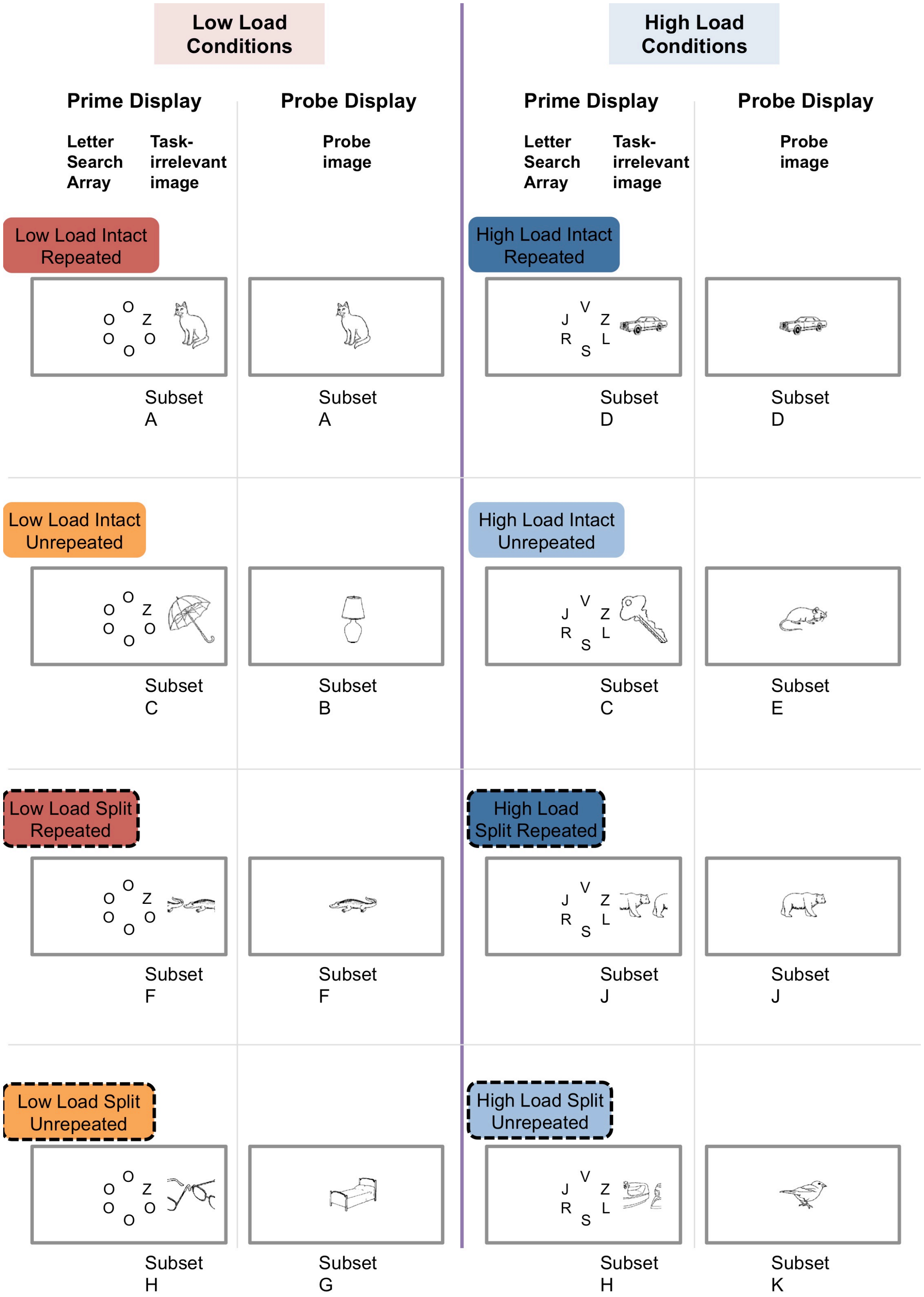


Figure 8-1: Schematic of conditions and stimulus subsets for the first participant in Experiment 6

As for Experiment 4, each of the object stimuli was allocated to one of 10 subsets (A, B, C, D, E, F, G, H, J and K as also shown in Figure 8-1). In Experiment 6, subsets contained 4 times as many objects as in Experiment 4. Subsets C and H contained 96 objects that appeared as unrepeated primes as intact images (C) and split images (H). Half of the objects in subsets C and D appeared under high load, the other half appeared under low load and this was counterbalanced across participants. To ensure that all objects only appeared once for each participant and that all objects in the repeated conditions appeared equally often in all conditions across participants, the subsets A, B, D, E, F, G, J and K, each containing 48 objects, were counterbalanced across participants. For the first participant, subsets A, B, D and E each contained objects that appeared in random order as intact images in low load conditions as repeated primes and probes (A), unrepeated probes (B) and similarly under high load (D) and (E) under high load. The same logic was applied to the subsets F, G, J and K for split objects under load (F, G) and high load (J, K). All trials were presented on a 17 inch CRT monitor, and images were standardised to subtend 3.8˚ x 3.8˚. Stimulus presentation was controlled using a PC running E-prime v.1 (Psychology Software Tools, Pittsburgh, PA).

8.4. Procedure

The trial sequence was the same as for Experiment 4 and the sequence is shown again in Figure 8-2. Only the number of trials differed between Experiments 4 and 6.

Before commencing EEG recording, participants completed a practice session, which gradually built-up the elements of the task. They first completed 18 trials of the letter search (responding to the ‘X’ or ‘Z’) all in the condition of low load with no flanking non-targets. Then a similar 18 trials were completed in the condition of high load. Then they completed 24 mixed-load trials randomised for low and high load. Finally, they completed 14 mixed-load trials, but with the additional distractor images in the prime display and the task of naming the probe image (all images in the practice were different from those used in the test-trials).

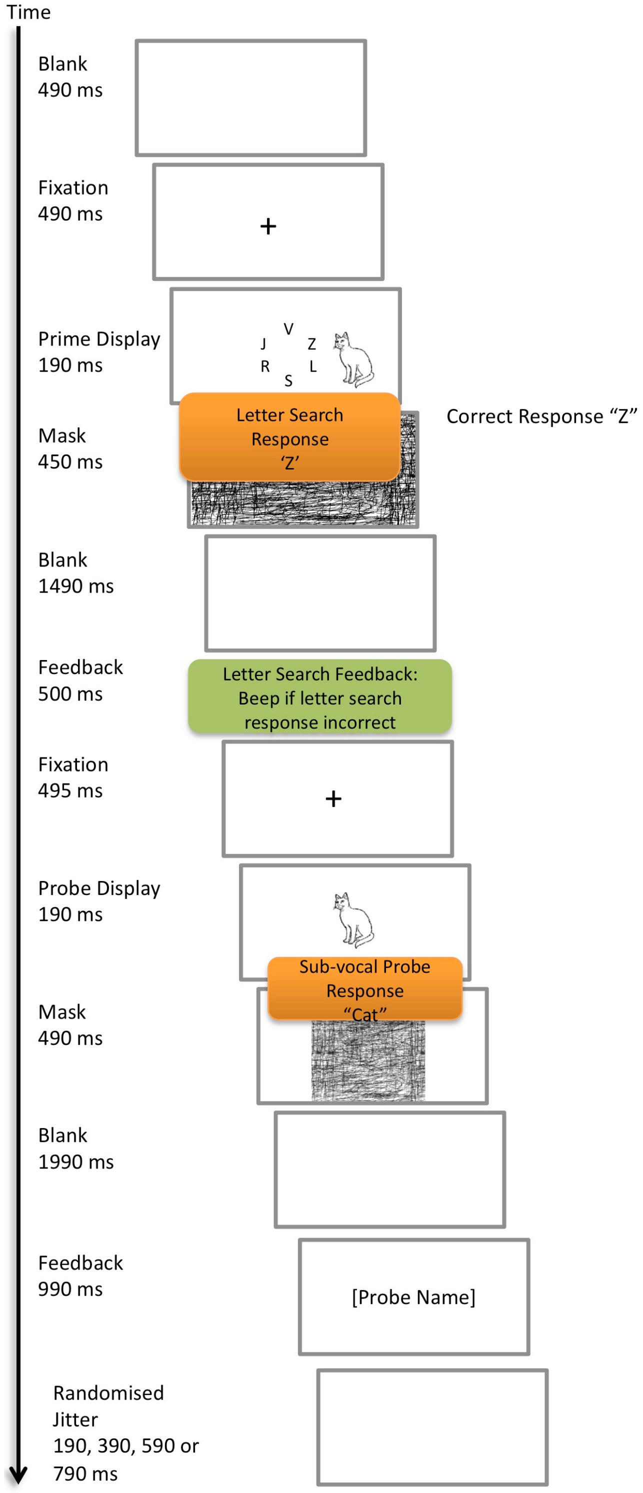


Figure 8-2: Example trial display sequence for Experiment 6.

8.5. Behavioural Results

Only those responses that were correct for both the letter search task and probe responses and where the probe RTs were between 300-2000 ms were used for the following analyses (69% of all trials). The percentage number of correct prime responses were analysed in a 2 x 2 within-participants ANOVA with factors of Load (high, low) and View (Intact, Split). This revealed a significant main effect of load F(1,11) = 18.78, p < .001, η_p^2 = .63. There were more correct responses in low load (*M* = 95.3%, *SD* = 4.59) than high load (*M* = 87.4%, *SD* = 9.18) as expected.

The percentage number of probe responses were analysed in a 2 x 2 x 2 within-participants ANOVA with factors Load (high, low) and View (intact, split) and Repetition (repeated, unrepeated). The interaction between Load x View x Repetition was not significant F(1,12) = 4.07, *p* = .069, η_p^2 = .27. There were no other significant main effects or interactions, *ps* > .10.

The prime RT were analysed in a 2 x 2 within-participants ANOVA with factors Load (high, low) and View (Intact, Split). This revealed a statistically significant main effect of load F(1,11) = 135.4, *p* < .001, η_p^2 = .93, with high load responses slower (*M* = 784.7 ms, *SD* = 94.9) than low load (*M* = 628.5 ms, *SD* = 103.2). The main effect of view was not significant, F(1,11) = 3.67, *p* = .082, and there was no significant interaction between view and load (*p* >.74). Therefore, the letter search manipulation effectively manipulated perceptual load.

The mean probe RT data were analysed in a 2 x 2 x 2 within-participants ANOVA with factors Load (high, low) and View (intact, split) and Repetition (repeated, unrepeated). This revealed a significant main effect of view F(1,11) = 5.21, *p* = .043, η_p^2 = .32, which showed that the RT for intact images (*M* = 573.9 ms, *SD* = 119.6) was faster than for split images (*M* = 587.8 ms, *SD* = 122.1). There was also a significant main effect of repetition F(1,11) = 8.90, *p* = .012, η_p^2 = .45, and a marginally significant interaction between Load x Repetition, F(1,11) = 4.67, *p* = .054. There were no other significant main effects or interactions, *ps* > .25. To follow up the near significant interaction between Load x Repetition, paired t-tests were performed and revealed that only the priming in low load was significant with repeated faster (*M* = 561.8 ms, *SD* = 111.22) than unrepeated (*M* =605.2 ms, *SD* = 128.9) t(11) = 3.27, *p* = .007, *d* = 0.95, whereas this was not the case for for high load *p* > .09. The mean probe RT data are shown Figure 8-3.

Although caution is required in interpreting the non-significant three-way interaction (here *p* > .25), as outlined by the statistical approach in Section 2.3.4, planned comparisons were performed in order to confirm significant priming in each condition. These revealed that only under low load were repeated images named faster than unrepeated (intact images t(11) = 3.11, *p* = .01, *d* = 0.90; split images t(11) = 2.48, *p* = .031, *d* = 0.71). For high load there was no significant priming found, *ps* > .13.

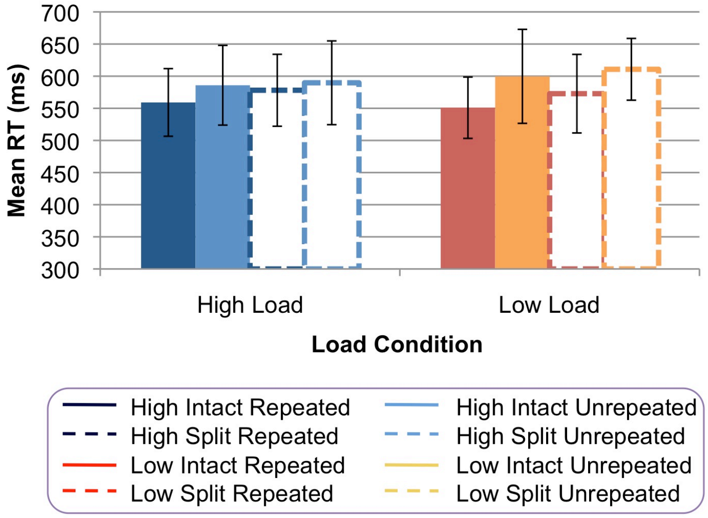


Figure 8-3: Mean probe RT for each condition ±1 standard error bars for Experiment 6

8.6. ERP Results

Pre-processing of the data was performed as described in detail in Section 2.5 and was the same as for the other experiments reported here. Only trials that were associated with a correct response both at the letter search (prime) and probe display were used in these analyses. Data analyses were focused on the electrode sites P7, P8, PO7, PO8, O1 and O2. All participants' ERP showed peaks within the time windows of P1: 60-130 ms and N1: 130-190 ms (as confirmed by visual inspection). For N250, visual inspection of the ERP waveforms indicated that there were two distinct patterns of modulation within the standard time window of the N250 (two portions of the N250r have also been identified in Zimmermann and Eimer (2013). Therefore, for the analyses here, the mean amplitude over the time windows of 230-270 ms and 270-310 ms were calculated for each participant. For P1 and N1, a peak-picking algorithm (EGI adaptive mean) was used to calculate the mean amplitudes ±15 ms around the peak for each participant, allowing the time window to extend out of the nominal time window. The choice of this smaller time window than for Experiments 1-3 (±20 ms) reflected the smaller extent of the peaks that were found for Experiment 6 upon visual inspection of the waveform, and thus avoided overlap between P1 and N1 components.

For electrode sites P7/8, PO7/8, these data were then submitted to a 2 x 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x View (intact, split) x Repetition (repeated, unrepeated) x Hemisphere (left, right) x Electrode Site (parietal P7/8, occipito-parietal PO7/8). For electrode sites O1/2, they were submitted to a separate a 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x View (intact, split) x Repetition (repeated, unrepeated) x Hemisphere (left, right). The grand-averaged waveform for each condition at each electrode site used in the analyses are shown in Figure 8-4.

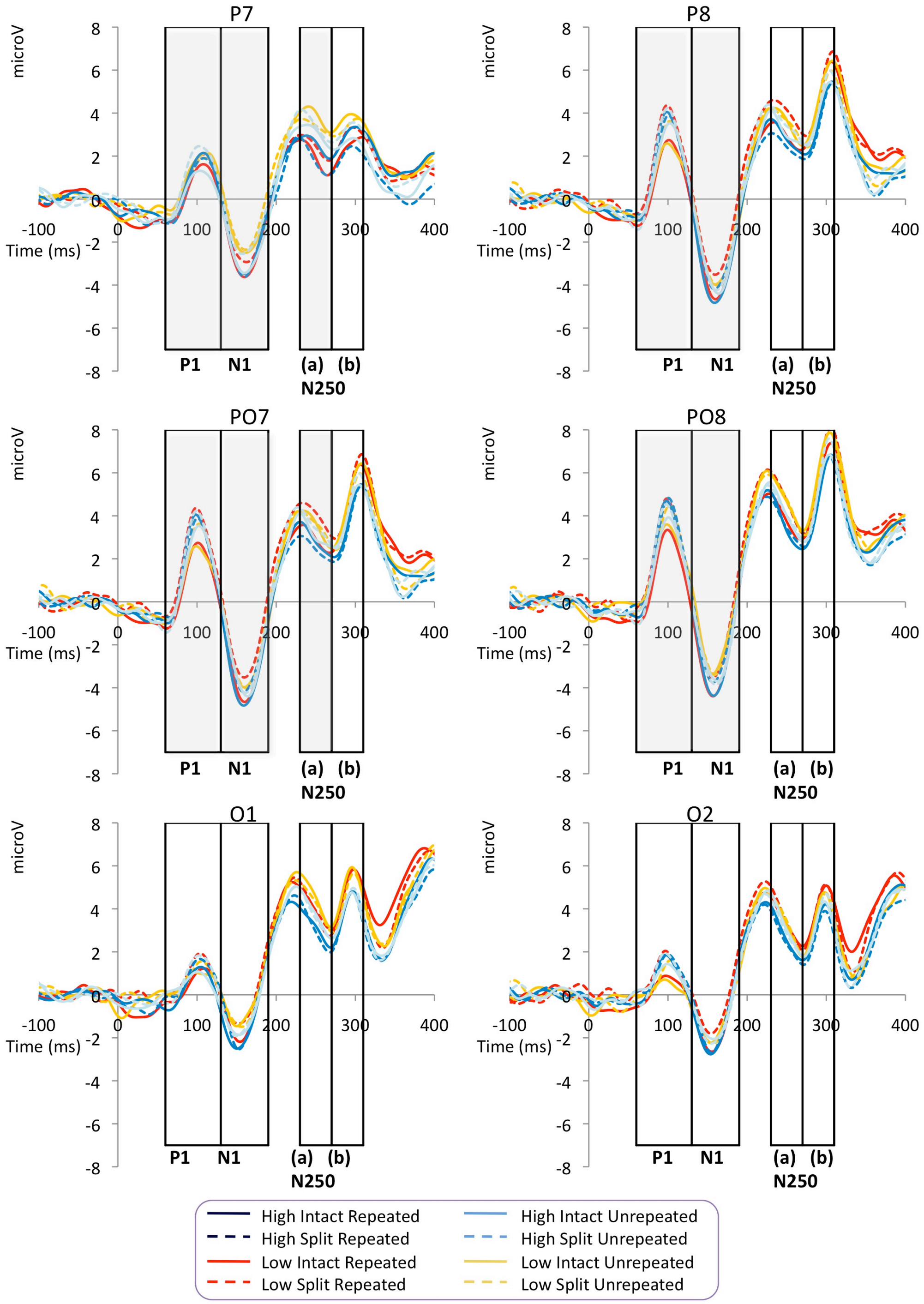


Figure 8-4: Grand-averaged probe-locked ERP waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7, PO8, O1 and O2 for Experiment 6. P1, N1 and N250(a & b) time windows are marked, where these boxes are grey indicates that statistically significant repetition effects were observed in these time windows. For those time windows where statistically significant effects were found, bar charts showing mean amplitudes are presented separately below.

8.6.1 Probe-locked P1

The analysis of P1 amplitude at the parietal (P7/8) and occipito-parietal (PO7/8) electrode revealed a significant main effects of hemisphere F(1,11) = 5.46, $p = .039$, $\eta_p^2 = .33$, for which the amplitude of the P1 was enhanced in the right ($M = 3.56$ µV, $SD = 1.94$) vs. left ($M = 2.15$ µV, $SD = 1.29$) hemisphere. There was also a significant main effect of electrode site F(1,11) = 5.72, $p = .036$, $\eta_p^2 = .34$, and the P1 was enhanced at occipito-parietal PO78 ($M = 3.30$ µV, $SD = 1.68$) vs. parietal P78 ($M = 2.41$ µV, $SD = 1.11$) locations. There was also a significant main effect of view F(1,11) = 5.12, $p = .045$, and this was qualified by a significant three-way interaction between Load x View x Repetition F(1,11) = 4.96, $p = .048$, $\eta_p^2 = .31$. The four-way interaction between Load x View x Repetition x Electrode Site was not significant F(1,11) = 4.18, $p = .066$. There were no other significant main effects or interactions in the main ANOVA, *ps* > .13.
The three-way interaction between Load x View x Repetition was followed up with separate 2 x 2 ANOVAs. These revealed that the interaction between Load x Repetition was only significant for intact primes F(1,11) = 6.01, $p = .032$, $\eta_p^2 = .35$. Paired t-tests then showed that only low load conditions resulted in near significant repetition effects t(11) = 1.94, $p = .039$ (one-tailed), $d = 0.56$. For split image primes the difference was not significant, $p > .30$.

The analysis of P1 amplitude at the occipital (O1/2) electrodes revealed a significant interaction between Load x View F(1,11) = 12.86, $p = .004$. The main effect of hemisphere was not significant F(1,11) = 3.81, $p = .077$, but these were further qualified by a significant interaction between Load x View x Hemisphere F(1,11) = 6.08, $p = .031$, $\eta_p^2 = .36$. There were no other significant main effects or interactions, *ps* >.15.
The three-way interaction between Load x View x Hemisphere was followed up with separate 2 x 2 ANOVAs. These revealed a significant main effect of view only in low load F(1,11) = 5.56, $p = .038$, $\eta_p^2 = .34$, for which the P1 was enhanced for split image primes ($M = 2.00$ µV, $SD = 1.98$) vs. intact ($M = 1.49$ µV, $SD = 1.56$) images, (all high load *ps* > .1). The effect of load was only significant for intact objects in the right

hemisphere t(11) = 3.90, *p* = .002, *d* = 1.13, (Bonferroni criterion for 4 comparisons *p* < .0125), with an enhanced P1 for high (*M* = 2.08 μV, *SD* = 2.25) vs. low (*M* = 1.46 μV, *SD* = 1.95) load. The mean amplitudes of the probe-locked P1 for all electrodes analysed are shown in Figure 8-5.

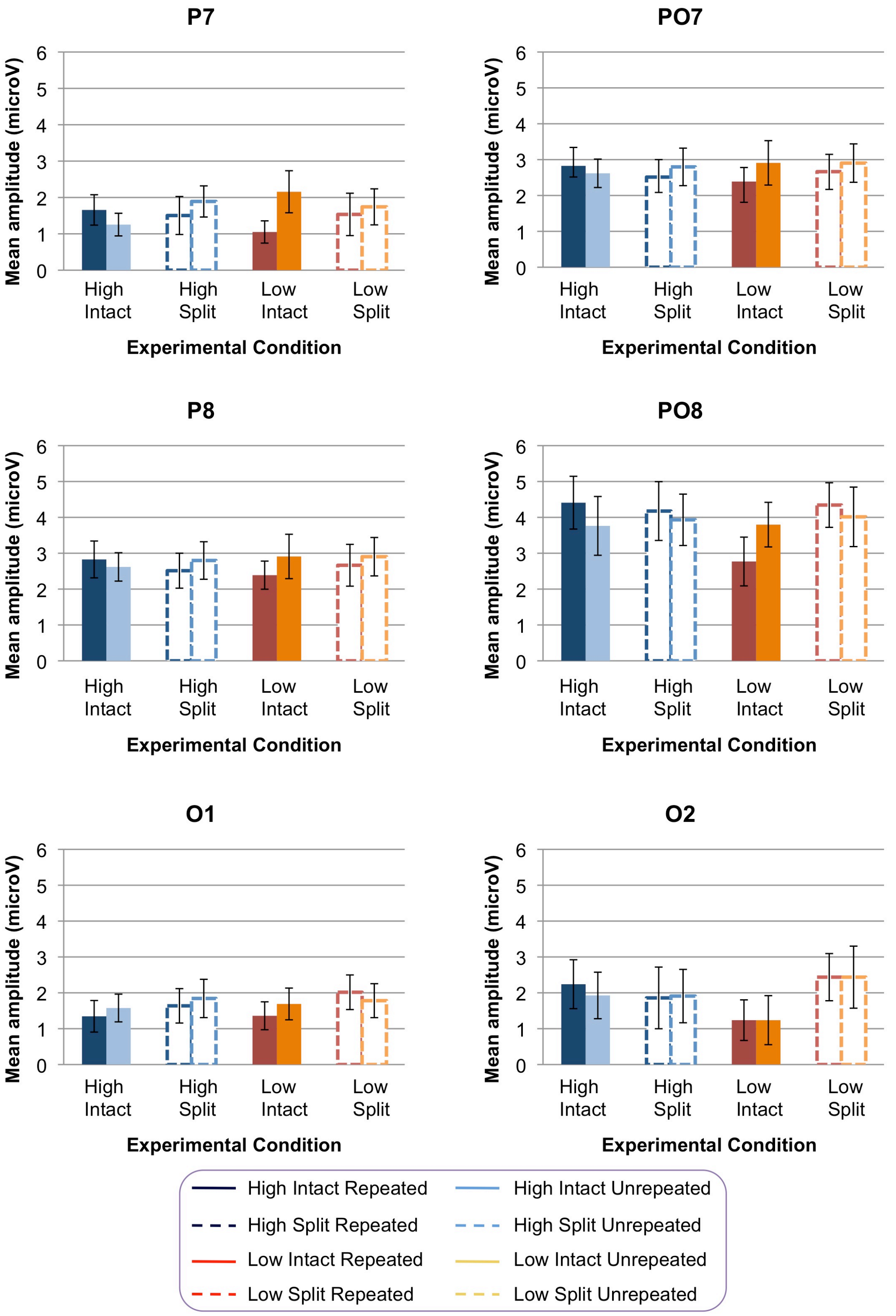


Figure 8-5: Probe-locked P1 mean amplitudes ±1 standard error bars for Experiment 6.

8.6.2 N1

The analysis of N1 amplitude at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a significant main effect of repetition F(1,11) = 5.10, *p* = .045, η_p^2 = .32, and the amplitude of the N1 was enhanced for repeated (*M* = -3.70 µV, *SD* = 3.02) vs. unrepeated (*M* = -3.16 µV, *SD* = 2.74) images. The main effect of view was not significant, F(1,11) = 4.36, *p* = .064. There were no other significant main effects or interactions, *ps* > .11.

The analysis of N1 amplitude at the occipital (O1/2) electrodes revealed a significant interaction between Load x Hemisphere F(1,11) = 6.24, *p* = .03, η_p^2 = .36. The interaction between Load x Repetition was not significant F(1,11) = 3.54, *p* = .087. There were no other significant main effects or interactions, *ps* > .13.
The interaction between Load x Hemisphere was followed up by paired t-tests, which revealed that there was an effect of load in only the left hemisphere, with an enhanced N1 for high (*M* = -2.12 µV, *SD* = 2.44) vs. low (*M* = -1.70 µV, *SD* = 2.41) load, t(11) = 2.85, *p* = .016 (however, this missed significance once corrected for Bonferroni 4 comparisons *p* < .0125). The mean amplitudes of the probe-locked N1 for all electrodes analysed are shown in Figure 8-6.

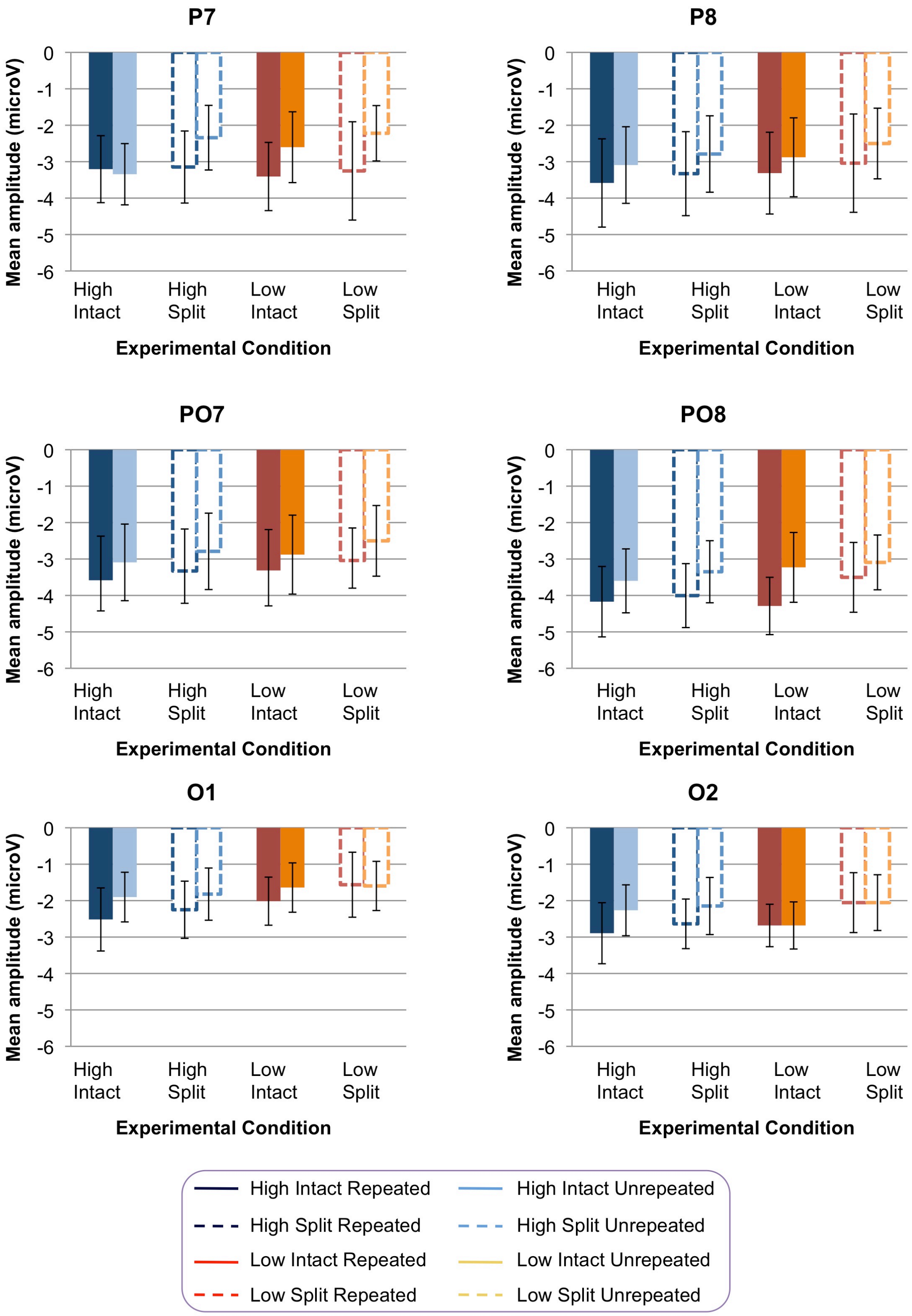


Figure 8-6: Probe-locked N1 mean amplitudes ±1 standard error bars for Experiment 6.

8.6.3 N250: 230-270 time window

This was the first of the two parts of the standard time window for the N250 that were separately analysed, based on visual inspection of the waveforms as mentioned previously. The analysis of N250 amplitude at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a significant main effect of load F(1,11) = 4.98, *p* = .047, η_p^2 = .31, for which the amplitude was more negative for high (*M* = 3.21 µV, *SD* = 5.50) vs. low (*M* = 3.71 µV, *SD* = 5.26) load. There was also a significant main effect of electrode site F(1,11) = 56.39, *p* < .001, η_p^2 = .84, for which there were more negative amplitudes at parietal P78 (*M* = 2.69 µV, *SD* = 5.11) vs. occipito-parietal PO78 (*M* = 4.22 µV, *SD* = 5.62) sites. There was also a main effect of repetition F(1,11) = 9.13, *p* = .012. The interaction between Load x View x Repetition x Electrode Site was not significant, F(1,11) = 4.23, *p* = .064. The interaction between Repetition x Hemisphere did reach significance, F(1,11) = 7.57, *p* = .019, η_p^2 =.41.
Follow-up paired t-tests for the interaction between Repetition x Hemisphere revealed that only the left hemisphere showed significant repetition effects with a more negative amplitude for repeated (*M* = 2.75 µV, *SD* = 4.98) vs. unrepeated (*M* = 4.08 µV, *SD* = 5.31) objects, t(11) = 3.87, *p* = .003, *d* = 1.12.

The analysis of N250 amplitude at the occipital (O1/2) electrodes revealed a significant main effect of load F(1,11) = 15.97, *p* = .002, η_p^2 = .59, for which there was a more negative amplitude for high (*M* = 2.98 µV, *SD* = 4.02) vs. low (*M* = 3.70 µV, *SD* = 3.76) load. The main effect of hemisphere was not significant F(1,11) = 3.89, *p* = .074, and neither was the interaction between Hemisphere x Repetition F(1,11) = 3.64, *p* = .083. There were no other significant main effects or interactions, *ps* > .2. The mean amplitudes of this probe-locked early portion of the probe-locked N250 for all electrodes are shown in Figure 8-7.

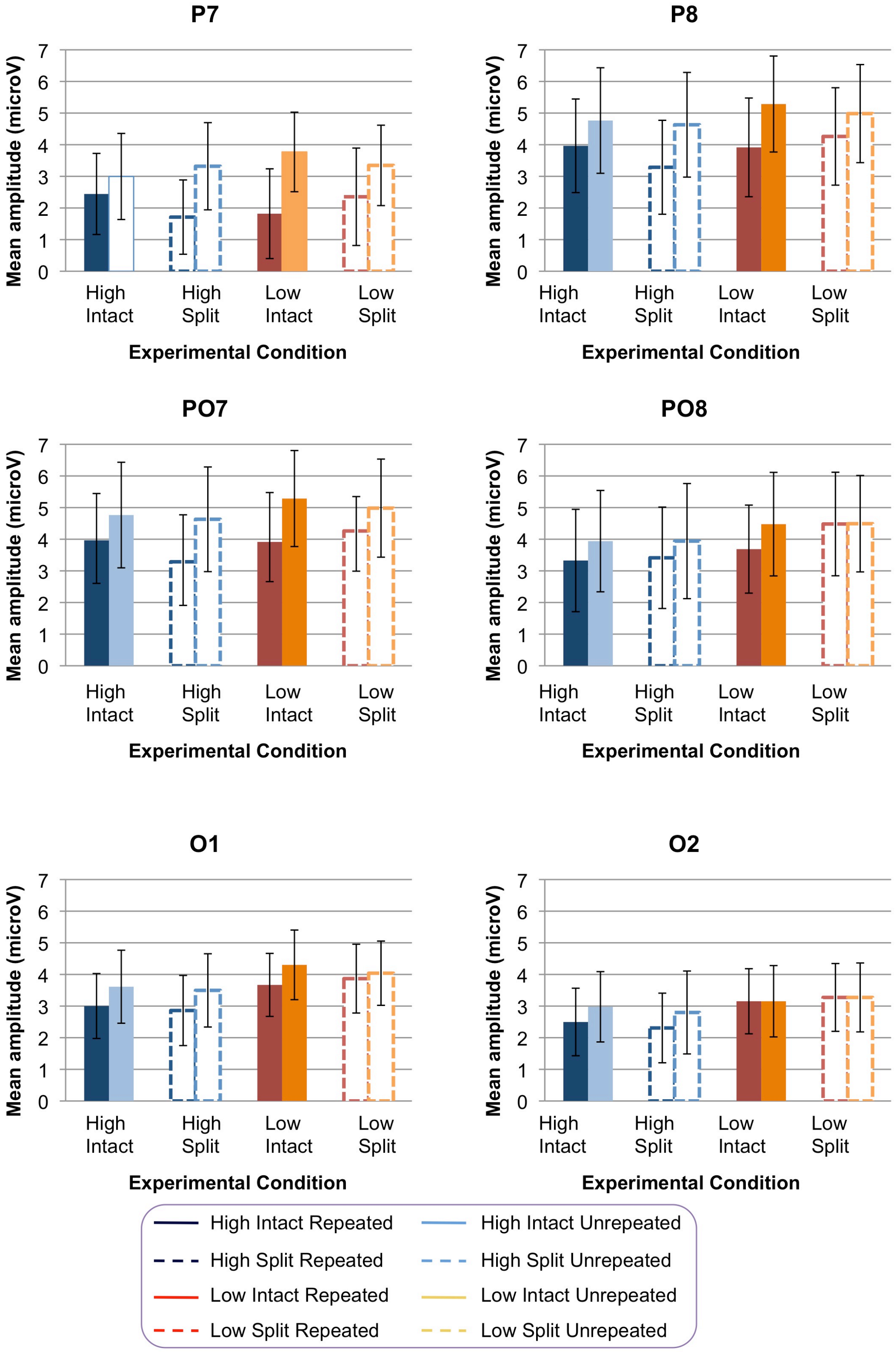


Figure 8-7: Probe-locked N250 (230-270 ms) mean amplitudes ±1 standard error bars for Experiment 6

8.6.4 N250: 270-310 time window

This was the second of the two parts of the standard time window for the N250 that were separately analysed. The analysis of N250 amplitude at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a significant main effect of load F(1,11) = 7.40, p = .02, η_p^2 = .40, for which there were more negative amplitudes for high (M = 4.26 µV, SD = 5.55) vs. low (M = 4.83 µV, SD = 5.52) load. There was also a significant main effect of electrode site F(1,11) = 34.18, p < .001, η_p^2 = .76, with more negative amplitudes for parietal P7/8 (M = 3.48 µV, SD = 5.07) than occipito-parietal PO78 (M = 5.61 µV, SD = 6.01) sites. There were no other significant main effects or interactions, *ps* > .15.

The analysis of N250 amplitude at the occipital (O1/2) electrodes, revealed that only the main effect of load reached significance F(1,11) = 12.40, p = .005, η_p^2 = .53, for which there were more negative amplitudes for high (M = 3.52 µV, SD = 4.65) vs. low (M = 4.29 µV, SD = 4.68) load. There were no other significant main effects or interactions, *ps* > .20.

8.6.5 Prime-locked ERP

The effect of view of the distractor image on the allocation of spatial attention at the target in the letter search was examined by the effect of view on the size of the N2pc. Data analyses were focused on the electrode sites P7, P8, PO7, PO8, O1 and O2. For the N2pc analysis, the mean amplitude for the time window of 230-280 ms was chosen (following Astle et al, 2010) and the data submitted to a 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x Contralaterality (contralateral, ipsilateral) x Hemisphere (left, right) x Electrode Site (P7/8, PO7/8, O1/2 The grand-averaged prime-locked waveform for each condition at each electrode site used in the analyses are shown in Figure 8-8.

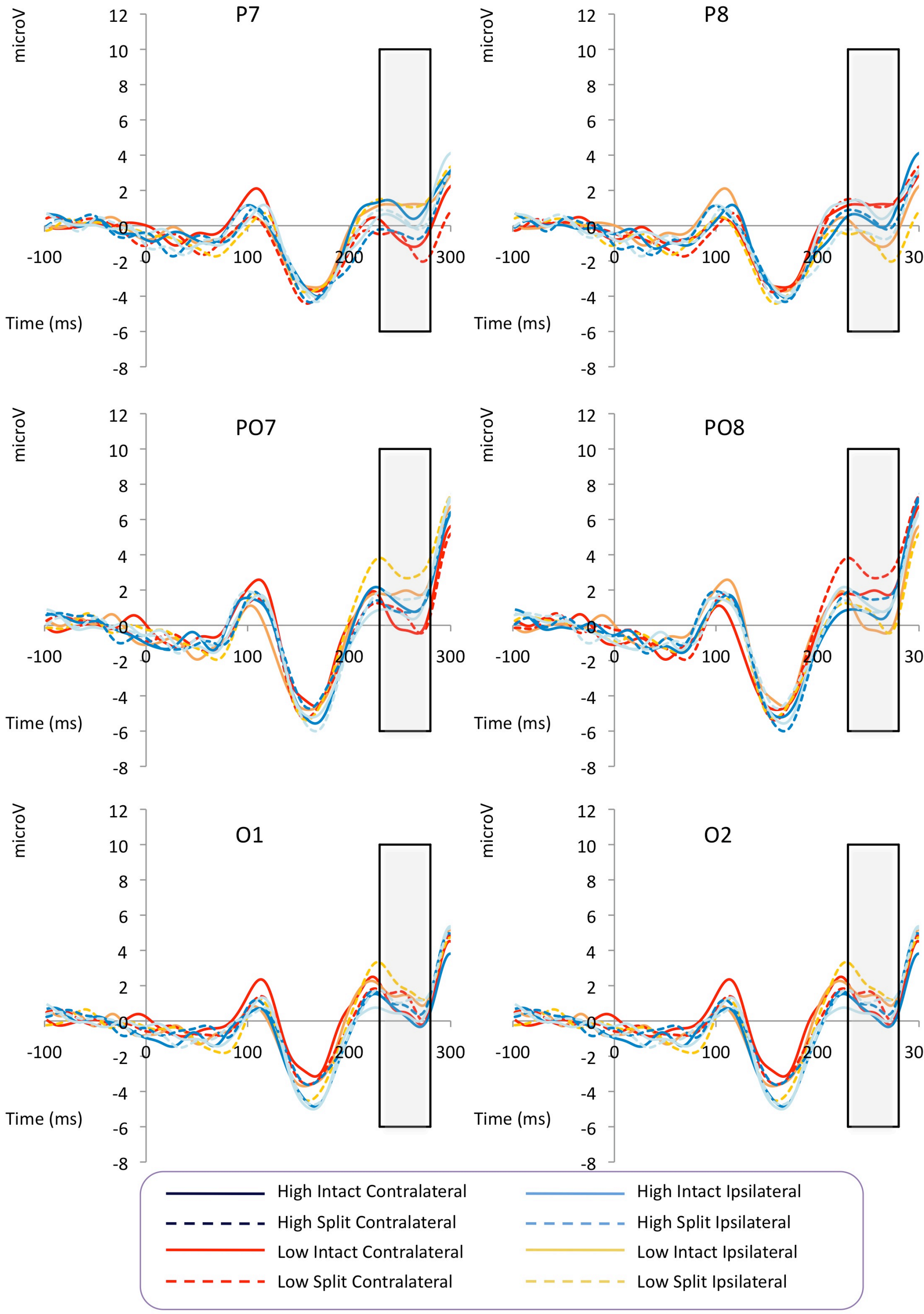


Figure 8-8: Grand-averaged prime-locked contralateral and ipsilateral waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7, PO8, O1 and O2 for Experiment 6. The time window for the N2pc is marked, where this is grey indicates that a statistically significant N2pc was observed.

The ANOVA revealed that there was a significant main effect of contralaterality F(1,11) = 15.83, *p* = .002 that was qualified by significant interactions between Load x Contralerality F(1,11) = 7.04, *p* = .022, η_p^2 = .39, and View x Contralaterality F(1,11) = 6.05, *p* = .032, η_p^2 = .36 . The interaction between Load x Hemisphere was not significant F(1.42, 15.65) = 3.09, *p* = .087. There were no other significant main effects or interactions, *ps* > .1

Follow up paired t tests on the interaction between Load x Contralaterality found that a significant N2pc was elicited under low load, such that the contralateral amplitude (*M* = -0.74 µV, *SD* = 1.20) was more negative than the ipsilateral (*M* = -0.25 µV, *SD* = 1.00), t(11) = 4.26, *p* = .001, *d* = 1.23. This was also the case for high load, although the difference was smaller (contralateral amplitude (*M* = -0.70 µV, *SD* = 1.27), ipsilateral amplitude (*M* = -0.56 µV, *SD* = 1.14)), t(11) = 2.67, *p* = .022, *d* = 0.78. A paired t-test showed that the N2pc for high load was significantly smaller than for low load, t(11) = 2.56, *p* = .026, *d* = 0.74.

Follow up paired t tests on the interaction between View x Contralaterality revealed that there was a significant N2pc was elicited for split image primes only, with contralateral amplitudes (*M* = -0.80 µV, *SD* = 1.25) significantly more negative than ipsilateral (*M* = -0.37 µV, *SD* = 1.19), t(11) = 4.67, *p* = .001, *d* = 1.34. For intact primes this difference did not reach significance, *p* = .059.

In summary, these N2pc results indicated that load and view had independent effects on the allocation of attention to the target in the letter search. The N2pc for low load was greater than than for high load, indicating greater distractor influence under low compared to high load. Only a significant N2pc was elicited for the split images and not for the case of intact images. This difference in size of the N2pc that distractor influence was greater from split, rather than the intact images.

8.7. Experiment 6: Summary and Discussion

Experiment 6 adapted the short-lag repetition-priming paradigm using the letter search manipulation of perceptual load employed in the behavioural Experiment 4 to investigate behavioural and ERP repetition effects. The aim was to investigate the view-sensitivity for ERP repetition effects under perceptual load.

The behavioural prime RT confirmed that the load manipulation produced the expected slower RTs for the letter search responses for high compared to low load. For the probe RT, there was a significant Load x Repetition interaction indicating priming only for low load conditions. This was in agreement with the Lavie et al (2009) results, and thus with the predictions from perceptual load theory. However, this was now discrepant to the behavioural results of the shorter version of the study used in Experiment 4. The planned comparisons indicated that for both experiments the priming in high load was not significantly above zero, and that only for low load the pattern of priming differed between experiments. The comparisons for Experiment 4 indicated that only intact primes under low load resulted in significant priming, but for Experiment 6 they indicated that the priming in low load for both intact and split-primes was significant.

In contrast to the behavioural priming, the ERP results for Experiment 6 indicated that there were significant repetition effects from the distractor objects under high load. However, these were only present in the time line after 130 ms, and prior to this, i.e. within the time window of the P1, repetition effects were observed from intact objects, but only under low load. For the time windows of the N1 and N250 (up to 270 ms) repetition effects were elicited from both intact and split objects under both low and high load. By the later portion of the N250 (270-310 ms) there were no significant effects of view or repetition, but there was a significant effect of load. This pattern of repetition effects is difficult to explain by either the hybrid model or perceptual load theory alone. That is, under the hybrid model, repetition effects from split images were not expected, and under perceptual load theory, repetition effects under high load were not expected.

A possible explanation for the pattern of ERP results is that split images captured attention and thus resulted in repetition effects. This was supported by the observation for a significant N2pc that was elicited by split and not intact objects. Under both the hybrid model and perceptual load theory, the presence of repetition effects for split images implies that they actually received attention (Thoma et al, 2004; Lavie et al, 2009). Intact images did not elicit a significant N2pc, implying that their presence did not affect the allocation of attention to the target location. As the presence of repetition effects from intact objects indicates that they had undergone processing at the prime display, here it is suggested that they did not require attention to elicit repetition effects.

Following the possibility that the repetition effects from split images were due to their propensity to capture attention, it must be asked why attention would be allocated to the split images in Experiment 6. In Experiment 2, using a spatial cuing paradigm, there was no evidence of repetition effects from split images. One possible explanation is that of grouping by the spatial cue leading to a greater restriction of spatial attention than during the uncued letter search task. Perceptual grouping will be discussed further in the General Discussion. Here, it must also be explained why attention was allocated to split images in Experiment 6 resulting in ERP repetition effects in both load conditions and behavioural priming in low load, when they did not prime in the near identical Experiment 4. The only difference between Experiments 4 and 6 was in the number of trials (96 and 384 respectively).

One suggestion is that the longer session used in Experiment 6 also allowed time for the tuning of the visual system to promote the saliency of split images. As discussed in Section 1.17, Desimone and Duncan (1995) have described how all visual input is potentially relevant, and thus must compete for attentional resources to allow for the processing required to complete a specific task. Task-relevant visual properties (e.g. location or a particular feature) are held in an attentional template, that can then draw attention towards them when encountered in the pre-attentively defined saliency map (Itti & Ullman, 1985) describing the saliency of features at locations in the visual array. In Experiment 6, the letter search task requires that a target letter ‘X’ or ‘Z’ be found in the array and thus relies on feature processing for task-completion. Therefore, this task may have promoted part-based or analytic processing and the saliency of featural ‘non-objects’ such as letters and split images, which would then capture attention. The split images share some visual properties with the letter stimuli. For example, the edges of each half of a split image present open-ended lines (rather than the closed lines of intact objects). Also, the sizes of the halves of the split images are closer in size to the letters than are the intact objects.

Another possible interpretation for the pattern of view and load insensitivity for the ERP repetition effect is that, rather than split images capturing attention, that attention simply spilled over to all distractors even under the conditions of high load. One possible reason for the spillover of attention would be that the high load condition was not sufficiently attentionally demanding. However, this was the same task that was used by Lavie et al (2009) in which high load behavioural priming was extinguished, as they were here, even though ERP repetition effects were observed. Under perceptual load theory, attentional resources should be exhausted by the perceptual demands of the high load letter search task. Thus resources cannot be allocated to allow the processing of the distractor objects. However, Experiment 5 indicated that although high load did not eliminate distractor perception, that it did affect the influence of distractor presence as measured by the amplitude of the N1 and N2pc at the occipital electrodes suggesting that high load restricts the effect of distractor processing rather than eliminating the processing itself.

In summary, the ERP results and the discrepancies between the behavioural results of Experiment 4 and the current Experiment 6 indicate a more complicated story than can be explained by either the hybrid model or perceptual load theory. In the context of the present research, it is important to note that the results did indicate that the ERP repetition effects from intact objects were robust under high perceptual load. Therefore, in order to examine whether the repetition effects from split images in Experiment 6 can be attributed to tuning effects (promoting the processing of split halves which are more akin to letters than intact images), Experiment 7 replaced split images with inverted (upside-down images).

Chapter 9. Experiment 7: The Effects of Perceptual Load and View (inverted images) on ERP Repetition Effects from Task-irrelevant Peripheral Images Using a Letter Search Task

9.1. Introduction

In the previously described Experiment 6 the view and load sensitivity of ERP repetition effects from peripheral task-irrelevant objects was investigated, using the comparison between intact image and split image primes (as in the behavioural Experiment 4). Repetition effects were observed for intact primes under low load for the P1, and across all load and view conditions from the time window of the N1. The presence of repetition effects across all conditions led to the suggestion that the distractor prime-images actually received some attention in this letter search paradigm. In contrast, uncued split images did not elicit ERP repetition effects under the spatial cuing paradigm of Experiment 2. However, there is a possibility that the repetition effects from split images were due to some idiocratic properties of this manipulation. For example, as explained in Chapter 8 (Experiment 6), the letter search task may have biased part-based recognition processes or visual tuning that particularly benefited the visual processing of split images (Desimone & Duncan, 1995; Itti & Ullman, 1985). This explanation was followed up in Experiment 7, which aimed to eliminate a possible relationship between the letter search and split images by changing the view manipulation from splitting object images to picture-plane inversion (reflection in the horizontal axis). Inverted images still present a configural change of the spatial relations of an object that will not allow recognition under the holistic route of the hybrid model (Thoma et al., 2007; Stankiewicz, 1997). However, they also present a shape that is a global whole and so are not expected to benefit from a part-based processing (tuning) bias,

Experiment 7 used the short-lag repetition-priming paradigm employed in Experiment 6 only replacing split images with inverted images. Therefore, the experimental conditions were determined by crossing factors of Load (low, high), View (upright, inverted) and

Repetition (repeated, unrepeated). The independent variables were load, view and repetition. The dependent variables for the ERP measure were the amplitudes of the probe-locked P1 and N1 peaks, and the mean amplitude of the N250 component. The prime-locked N2pc was also derived. The naming response times at prime and probe were also recorded. The choice of electrode sites was the occipital O1/2 as well as the parietal/occipito-parietal (P7/8; PO7/8).

The design and predictions for Experiment 7 were equivalent to Experiment 6 except for replacing split images with inverted images. The predictions were the same as for Experiment 6: The hybrid model predicts that only upright objects elicit ERP repetition effects, under both conditions of load resulting in an interaction between View x Repetition. Perceptual load theory predicts that the distractor images presented under low load only elicit repetition effects, relatively independent of view, because the spillover of attention to even the rotated distractor images would processing, resulting in an interaction between Load x Repetition (Lavie et al., 2009).

9.2. Participants

There were originally 17 right-handed participants, all reported normal or normal-to-corrected vision and were native English speakers. They received either course credits or £15 high street vouchers for their time. However, due to insufficient numbers of artifact-free trials (less than 60%), three participants' data were excluded from further analysis. The remaining fourteen participants (ten female) were aged between 19-40 years (*M* = 23.9 years, *SD* = 5.59).

9.3. Stimuli & Design

These were as used in Experiment 6, however some of the images used for Experiment 6 were replaced to ensure that all stimuli had a canonical upright view (objects with a definite base, see Thoma et al., 2007) appropriate for the view-manipulation. A sorting exercise was used in order to confirm that those objects did have a canonical (upright) view. Five independent participants were presented with individually printed copies of all of the stimuli used in Experiment 6 and asked to align them in their canonical view. It was stressed that there was no right or wrong answer and that the exercise was just to help in sorting the images. The consensus (chosen by 3 or more participants) canonical view was chosen for the upright view for the experiment. Any images that did not reach a consensus were excluded from the stimulus set.

A set of 432 black and white line drawings of familiar everyday objects from the picture sets of Snodgrass and Vanderwart (1980), Rossion and Pourtois (2004), Cycowicz, Friedman and Rothstein (1997) and some copyright-free images available from the internet were thus used. An additional 22 images were used for practice trials.

The eight experimental conditions were (1) low load upright repeated (2) low load upright unrepeated (3) high load upright repeated (4) high load upright unrepeated (5) low load inverted repeated (6) low load inverted unrepeated (7) high load inverted repeated (8) high load inverted unrepeated. There were 36 trials in each of the eight conditions, giving a total of 288 trials. Each trial in this experiment was identical to Experiment 6: each trial included a prime display comprising a letter search task with a flanking non-target image of an everyday object, and a probe display consisting of one object image. The letter search array was identical to that of Experiment 6.

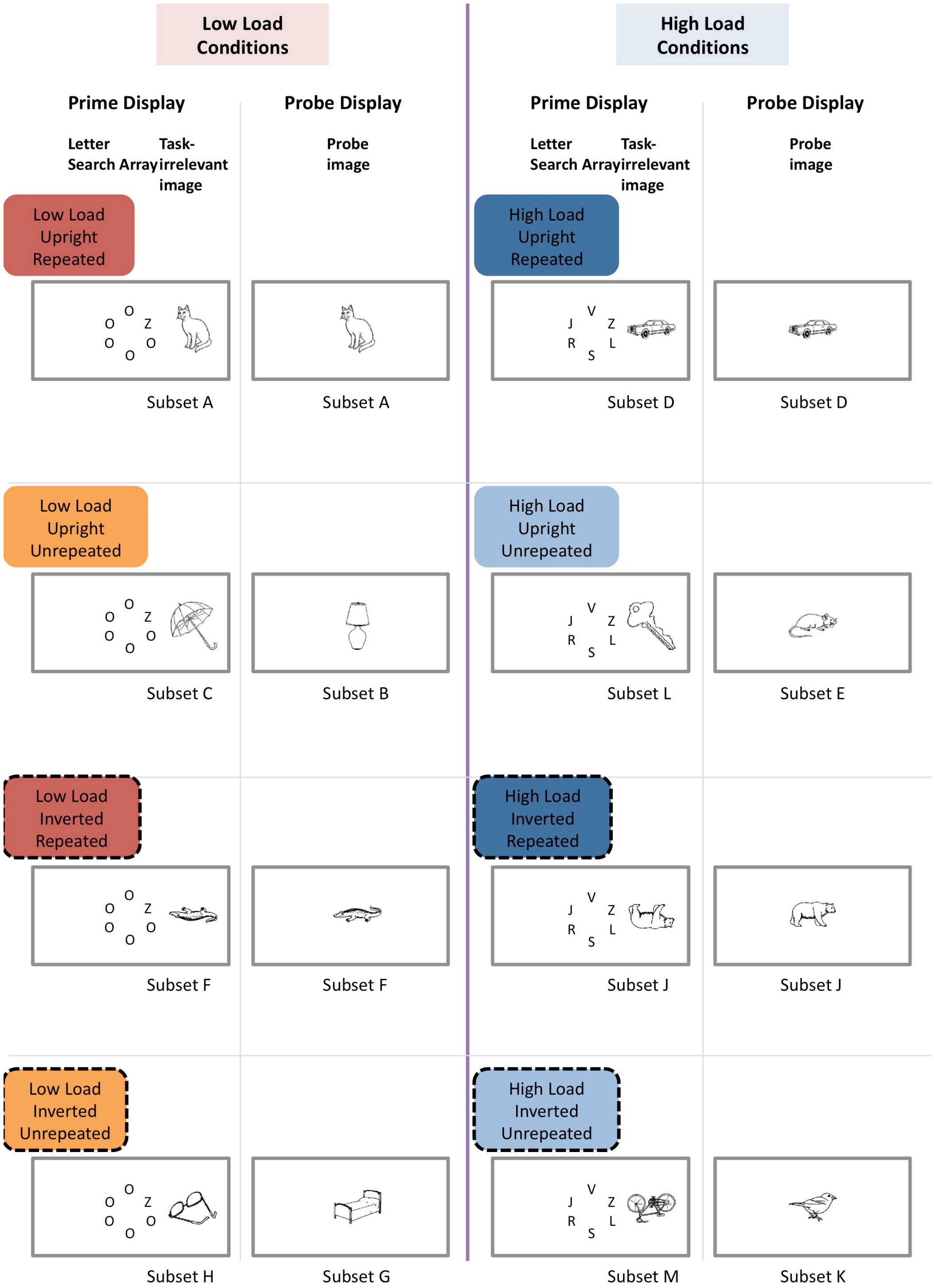


Figure 9-1:Schematic of conditions and stimulus subsets for the first participant in Experiment 7.

Each of the object stimuli was allocated to one of 12 subsets (A, B, C, D, E, F, G, H, J, K, L and M), as also shown in Figure 9-1. All subsets contained 36 objects and were counterbalanced so that all objects appeared in each presentation condition across participants. Trials were presented on a 17 inch CRT monitor, and images were standardised to subtend 3.8˚ x 3.8˚ of visual angle. Stimulus presentation was controlled using a PC running E-prime v.1 (Psychology Software Tools, Pittsburgh, PA).

9.4. Procedure

The trial procedure and testing conditions were the same as Experiment 6. However, due to the limitation of the number of appropriate stimuli for objects with a defined base, here, there were a total of 288 test trials, with counterbalanced load and view conditions by letter search target positions and non-target location

9.5. Behavioural Results

Only trials with a correct prime and probe response and in which probe RT were between 300-2000 ms (86% of trials) were used for the following analyses. The percentage number of correct prime responses were entered into a 2 x 2 within participants ANOVA with factors Load (high, low) x View (upright, inverted). This revealed a significant main effect of load F(1,13) = 40.2, $p < .001$, $\eta_p^2 = .76$, with more correct responses in low load (M = 92.7%, SD = 12.8) than high load (M = 81.3%, SD = 14.1). The main effect of view did not reach significance, F(1,13) = 3.96, $p = .068$, $\eta_p^2 = .23$. There was no significant interaction between these factors, $p > .2$.

The percentage of probe responses in each condition were entered into a 2 x 2 x 2 within participants ANOVA with factors Load (high, low) x View (upright, inverted) x Repetition (repeated, unrepeated). There were no significant main effects or interactions, $ps > .20$.

The prime RT were entered into a 2 x 2 within participants ANOVA with factors Load (high, low) x View (upright, inverted). There was a significant main effect of load

F(1,13) = 61.5, p < .001, η_p^2 = .83, with greater RTs for high load (*M* = 798.1 ms, *SD* = 166.8) than for low load (*M* = 594.2 ms, *SD* = 109.8) as predicted. There were no other significant main effects or interactions in the ANOVA, *ps* > .31.

The probe RTs were entered into a 2 x 2 x 2 within participants ANOVA with factors Load (high, low) x View (upright, inverted) x Repetition (repeated, unrepeated). When all (*N* = 14) participants data were included in the analysis, there were no significant main effects or interactions, all *ps* > .26. However, on excluding the data from one participant who admitted on debriefing that they were not naming the objects, rather, just pressing on the presentation of the image, the ANOVA revealed a significant main effect of repetition F(1,11) = 6.38, *p* = .027, η_p^2 = .35, with repeated objects being named faster (*M* = 582.0 ms, *SD* = 167.8) than unrepeated objects (*M* = 596.0 ms, *SD* = 177.3). There were no other significant main effects or interactions, *ps* > .23. The mean RT data for the probe responses for the *N* = 13 participants are shown in Figure 9-2.

Although caution is required in interpreting the non-significant three-way interaction (here *p* > .23), as outlined by the statistical approach in Section 2.3.4, planned comparisons were performed in order to confirm significant priming in each condition. These revealed that this was only the case for low load upright images, t(12) = 2.67, *p* = .010 (one-tailed), *d* = 0.74, other *ps* > .12. This result was consistent with that found in Experiment 4, in which there was only significant priming from low load intact (and not split) images.

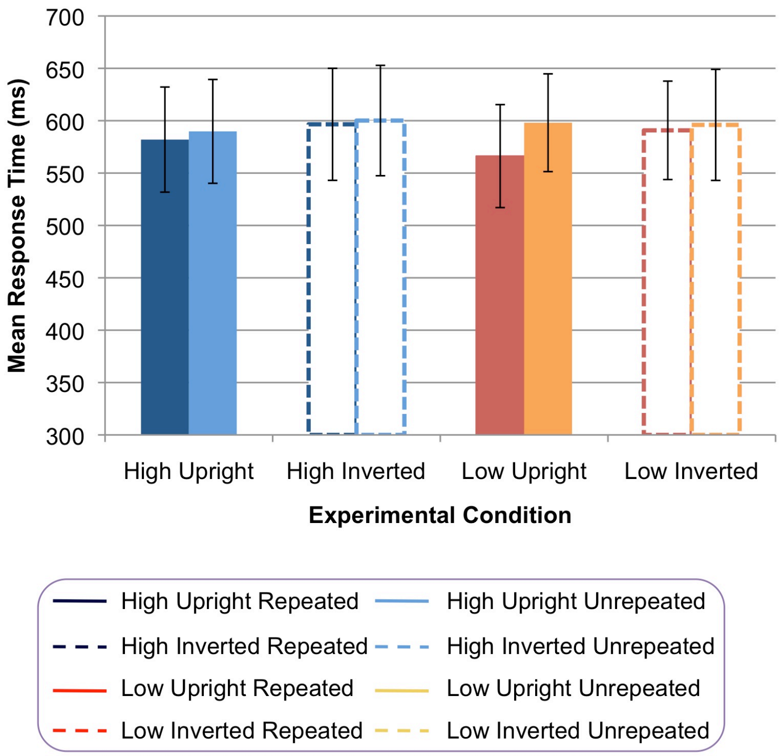


Figure 9-2: Mean probe RT for each condition ±1 standard error bars for Experiment 7.

9.6. ERP Results

Pre-processing of the data is described in detail in Section 2.5 and was the same as for the other experiments reported here. Only those responses that were associated with a correct response both at the letter search (prime) and probe display were used in these analyses. The reported ERP analyses used the data from all 14 participants. Analyses where the ERP data were excluded from the participant whose behavioural results were excluded did not differ in the pattern of the results, and are reported in Appendix II. Data analyses were focused on the electrode sites P7, P8, PO7, PO8, O1 and O2. All participants' ERP showed peaks within the time windows of P1: 60-130 ms and N1: 130-190 ms (as confirmed by visual inspection). For N250, as for Experiment 6, visual inspection of the ERP waveforms indicated that there were two distinct patterns of amplitude modulation with condition within the standard time window of the N250. Therefore, for the analyses here, the mean amplitude over the time window of 200-240 ms and 240-270 ms were separately calculated for each participant. For P1 and N1, a peak-picking algorithm (EGI adaptive mean) was used to calculate the mean amplitudes ±15 ms around the peak for each participant, allowing the time window to extend out of the nominal time window when necessary.

For electrode sites P7/8, PO7/8, these data were then submitted to a 2 x 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x View (upright, inverted) x Repetition (repeated, unrepeated) x Hemisphere (left, right) x Electrode Site (parietal P7/8, occipito-parietal PO7/8). For electrode sites O1/2, they were submitted to a separate a 2 x 2 x 2 x 2 within-participant ANOVA for each component, with factors Load (high, low) x View (upright, inverted) x Repetition (repeated, unrepeated) x Hemisphere (left, right). The grand-averaged waveforms for each condition at each electrode site used in the analyses are shown in Figure 9-1.

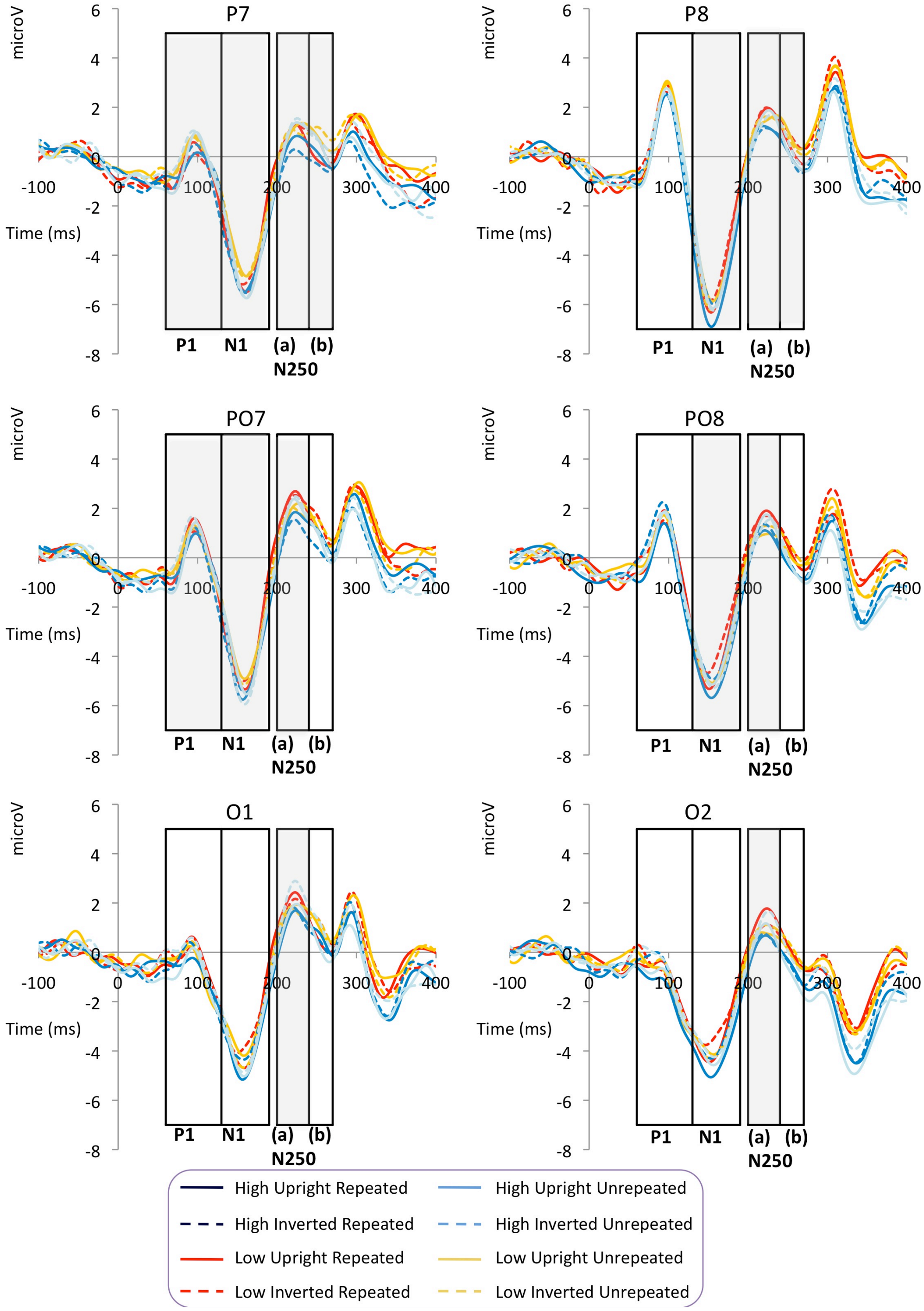


Figure 9-3: Grand-averaged probe-locked ERP waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7, PO8, O1 and O2 for Experiment 7. P1, N1 and N250(a & b) time windows are marked, where these boxes are grey indicates that statistically significant repetition effects were observed in these time windows. For those time windows where statistically significant effects were found, bar charts showing mean amplitudes are presented separately below.

9.6.1 Probe-locked P1

The analysis of the amplitude of the P1 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes, revealed a significant interaction between View x Repetition x Hemisphere F(1,13) = 11.58, p = .005, η_p^2 = .47. There was also a significant interaction between Hemisphere x Electrode Site F(1,13) = 7.66, p = .016, η_p^2 = .37. There were no other significant main effects or interactions in the main ANOVA, *ps* > .18.
In order to follow-up the interaction between View x Repetition x Hemisphere, two separate ANOVAs were performed on each hemisphere. In the right hemisphere, the interaction between View x Repetition was not significant F(1,13) = 3.84, p = .072. There were no significant main effects or interactions in the left hemisphere *ps* > .11.
Although the interaction between View x Repetition in the right hemisphere did not reach significance, as this as a key interaction, planned t-tests were perfomed and revealed that the amplitude for repeated objects (M = 2.16 µV, SD = 2.78) was almost significantly less than that for unrepeated objects (M = 2.61 µV, SD = 2.87) and that this was only the case for upright objects, t(13) = 1.77, p = .051 (one-tailed), d = 0.47. There was no difference for inverted objects, p = .091 (one-tailed).

The analysis of the amplitude of the P1 at the occipital (O1/2) electrodes revealed a significant interaction between View x Repetition x Hemisphere F(1,13) = 4.97, p = .04, 4, η_p^2 = .28. There were no other significant main effects or interactions, *ps* > .13. In order to follow up the three way interaction, two separate ANOVAs were performed on each hemisphere. There was a trend for a main effect of view F(1,13) = 3.66, p = .078 in the right hemisphere, all other *ps* > .39. The mean amplitudes of the probe-locked P1 for each electrode analysed are shown in Figure 9-1.

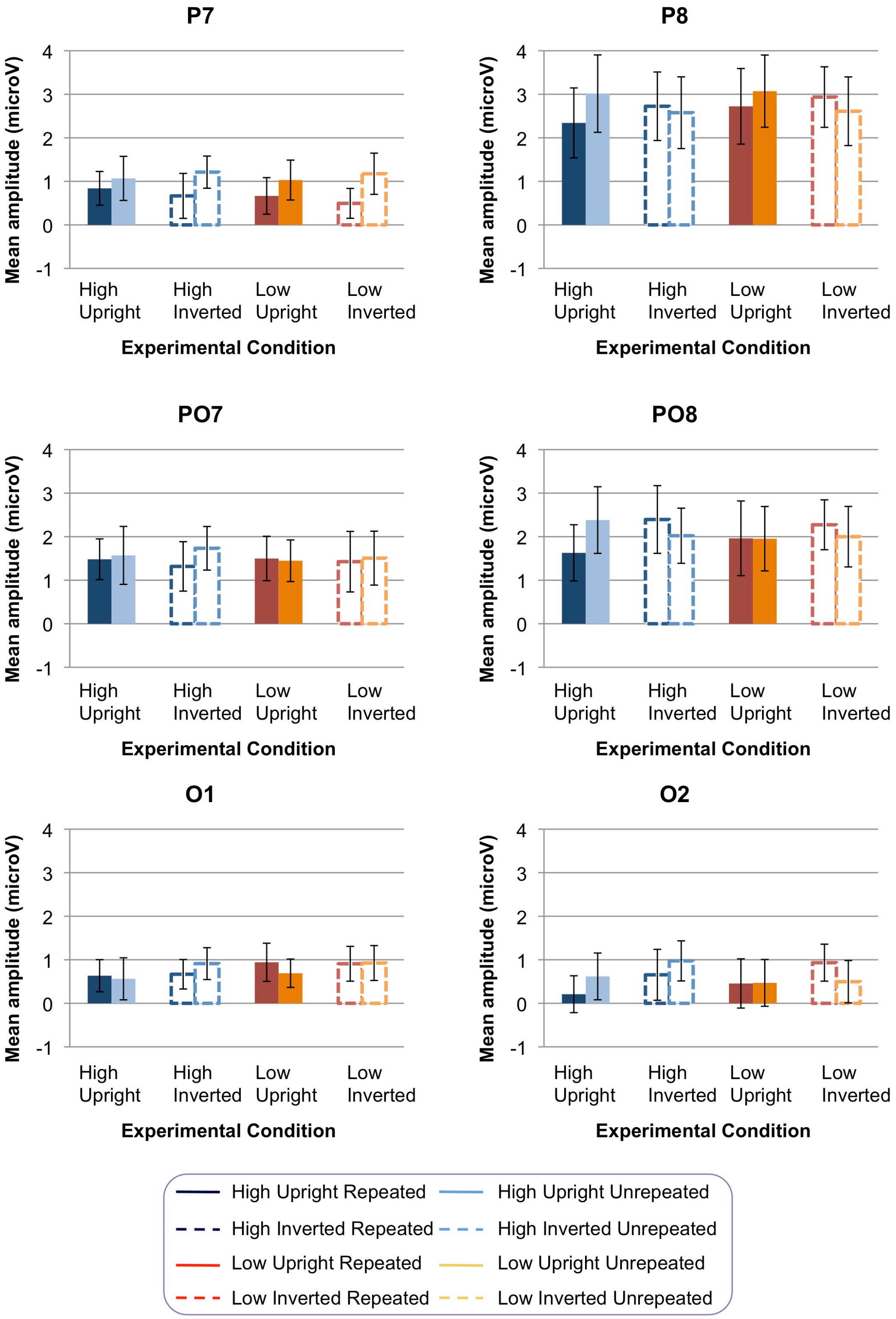


Figure 9-4: Probe-locked P1 mean amplitudes ±1 standard error bars for Experiment 7.

9.6.2 Probe-locked N1

The analysis of the amplitude of the N1 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a near-significant interaction between View x Repetition F(1,13) = 4.37, $p = .057$, $\eta_p^2 = .25$. Follow-up paired t-tests revealed that only upright images resulted in significant repetition effects of an enhanced N1 for repeated (*M* = -6.02 µV, *SD* = 1.93) vs. unrepeated (*M* = -5.55 µV, *SD* = 2.09) images, t(13) = 1.86, $p = .042$ (one-tailed), $d = 0.51$, inverted $p > .25$ (one-tailed). The interaction between Hemisphere x Electrode Site did not reach significance, F(1,13) = .07, $p = .065$, $\eta_p^2 = .24$. There were no other significant main effects or interactions, *ps* > .17.

The analysis of the amplitude of the N1 at the occipital (O1/2) electrodes revealed that none of the main effects or interactions reached significance, all *ps* > .25. The mean amplitudes of the probe-locked N1 for each electrode analysed are shown in Figure 9-5.

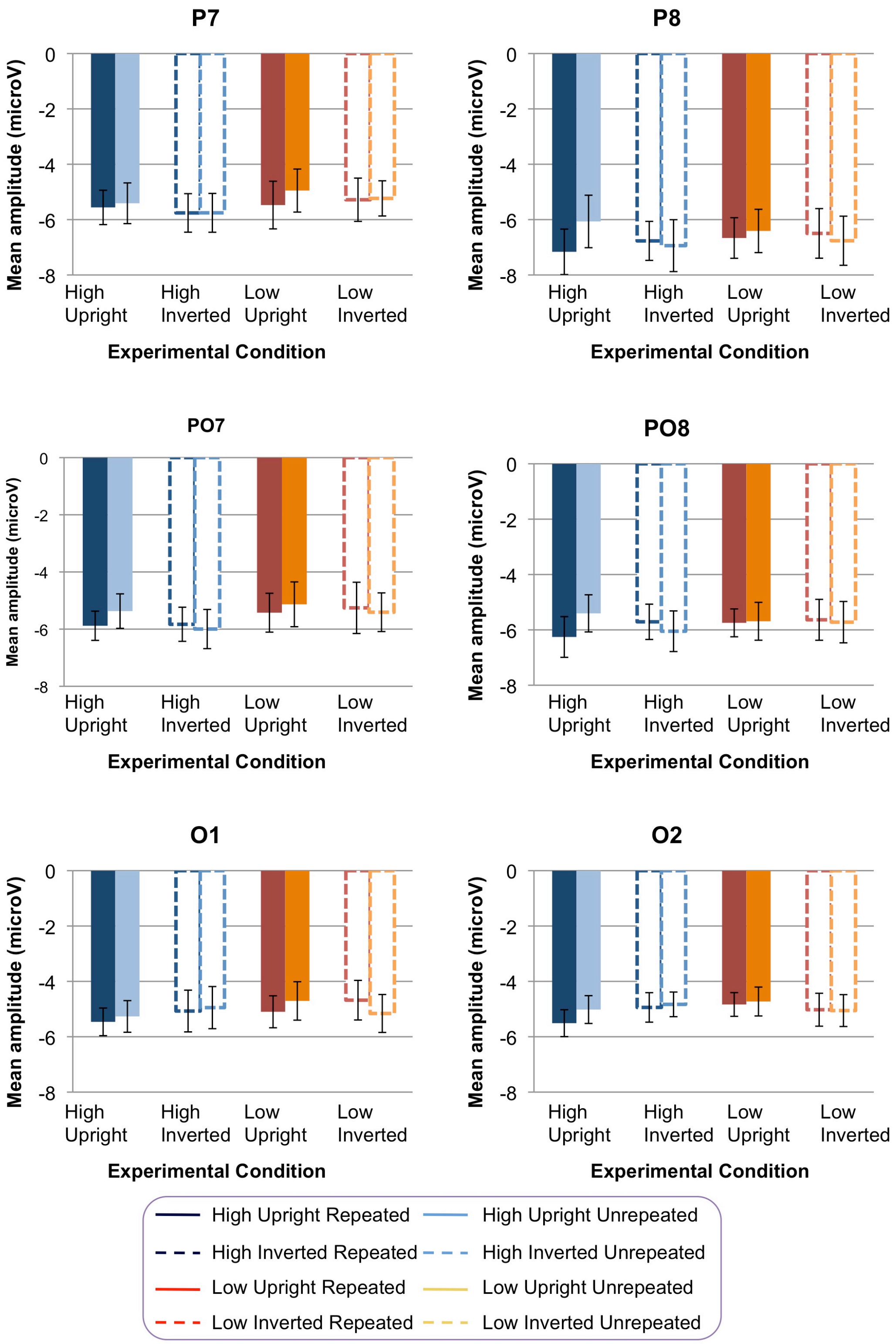


Figure 9-5: Probe-locked N1 mean amplitudes ±1 standard error bars for Experiment 7.

9.6.3 Probe-locked N250: 200-240 ms

This was the first of the two parts of the standard time window for the N250 that were separately analysed, based on visual inspection of the waveforms as mentioned previously. The analysis of the amplitude of the early portion of the N250 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a just significant interaction between Load x Repetition F(1,13) = 4.67, $p = .050$, $\eta_p^2 = .26$. There was also a significant interaction between Repetition x Electrode Site F(1,13) = 7.98, $p = .014$, $\eta_p^2 = .38$. There were no other significant main effects or interactions, all *ps* > .1.

The Load x Repetition interaction was followed up by paired t-tests, which revealed that for high load, the amplitude for repeated images ($M = 0.81$ µV, $SD = 3.24$) was more negative than for unrepeated ($M = 1.31$ µV, $SD = 3.19$), t(13) = 2.25, $p = .021$ (one-tailed), $d = 0.60$. For low load there was no significant difference in repetition, $p = .18$. Follow-up paired t-tests for the interaction between Repetition x Electrode Site found no significant repetition at either electrode site, *ps* > .157.

At the occipital (O1/2) electrodes the analysis of the amplitude of the early portion of the N250 revealed a significant interaction between Load x Repetition F(1,13) = 4.73, $p = .049$, $\eta_p^2 = .27$. There were no other significant main effects or interaction in the main ANOVA, *ps* > .11. The follow-up paired t-tests for the interaction between Load x Repetition revealed that in high load, the amplitude for repeated images ($M = 0.83$ µV, $SD = 3.24$) was more negative than that for unrepeated ($M = 1.36$ µV, $SD = 3.18$), t(13) = 1.79, $p = .048$ (one-tailed), $d = 0.48$. For low load there was no significant difference in repetition, $p = .23$. The mean amplitudes of this probe-locked earlier part of the N250 for each electrode analysed are shown in Figure 9-6.

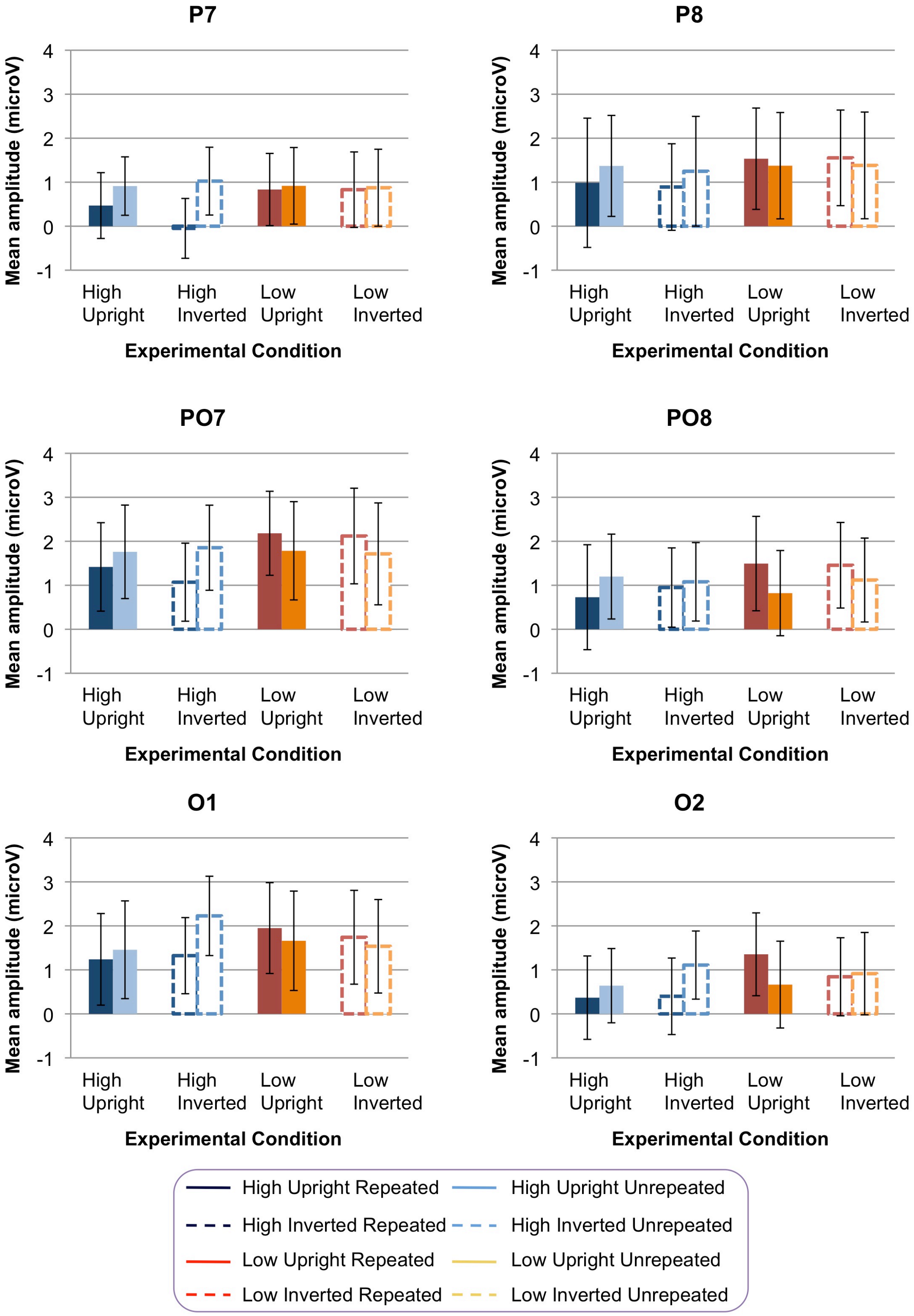


Figure 9-6: Probe-locked N250 (200-240 ms) mean amplitudes ±1 standard error bars for Experiment 7.

9.6.4 Probe-locked N250: 240-270ms

The analysis of the amplitude at time window of 240-270ms after probe onset for the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a significant interaction between Repetition x Electrode Site F(1,13) = 12.15, p = .004, η_p^2 = .48. There were no other significant main effects or interactions in the main ANOVA, *ps* > .11. Follow-up paired t-tests for the interaction between Repetition x Electrode Site revealed that for parietal electrodes P7/8 the amplitude for repeated objects (*M* = 0.03 µV, *SD* = 2.58) was more negative than that for unrepeated (*M* = 0.46 µV, *SD* = 2.78), t(13) = 2.27, p = .021 (one-tailed), *d* = 0.61. For occipito-parietal (PO7/8) electrodes there was no significant difference in repetition, p = .40.

The analysis of the amplitude of the N250 at the occipital (O1/2) electrodes revealed only a significant main effect of hemisphere F(1,13) = 5.68, p = .033, η_p^2 = .30, with the amplitude for the right hemisphere (*M* = -0.40 µV, *SD* = 2.83) more negative than that for the left hemisphere (*M* = 0.62 µV, *SD* = 3.26). The main effect of load was not significant F(1,13) = 4.07, p = .065. There were no other significant main effects or interactions in the main ANOVA, *ps* > .23. The mean amplitudes of this probe-locked later portion of the N250 for each electrode analysed are shown in Figure 9-7.

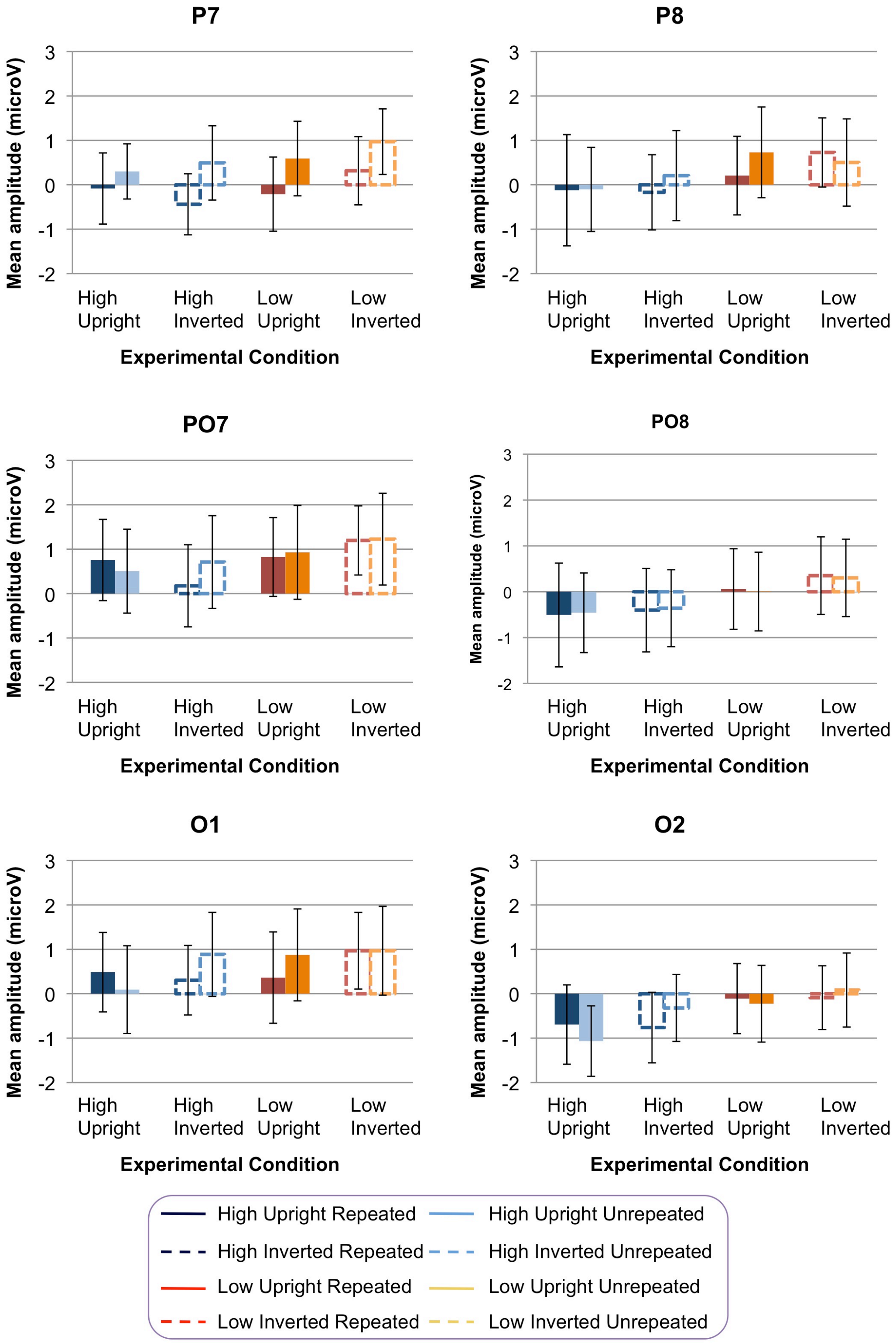


Figure 9-7: Probe-locked N250 (240-270 ms) mean amplitudes ±1 standard error bars for Experiment 7.

9.6.5 Prime-Locked ERP

The possibility of potential differences in the attentional allocation at the target being due to the view of the distractor prime-images and load was tested by examining their effect on the size of the N2pc. The choice of the electrode sites P7, P8, PO7, PO8, O1 and O2 and time window of 230-280 ms for mean amplitude followed Astle et al (2010). The data were submitted to a 2 x 2 x 2 x 2 x 3 within-participant ANOVA for each component, with factors Load (high, low) x View (upright, inverted) x Contralaterality (contralateral, ipsilateral) x Hemisphere (left, right) x Electrode Site (P7/8, PO7/8, O1/2). The grand-averaged prime-locked waveforms for each condition at the electrode sites used in the analyses are shown in Figure 9-8.

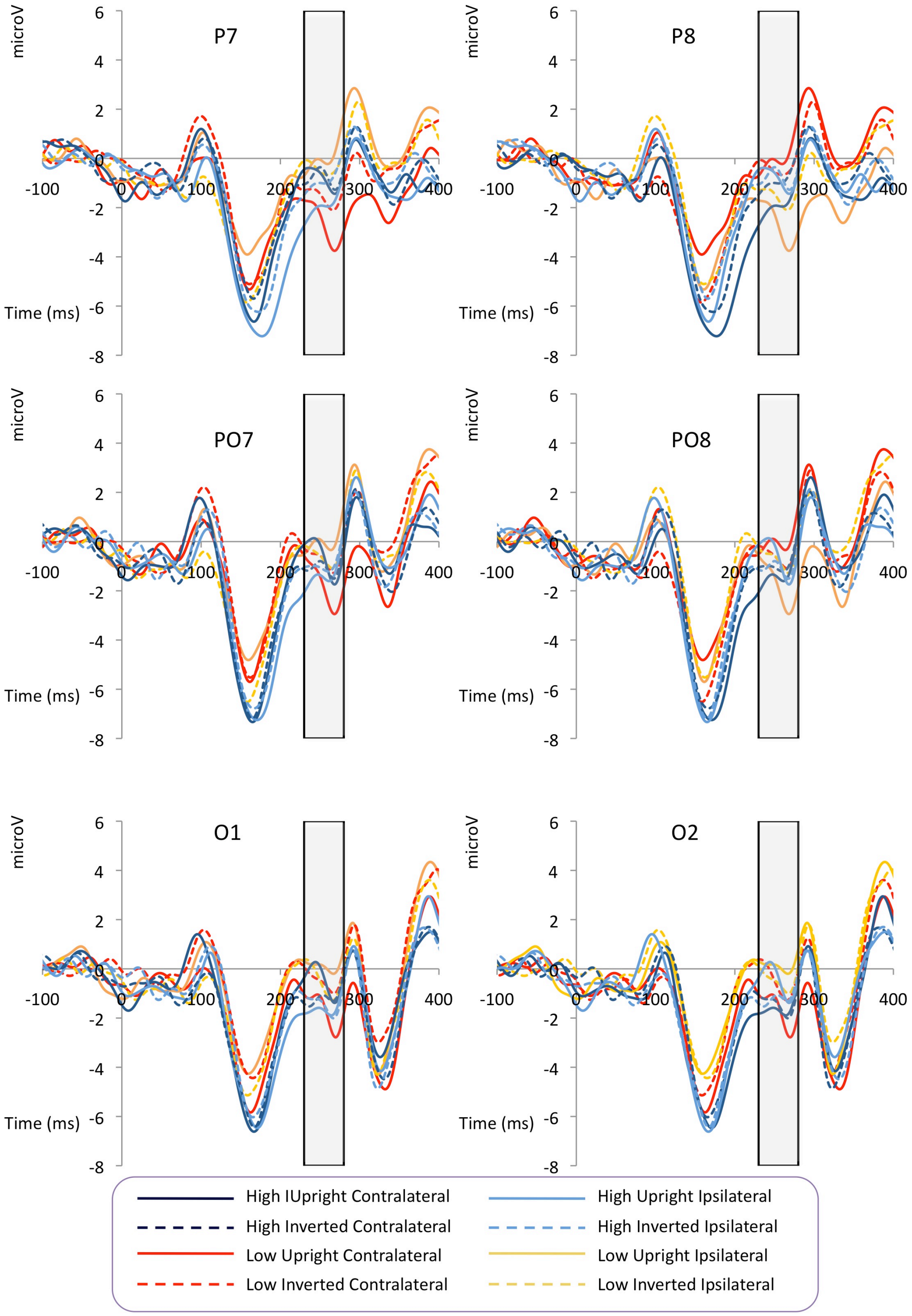


Figure 9-8: Grand-averaged prime-locked contralateral and ipsilateral waveforms for 30 Hz low-pass filtered data for each experimental condition for P7, P8, PO7, PO8, O1 and O2 for Experiment 7. The time window for the N2pc is marked, where this is grey indicates that a statistically significant N2pc was observed.

The analysis revealed a marginally significant interaction between View x Contralaterality F(1, 13) = 4.43, p = .055, η_p^2 = .25. There were significant interactions between Contralaterality x Hemisphere F(1,13) = 14.30, p = .002, η_p^2 = .52, Contralaterality x Hemisphere x Electrode Site F(1.8, 22.9) = 3.67, p = .046, η_p^2 = .22, and Load x Contralaterality x Hemisphere x Electrode Site = 5.79, p = .011, η_p^2 = .31. The interaction between Load x View x Electrode Site was not significant F(1.2, 15.8) = 3.29, p = .083. There were no other significant main effects or interactions, *ps* > .26. The interaction between View x Contralaterality was followed up by paired t-tests, which revealed that only inverted objects elicted a significant N2pc, with the contralateral amplitude (*M* = -1.44 µV, *SD* = 3.51) significantly more negative than for the ipsilateral amplitude (*M* = -0.64 µV, *SD* = 3.03), t(13) = 3.33, p = .005, d = 0.89. In contrast, there was no difference for upright objects p >.16.

In order to follow-up the interaction between Load x Contralaterality x Hemisphere x Electrode Site separate ANOVA's were performed for each level of Electrode Site. For the parietal P7/8, this revealed a significant main effect of contralaterality F(1,13) = 10.8, p = .006, which was qualified by a significant interaction between Load x Contralaterality F(1,13) = 10.16, p = .007, η_p^2 = .44. There were no other significant main effects or interactions at these electrodes, *ps* > .18. The Load x Contralaterality interaction was followed up by paired t-tests, which revealed that there was only a significant N2pc in low load, such that the contralateral amplitude (*M* = -1.96 µV, *SD* = 3.44) was significantly more negative than the ipsilateral amplitude (*M* = 0.18 µV, *SD* = 2.74), t(12) = 4.32, p = .001, d = 1.15. For high load this difference was not significant, p > .65. For occipito-parietal electrodes PO7/8, there was a nonsignificant interaction between Load x Contralaterality F(1,13) = 3.20, p = .097. There were no other significant main effects or interactions, *ps* > .1. Planned t-tests were performed for the key interaction of Load x Contralaterality, and revealed that only under low load there was a significant difference between the contralateral amplitude (*M* = -1.39 µV, *SD* = 3.52) which was more negative than the ipsilateral amplitude (*M* = -0.30, *SD* = 2.78), t(13) = 2.41, p = .031, d = 0.65. This was consistent with the pattern of deflections at parietal electrodes (P7/8).

For the occipital O1/2, the main effect of load F(1,13) = 4.33, *p* = .058 was marginally significant. There were significant main effects of contralaterality F(1,13) = 7.69, *p* = .016 and hemisphere F(1,13) = 15.51, *p* = .002, and these were qualified by a significant interaction between Contralaterality x Hemisphere F(1,13) = 12.95, *p* = .003, η_p^2 = .50. Follow-up paired t-tests then revealed that only in the left hemisphere there was a significant difference between contralateral amplitude (*M* = 4.58 μV, *SD* = 4.18) and ipsilateral amplitude (*M* = -0.81 μV, *SD* = 3.62) t(13) = 3.28, *p* = .006, *d* = 0.89 (Bonferroni criterion for 2 comparisons, *p* < .025). However, this was in the opposite direction to that expected for the N2pc. For the right hemisphere this difference was not significant, *p* > .38.

These analyses showed that there were independent effects from view and load on the allocation of attention at the target as indexed by the size of the N2pc. There was only a significant N2pc elicited from inverted objects, implying that they (but not upright objects) affected the allocation of attention to the target in the letter search array. There was also only a significant N2pc elicited under low (and not high) load.

9.7. Experiment 7: Summary and Discussion

In Experiment 7 the same short-lag repetition-priming paradigm with a letter search task to manipulate perceptual load was used as in Experiment 6, replacing the split images with inverted (upside-down) images. Experiment 7 aimed to address the possibility that the repetition effects from split images were due to the specific properties of the splitting manipulation, notably the tuning of the visual system towards more part-based recognition processes induced by the letter search task.

The behavioural data for Experiment 7 showed only a significant main effect of repetition, suggesting that repeated objects produce priming regardless of the view that they are shown in. However, planned t-tests showed that the effect of repetition was only significant for low load upright primes, consistent with the behavioural results of Experiment 4, but not those of Experiment 6 which indicated priming from low load split images. This pattern of priming results neither directly supports either the hybrid model or perceptual load theory. The hybrid model of object recognition predicts that only upright objects should result in priming (as was observed), however, this should be as much the case in high load as in low load as it is posited as an automatic process, implying no need for attentional resources. Perceptual load theory does predict that priming is eliminated for high load (as was observed), but it also predicts that the priming in low load should be view-independent (and not only for upright primes as was also observed).

Overall, the ERP repetition effects from intact, upright objects appear to be resilient to high perceptual load (consistent with the results of Experiment 3). However, the results of Experiment 7 also indicated that neither model alone can account for the observed effects. The patterns of repetition effects on the amplitude in the P1 and N1 time windows at parietal and occipito-parietal sites did indeed follow the pattern predicted by the hybrid model, as significant repetition effects were observed only from upright objects, regardless of load. However, in the time window of the N250, the pattern of repetition effects was not consistent with the hybrid model. For the early time window (200-240 ms) there were significant repetition effects for the high load (and not low load) conditions, and this was the case for both upright and inverted views of the prime. Later, in the time window of the N250 (240 – 270 ms), additional repetition effects on amplitude were observed for both upright and inverted objects. Assuming that the letter search task successfully controls spatial attention, inverted objects would not be expected to result in repetition effects under the hybrid model. Further, these repetition effects at the N250 were observed for both low and high conditions of load. Although repetition effects from upright objects under high load were expected based on the hybrid model, the repetition effects from the inverted objects under high load cannot be accommodated under either the hybrid model, or perceptual load theory.

As in Experiment 6, the N2pc was used to test the influence of the view of the distractor upon the allocation of attention at the target in the letter search array. In Experiment 6, the presence of the N2pc for split (but not intact) images suggested that they captured attention. In Experiment 7 there was a significant N2pc elicited for inverted (and not upright) images. Therefore, it is suggested that the repetition effects elicited by inverted primes also resulted from their being under attention. This suggests that it was not the combination of letter search and split images that resulted in the repetition effects from split images in Experiment 6. Rather, as repetition effects were not observed from split images in Experiment 2, which used a spatial cuing paradigm, it would suggest that the lack of a cue in this letter search paradigm allows attention to be drawn to distractors even under high load.

Forster and Lavie (2008) suggested that distractor images captured attention but that this was prevented under high perceptual load. However, theirs was a behavioural study and the lack of distractor influence under high load was used to infer the lack of attentional capture. Taking the results of Experiments 6 and 7 here together indicates that distractors did capture attention and were processed even under high load. This aspect of attentional capture in the letter search task, and the finding in both Experiments 6 and 7 that repetition effects that resulted under high load conditions and also for view-changed conditions were observed at later time windows than for those under low load and identical-view conditions will be taken up in the General Discussion. This following chapter brings together the experimental results found in this thesis and contextualises them in terms of the hybrid model and perceptual load theory.

Chapter 10. General Discussion

The research work presented in this thesis investigated the visual processing of spatially unattended familiar objects through ERP measurements. The behavioural results were also collated and have been discussed in earlier chapters. The purpose of this chapter is to discuss the behavioural and ERP results across the experiments in this thesis. Therefore the chapter begins with the motivation behind the research topic and the main findings across experiments. This is followed by an overview of the experiments and the ERP results, and how these addressed the two main research aims of the thesis. The specific results are then integrated with the current ERP literature in object recognition and attention research. This is followed by an evaluation of the two key models (hybrid model and perceptual load theory) in terms of the present ERP results, and their relevance in theory development. The limitations of the experiments are considered and suggestions for how these may be addressed by further research. Finally, the conclusions from the current work are presented.

10.1. Research Motivation

The interest in the processing fate of unattended objects in this thesis stems from two theoretical questions. The first one is whether visual attention has a role regarding the format of object representations to solve the need for both speed and view-invariance in object recognition. The second one is whether the processing of unattended images can shed light on the debate of attentional selection in relation to object recognition. The first question has divided theories of object recognition into those that are reliant on either view-based or view-invariant representations (Hummel, 2013), and this division is the basis of the viewpoint debate in object-recognition (Peissig & Tarr, 2007).
View-based and view-invariant representations differ in the way that an objects component parts and their spatial locations are bound into its description in long-term memory. View-based descriptions rely on static binding whereas view-invariant

descriptions rely on dynamic binding. As discussed in Section 1.10, dynamic binding requires attentional resources, therefore without attention only the statically bound view-based descriptions can be formed. Consequently, the recognition of unattended objects is only possible via a view-based representation. Such view-based representations form the basis of the holistic route of Hummel's (2001) hybrid model of object recognition. Recognition under this holistic route occurs without attention. In contrast, view-invariant (part-based or analytic) representations form the basis of the parallel analytic route. Recognition under this analytic route requires the allocation of attentional resources. Empirical evidence for the recognition of unattended objects would therefore support the existence of holistic representations and such evidence has been found in the behavioural priming studies of Hummel and colleagues. The hybrid model proposes that the holistic route acts in an automatic fashion (fast, mandatory, and capacity-free). However, regarding the second question, the behavioural priming study of Lavie et al (2009) has shown that objects that are rendered unattended via high perceptual load do not result in priming, a finding that is in conflict with the observations of Hummel and colleagues. This raises the question of whether the holistic route is activated automatically in all situations which render objects 'unattended'. Lavie et al. (2009) claimed that the observed differences may be due to the specific nature of attentional manipulation inherent in spatial cuing, as employed in the behavioural work by Hummel and colleagues, and Thoma and colleagues. ERP is a fast measure of the neural activity elicited by the presentation of a stimulus and therefore a useful tool in examining the possibility of automatic processing associated with the holistic route. ERP measures also allow a more detailed analysis of processes happening at both prime and probe trials. Therefore, an examination of the properties of the ERP repetition effects from unattended objects under different manipulations of attention was undertaken for the research work here.

10.1.1 Main Findings

1) ERP repetition effects were observed for unattended objects, in situations when attention was controlled by spatial cuing or via the perceptual load of a letter

search task. These were manifested at posterior parietal and occipito-parietal electrode sites (P7/8 and PO7/8), where repeated primes elicited more negative amplitudes than unrepeated primes.

2) ERP repetition effects were found predominantly for identical pairs of an image between prime and probe, but also for scaled versions. These repetition effects were largely robust to view manipulations of splitting when attention was manipulated via cuing.
3) In uncued letter search load paradigms, in addition to view-sensitive ERP repetition effects, view- and load- independent repetition effects were also observed. In these experiments, the view-sensitive repetition effects were observed at earlier time windows than the view- and load- independent repetition effects.
4) Overall, a persistent finding was that percepetual load manipulations could not completely eliminate repetition effects (ie. processing of) from unattended (task-irrelevant) objects.

Taken together, the present findings demonstrate that unattended objects elicited ERP repetition effects, which are largely, but not completely, view-dependent. The results also demonstrate that the view-sensitive repetition effects concur with the properties of the holistic route of recognition of the hybrid model. However, view- and load- independent repetition effects were also observed, in addition to view-sensitive repetition effects, in the uncued perceptual load studies, which are difficult to interpret within either the hybrid model or perceptual load theory.

10.2. Overview of Experiments and Main Results

The first research question of this work was to establish whether unattended objects elicited ERP repetition effects, and whether such repetition effects would conform to the view-sensitivity associated with the holistic route of the hybrid model. Stankiewicz and Hummel (2002) described how the recognition under the holistic route was predicted to be invariant to scale and translation but sensitive to changes in the configuration of the objects component parts, and they confirmed this with tests of behavioural priming. Experiment 1 addressed the first part of the first research question by adapting a spatial cuing paradigm that has previously been used to demonstrate the behavioural priming from spatially unattended objects (e.g. Stankiewicz et al, 1998). In Experiment 1, the probe object was either the same object as had been shown as the unattended prime (repeated), or a different object (unrepeated). All the probe images were scaled to twice the size of the prime images. The dependent variable was the probe-locked ERP amplitude (examined at the time windows of the P1, N1 and N250).

The results of Experiment 1 confirmed a significant ERP repetition effect elicited by the spatially unattended objects in the time window of the N1 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes, which showed an enhanced negativity in amplitude for repeated vs. unrepeated objects. Experiment 1 did not test for the quantitative aspect of how scaling and translation may have affected repetition effects, as there was no control condition for either factor in the experimental design. However, the results established that robust repetition effects were obtained when the object images were scaled in size or translated between prime and probe trial, in line with predictions and tests of the hybrid model (e.g., Stankiewicz & Hummel, 2002).

Experiment 2 tested the view-sensitivity of the repetition effects to split images. This was achieved by presenting the prime and probe objects as either intact or split images. In Experiment 2 the view of the prime and probe objects was matched such that an intact-image prime was followed by an intact-image probe, and a split image prime by a split image probe. The ERP repetition effects were present for intact but not split images. The repetition effects from split images were absent despite being matched in view to split image probes. In Experiment 2 the repetition effects were manifested at the time window of the N250, rather than the N1 as in Experiment 1. However, the amplitude modulation of an enhanced negativity for repeated vs. unrepeated objects at the parietal and occipito-parietal sites was consistent with Experiment 1. The analysis of the topography of the repetition effects in Experiments 1 and 2 indicated that there was no significant difference between the topography of the repetition effects. The absence of repetition effects from unattended split images for the matching split image probes also supported that the repetition effects from unattended images was not due purely to the matching of low-level visual features. If this had been the case, both the intact and split images would have elicited repetition effects, which was not observed[12]. The results of Experiments 1 and 2 thus answered the first research question by confirming the presence of ERP repetition effects from spatially unattended objects, and also demonstrating that the view-sensitivity of the repetition effects conformed to that predicted for the holistic route of the hybrid model.

The second research question asked whether the ERP repetition effects from peripheral, task-irrelevant objects (such as the unattended primes in Experiments 1 and 2) would be affected by perceptual load. In the hybrid model, the holistic route of recognition is considered to be automatic, and such automatic processes, according to Schneider and Chein (2003) and Schneider and Shiffrin (1977) are fast, mandatory and capacity-free, in contrast to “controlled processing (which) is slow and serial” (Schneider & Chein, 2003, p.529). Automatic processing is mandatory and thus “nearly always becomes active in response to a particular input configuration” (Schneider & Shiffrin, 1977, p.2) and acts without attention, i.e. “without the necessity for active control or attention by the subject” (Schneider & Shiffrin, 1977, p.2). Finally automatic processing is capacity-free and so “requires little effort and can operate in high workload situations” (Schneider & Chein, 2003, p.529).

The results of Experiments 1 and 2 indicated that processing was possible without spatial attention, and were thus consistent with the behavioural work of Hummel and colleagues, linking this to a capacity-free holistic route for recognition. However, it has been demonstrated that under a condition of exhausted capacity (high perceptual load), that the priming from ‘unattended’ peripheral task-irrelevant objects was eliminated (Lavie et al, 2009). Perceptual load theory has been described in Section 1.14. The theory proposes that when a task (target) is perceptually undemanding (low load) attentional resources spillover to task-irrelevant (distractor) stimuli, which are then processed. In contrast, if

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[12] See also the results of Thoma et al (2004) as discussed in Chapter 4 and their argument that behavioural priming (cf ERP repetition effects here) from the unattended intact objects resulted from the access of a holistic representation in LTM.

the task exhausts attentional capacity (high load) then there are no available (‘spare’) resources to allocate to the task-irrelevant stimuli, which therefore cannot be processed. Lavie et al. (2009) had proposed that the priming found for unattended objects in spatial cuing pradigms was possible because there was no (or not a sufficient) manipulation of load. Experiment 3 addressed whether the perceptual load would affect the ERP repetition from spatially unattended intact objects, adding the factor of perceptual load in the spatial cuing paradigm. Under perceptual load theory, it would be expected that the repetition effects for uncued objects would be extinguished under condition of high load at the cued location. The results of Experiment 3 indicated that load did not interact with repetition, that is, that the repetition effects were robust to high perceptual load in the spatial cuing paradigm.

The second set of experiments in this thesis (Experiments 4-7) moved away from the spatial cuing paradigm and instead used the letter search load paradigm typically used by Lavie and colleagues. This paradigm does not involve a spatial cue and relies solely on the control of spatial attention via the perceptual load of the letter search task. Experiment 4, was a behavioural partial-replication of the Lavie et al (2009) study, manipulating both factors of load (high, low) and view (intact, split) in the same experiment, the results of which showed that priming of unattended objects under load manipulations cannot be accounted for by eye movements, as discussed in Chapter 6. Experiment 6 was an ERP version of Experiment 4, the only difference being the increased number of trials[13]. Experiment 6 again demonstrated ERP repetition effects at the parietal (P7/8) and occipito-parietal (PO7/8) electrode sites that were manifested by more negative amplitudes for repeated vs. unrepeated objects. In the time window of the P1 repetition effects were only elicited by intact objects under low load conditions. In the time windows of the N1 and the early part of the N250 (230-270 ms) repetition effects were elicited across all conditions of view and load. That is, the repetition effects were view- and load- independent. In the time window of the later part of the N250 (270-310) there was a main effect of load, but this did not interact with repetition.

Experiment 7 was a near identical experiment to Experiment 6, but replacing the split

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[13] The increased number of trials did also result in an increased number of stimuli, those of Experiment 4 were added to in order to create the stimulus set of Experiment 6.

images with inverted ones. As in all the previous experiments, ERP repetition effects were observed at the parietal (P7/8) and occipito-parietal (PO7/8) electrode sites that were manifested by more negative amplitudes for repeated vs. unrepeated objects. In the time windows of the P1 and N1, only upright objects elicited repetition effects, under both load conditions. For the early part of the N250 (200-240 ms), only objects under high load trials elicited repetition effects. For the later part of the N250 (240-270 ms) all repeated objects elicited repetition effects that were view- and load- independent.

The presence of repetition effects has been taken as evidence of the prior processing of the prime (Eddy et al, 2006), however, Experiment 5 directly examined distractor processing under perceptual load, and the assumption that high perceptual load eliminates the perception of distractors (Lavie et al, 2004). The letter search load task was used, and here it was presented either alone (no distractor) or with a flanking distractor that was either presented near to the target letter in the letter search array (that is, next to it) or far from the target letter (that is, on the opposite side of the array). Forster and Lavie (2008) similarly tested the attentional capture of a salient, but task-irrelevant, distractor under low and high perceptual load. They found that the distractor influence (as measured by RT) was extinguished under high perceptual load. Experiment 5 used the ERP components N1 and N2pc that have been implicated in the allocation of spatial attention to test distractor influence under low and high load. Distractor influence was observed under both low and high load, however the effect of distractor presence on the amplitude at the occipital (O1/2) electrode sites was not present for high load.

The results of all the experiments are summarised in Table 10-1. The results will be compared with the previous ERP literature in the next section. In general, not only were repetition effects found that were view- and load- sensitive, but these were observed at different time windows than those that were insensitive to load and view.

Table 10-1: Summary of experiments with outcomes. Note: all effects concern unattended (flanker) objects, with the manipulation of view and attention (Load) in the prime display, except Experiment 5, where there was no repetition.

<table>
<tr><th>Exp. No.</th><th>Aim to establish</th><th>Factors</th><th>Results: ERP repetition effects</th><th>Results: Attention</th><th>View-specificity</th></tr>
<tr><td></td><td colspan="5">**Experiment 1-3 – Spatial Cuing Paradigm**</td></tr>
<tr><td>**1**</td><td>ERP repetition effects elicited from spatially unattended objects</td><td>Repetition x View of probe (identical vs. size-**scaled**)</td><td><table><tr><th></th><th>N1</th><th>N250</th></tr><tr><td>P7/8</td><td>√</td><td>-</td></tr><tr><td>PO7/8</td><td>√</td><td>-</td></tr><tr><td>O1/2</td><td>-</td><td>-</td></tr></table></td><td>n/a</td><td>No
(HM)</td></tr>
<tr><td>**2**</td><td>View-sensitivity of ERP repetition effects regarding holistic representation</td><td>Repetition x View of prime (identical vs **split**)</td><td><table><tr><th></th><th>N1</th><th>N250</th></tr><tr><td>P7/8</td><td>-</td><td>√</td></tr><tr><td>PO7/8</td><td>-</td><td>√</td></tr><tr><td>O1/2</td><td>-</td><td>-</td></tr></table></td><td>N2pc: No difference in view</td><td>Yes
(HM)</td></tr>
<tr><td>**3**</td><td>ERP repetition effects under Perceptual Load and cuing</td><td>Repetition x Load (low vs. high)</td><td><table><tr><th></th><th>N1</th><th>N250</th></tr><tr><td>P7/8</td><td>√</td><td>-</td></tr><tr><td>PO7/8</td><td>-</td><td>-</td></tr><tr><td>O1/2</td><td>-</td><td>-</td></tr></table></td><td>N2pc: No difference in load</td><td></td></tr>
<tr><td colspan="6">**Experiment 4-7 – Perceptual Load (Letter search)**</td></tr>
<tr><td>**4**</td><td>Behavioral priming under load; eye-tracking overt attention</td><td>Repetition x Load x View (identical vs. **split**)</td><td>• Priming across load
• Eye-tracking: no saccades</td><td>n/a</td><td>Yes
(HM)</td></tr>
<tr><td>**5**</td><td>Perception of irrelevant distractor images under load; proximity to the target in letter search</td><td>Load x proximity (distractor-target)</td><td>No probe image, interest only at prime display</td><td>N2pc, N1: for P7/8 PO7/8 No difference in load, for O1/2 low load only</td><td>n/a</td></tr>
<tr><td>**6**</td><td>View-sensitivity of ERP repetition effects regarding holistic representation</td><td>Repetition x Load x View of prime (identical vs. **split**)</td><td><table><tr><th></th><th>P1</th><th>N1</th><th>N250</th></tr><tr><td>P7/8</td><td>√</td><td>√</td><td>√</td></tr><tr><td>PO7/8</td><td>√</td><td>√</td><td>√</td></tr><tr><td>O1/2</td><td>-</td><td>-</td><td>-</td></tr></table></td><td>N2pc for split images and for low load</td><td>P1: Yes
N1: No
N250: No</td></tr>
<tr><td>**7**</td><td>View-sensitivity of ERP repetition effects regarding holistic representation</td><td>Repetition x Load x View of prime (identical vs. **rotated**)</td><td><table><tr><th></th><th>P1</th><th>N1</th><th>N250</th></tr><tr><td>P7/8</td><td>√</td><td>√</td><td>√</td></tr><tr><td>PO7/8</td><td>√</td><td>√</td><td>√</td></tr><tr><td>O1/2</td><td>-</td><td>-</td><td>-</td></tr></table></td><td>N2pc for inverted images and for low load</td><td>P1: Yes (HM)
N1: Yes (HM)
N250: No</td></tr>
</table>

10.3. Implications for Object Recognition

10.3.1 ERP Repetition Effects from Unattended Objects

The first important result from this thesis was that ERP repetition effects were elicited from spatially unattended objects. This result is important because it adds to the evidence found behaviourally for the recognition of unattended objects (e.g. Bartram, 1976; Biederman & Bar, 1999; Biederman & Cooper, 1992; Schacter et al, 1990). Further, it adds to the previous ERP investigations of repetition effects from unattended objects that are currently few in number. The present results are in contrast to the claim, discussed in Section 1.13, that unattended objects are neither processed beyond low-level features, nor identified (Lachter et al, 2004; Lavie et al, 2009). The implications for this result for the selection debate will be discussed in Section 10.4. The implication of these results for object recognition theories is that it supports the existence of view-based, holistic object representations. Such view-based representations form the basis of the holistic route of the hybrid model of object recognition (Hummel, 2001). This holistic route acts on objects that have not been allocated attention. The model also proposes a parallel analytic route for recognition, which acts for objects placed under attention.

Therefore, the presence of ERP repetition effects from unattended objects adds to the behavioural evidence for holistic representations and its particular properties (e.g. Stankiewicz et al, 1998, 2002; Thoma et al, 2004, 2007). The view-sensitivity that is predicted for the holistic route of recognition, and that was demonstrated by the present ERP repetition effects, will be discussed in the next section.

Repetition effects were observed across all ERP experiments of this thesis. They were manifested as a more negative voltage for repeated vs. unrepeated objects at the parietal (P7/8) and PO7/8 electrode sites. However, the repetition effects were sometimes observed only in specific time windows. Specifically for the spatial cuing experiments they were observed at the N1 only for Experiments 1 and 3 and N250 only for Experiment 2. For the letter search load experiments they were observed in the time windows of the P1, N1 and N250 for both Experiments 6 and 7.

The following comparison between the present results and those of previous ERP studies is therefore focused on their consistency in terms of the amplitude deflection upon repetition and the time windows at which repetition effects were observed. There are not many studies on the ERP repetition effects from unattended objects with which to compare the present results. Therefore, whether the present results are consistent with those found previously for attended objects is discussed before considering studies that have examined repetition effects from unattended objects using techniques of masked priming and the control of attention by object-feature (i.e. colour) and via perceptual load.

The present effects of repetition on ERP amplitude were consistent with those that have been previously observed in short-lag repetition priming studies for attended objects, which also identified repetition effects at a number of different time windows. For example, Zhang et al (1997) found repetition effects from 110 ms onwards, Henson et al (2004) from 150 ms to 300 ms, Schendan and Kutas (2003) from the time window of the P150 onwards, and Penney et al (2001) at the time window of the N1.

It is possible that an explanation for the difference in time window is indicated by the study of Henson et al (2004) who also used line drawings of everyday objects in a repetition paradigm[14]. In their combined ERP/fMRI study, they found both an early repetition effect (enhanced, occipito-temporal N1) between 160-190 ms, and a later (and stronger) effect at 200-300 ms. Henson et al showed that their repetition effects at the N1 and N250 time windows did not differ in their topography, and suggested that they may have originated from a shared neural generator. Therefore, although the present ERP repetition effects were found at a number of time windows, this does not mean that they must be associated with different processes, and rather may share neural generators. That is, the present repetition effects may reflect the same neural processes, but only elicit the repetition effects at different time windows, depending on the different aspects of each experiment.

Some support for the link between the repetition effects across the timeline was also found here in the topographical analysis of the repetition effects between Experiment 1 (N1) and Experiment 2 (N250). This analysis, similar to Henson et al (2004), found no

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[14] Although they used a semantic judgement task in contrast to our naming task.

difference between the effects at the two time windows. The implication that these effects therefore reflect a similar neural generator must be tempered not only by the difficulty in the interpretation of a null result, but also by the evidence from other studies suggesting that the N170 and N250r have different characteristics as mentioned in Section 2.2.2. However, the present results are consistent not only with those of Henson et al, but also the work of Doniger et al (2000; 2001). Doniger et al also found that a repetition effect observed in the time window of the N170 shared topography with the Ncl[15] (time window of 200-300 ms). In their (2000) study, Doniger et al presented participants with gradually less fragmented images and found that the Ncl became more negative as closure information built up to point of identification. Henson et al (2004) took their own results and concluded with those of Doniger et al. that the repetition effects within the time window of the N1 reflected the earlier onset of similar processes to those at the time window of the N250. Therefore, the present results as well as those of Henson et al and Doniger et al indicate a shared topography between the ERP effects at the earlier and later time windows and therefore support the suggestion that the present repetition effects reflect similar processes although they manifest at different time windows.

In the set of experiments that were spatially cued (Experiments 1, 2 and 3) only in Experiment 2 were repetition effects not found in the N1 time window, but observed instead in the time window of the N250. Experiments 1 and 3 used only intact images of objects, whereas Experiment 2 used both intact and split images. Therefore, the difference in time window for the repetition effects in the spatially cued set of experiments may reflect differences in figure-ground requirements due to the different views of the objects presented. Changes in canonical views have been shown to delay the time window at which repetition effects are observed (Itier & Taylor, 2004).

The repetition effects found in the studies cited above relate to attended stimuli, and there is a lack of previous ERP research on the processing of spatially unattended objects in which spatial attention is controlled, rather than assumed through relying on participants' unawareness of stimuli. Previous studies have used, for example, rapid masked priming (Eddy et al, 2006; Forster & Davies, 1984), or overlapping stimuli of different colours

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[15] The Ncl is a bilateral component, at occipito-temporal electrode sites, onsetting at about 230 ms, maximal at around 290 ms and associated with perceptual closure.

where participants' attention is directed to only one colour through instruction (e.g. Ballesteros et al, 2006; Vuilleumier et al, 2005). The above discussion has described how the present repetition effects from unattended objects are consistent with previous studies using attended objects. However, it is possible that qualitative differences between the effects from attended and unattended objects would have been expected, as indicated by the modulation by attention on fMRI effects (e.g. Vuilleumier et al). Therefore it is next argued that although fMRI effects may differ between conditions of attention, the ERP repetition effects from attended and unattended objects do not differ qualitatively.

One technique to limit participants' awareness of stimuli is that of rapid masked repetition priming, as used by Eddy et al (2006) and Forster and Davies (1984). The onset of the mask presentation, which follows the prime presentation, can be controlled to limit the visual processing and awareness of the prime stimulus (Eddy et al, 2006). Although it could be argued that both prime and probe images are within the same spatial attentional window (participants will be looking at that central area of the display throughout the task), under such conditions, participants are often unaware of the prime images at all. Therefore, it is assumed that it is the bottom-up (feed-forward) properties of the prime image that will contribute most to the observed priming. Eddy et al displayed their images for 50 ms before being masked for a further 50 ms, and participants performed a semantic categorisation (food vs. non-food) task. Repetition effects in the ERP timeline were observed to onset from 100 ms and were present within the windows of N/P190 (100-250 ms), N300 (250-350 ms) and N400 (350-650 ms). At the electrode sites of O1/2, repeated vs. unrepeated objects elicited a significantly more negative deflection from 100 ms, maintained until 400 ms, as tested in 20 ms intervals. These repetition effects are therefore consistent with the present results in terms of the direction of amplitude modulation upon repetition. However, the present repetition effects were observed at the parietal (P7/8) and occipito-parietal (PO7/8) rather than the occipital (O1/2) electrodes at which they were observed in the Eddy et al study.

Thus, the effect of repetition on the ERP observed in this thesis displayed the same amplitude modulation and similar electrode locations to those that have previously been found for attended objects and masked objects in short-lag repetition priming studies. However, the findings from fMRI studies demonstrate qualitatively different effects for attended and unattended objects, for example the study of Vuilleumier et al (2005). In their fMRI study of the repetition priming effects modulated by attention, they used overlapping line drawings of everyday objects. For each display, one image was drawn in cyan and the other in magenta. Attention to the target image was controlled by instructing participants to only attend to drawings of one of the pre-specified colours. Thus, although the images were both within the spatial focus of attention, only those of the relevant colour were considered to have been attended whereas the others were considered to have been ignored. Those ignored images were found to elicit increased activation (repetition enhancement) in bilateral lingual gyri vs. previously unseen objects. In contrast, attended images were found to elicit decreased activation (repetition suppression) in right posterior fusiform, lateral occipital and left inferior frontal regions. The authors therefore suggested that this distinction supported separate neural regions for the repetition effects associated with attended and unattended objects.

However, in the Vuilleumier et al. (2005) study, the ‘unattended’ prime stimuli were presented at the location of the attended target, and thus may have received some visual processing from simply being in the same spatial location even if participants were unaware of the image. Here, ‘unawareness’ of a stimulus indicates that it has been ‘unattended’. This does not entirely exclude the possibility that the stimulus has received some processing resources, which may have been simply insufficient to bring it into conscious awareness, or whether it has not received any of those resources at all (cf. Wolfe, 2001). Although the primes and probes were also presented at the same spatial location in Eddy et al’s (2006) study, they were not shown overlapping (i.e. they were temporally separated) and further the prime was masked.

This ambiguity introduced by the overlapping stimuli in the Vuilleumier study was addressed by Thoma and Henson (2011) in their fMRI study by their use of a spatial cuing paradigm (similar to that of Stankiewicz et al, 1998; Thoma et al, 2004, and this thesis) to separate the attended target image from the unattended image. In this paradigm, as the cue appears shortly prior to the target image, attention is allocated to that location temporally as well as spatially. Their results again supported a qualitative difference in activation, but rather than associated with differences purely in attention (as Vuilleumier et al, 2005, described above), here the difference was associated with view-sensitivity.

View-sensitive recognition was associated with repetition enhancement in a right intra-parietal region. View-independent recognition was associated with repetition suppression in a region of the left mid-fusiform. Therefore, not only were different regions involved for view-sensitive and view-insensitive recognition, but also their type of activation was also different. Attended images supported both unattended and attended (view-specific and view-independent) recognition whereas unattended only view-dependent recognition, as predicted by Hummel's hybrid model.

Therefore, although fMRI studies indicate that there are different neural locations and patterns of activation for the repetition of attended vs. unattended objects, the ERP studies find qualitatively similar effects (direction of amplitude modulation and time windows and electrode sites) for the repetition of these objects. It can be difficult to directly compare studies using ERP and fMRI due to their complementary nature, specifically, temporal limitations of (non-event-related) fMRI and the spatial limitations of ERP (Henson, 2009). The activation from different neural regions could be seen at the same temporal point in the ERP waveform and at the same electrode sites, and to differentiate these, it would be necessary to compare the topography of the ERP from the recognition of attended vs. unattended objects to see if their neural generators are different, or use source location techniques or complementary fMRI measures.

In summary, the present ERP repetition effects from unattended objects showed a similar amplitude deflection and electrode location to those previously reported for attended (Henson et al, 2004) and masked (Eddy et al, 2006) objects. The time window for the present repetition effects varied according to the experiment. Various time windows for repetition effects have also been found in previous studies and those time windows were consistent with the present results. The variation in time window may reflect the onset of certain processes or that recognition was delayed under certain experimental conditions. The same set of neural generators may be involved for the repetition effects despite their manifestation at different time windows. The present results demonstrated a repetition effect during the time window of the N1 for all but one of the ERP repetition-priming studies (Experiment 2).

10.3.2 View-sensitivity of ERP Repetition Effects from Unattended Objects

The view-sensitivity of recognition is an important test of whether an object is represented holistically or analytically. Recognition relying on view-based, holistic, representations will be view-dependent (recognition performance will be worse for objects presented in a different view to that initially encoded). Recognition relying on view-invariant, analytic, representations will be view-independent (recognition performance is equivalent for all views of an object as long as the component parts are visible). Based on the premise that only a holistic format of representation is possible without attention (according to the theories discussed in Chapter 1), ERP repetition effects associated with unattended objects would be expected to be view-dependent (i.e. view-sensitive).

The present ERP repetition effects showed different properties of view-sensitivity according to the paradigms used. The experiments were divided into the first spatial cuing experiments (Experiments 1, 2 and 3) and the second letter search load (without spatial cuing) experiments (Experiments 4, 5, 6 and 7).

In the spatially cued Experiment 2, the only repetition effects observed were view-sensitive (to split images). In each of the uncued letter search Experiments 6 and 7, view-sensitive repetition effects were found as well as view-insensitive repetition effects. Therefore, the first notable result is the consistency of the view-sensitivity of the ERP repetition effects in the spatial cuing experiments with that of the behavioural priming in the spatial cuing studies of Hummel and colleagues, and this is discussed first. The second notable result is that by changing the attentional manipulation, both view-sensitive and view-insensitive repetition effects were observed. The implications of this result for object recognition theories are discussed afterwards, while the possible influences of task-demand and type of stimuli (in terms of the implications for the topic for attentional selection theories) will be discussed in Sections 10.4.3 and 10.5.1.

The present spatial cuing experiments (1, 2 and 3) were directly comparable to the behavioural and fMRI studies of Hummel and colleagues, which have also used spatial cuing manipulations. In the present spatial cuing set of experiments, only the repetition effects from unattended objects was tested. Of these unattended objects, only those shown in an intact view elicited repetition effects. Experiment 1 demonstrated that the repetition effects were largely robust to changes in scale and translation. Experiment 2 demonstrated that the repetition effects were sensitive to splitting the image, and further, unattended split images did not elicit repetition effects even though the probe objects were shown as identical split images. The lack of repetition effects from split images to probe split images together with repetition effects for scaled objects was important for two reasons. Firstly, taking the results of Experiments 1 and 2 together, the view-sensitivity of the ERP repetition effects that were observed conformed with the robustness to scale-changes and sensitivity to changes in part locations that is predicted for the recognition of unattended objects via the holistic route from the hybrid model (Stankiewicz & Hummel, 2002) and that was demonstrated by the behavioural studies of Hummel and colleagues and the fMRI study of Thoma and Henson (2011). Secondly, the pattern of repetition effects provides support for the suggestion of access to a holistic long-term representation rather than the matching of low-level visual features. In Experiment 1, repetition effects were observed despite the lack of any pixel-overlap between the prime and probe images. This robustness of repetition effects despite lack of pixel-overlap due to scaling for face stimuli has been previously also observed for the N250r by Zimmerman and Eimer (2013) and Bindemann et al (2008). In Experiment 2, there were no repetition effects from split images only (intact images did still elicit repetition effects) even though, arguably[16], there was pixel-overlap in this case. These results also strongly suggest that the manipulation of attention was successful, and no attention had been allocated to allow the analytic processing of the split images (see also Stankiewicz & Hummel, 2001; Thoma et al, 2004).

Across the present experiments, view-sensitive repetition effects were found at various time windows. In the time window of the P1 repetition effects were present for upright intact images, but not split images or inverted images (Experiment 6 and 7). In the time window of the N1 repetition effects were present for upright images, but not for inverted images (Experiment 7), but view-insensitive repetition effects were observed at this time window in Experiment 6. In the time window of the N250 repetition effects in the time

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[16] If the translation between the prime and probe images is ignored. This was the same for both intact and split image conditions.

window of the N250 were present for intact but not split images (Experiment 2), but view-insensitive repetition effects were observed in this time window for Experiments 6 and 7. The presence of both view-sensitive and view-insensitive repetition effects will be discussed after first considering whether the time windows of the repetition effects exhibiting view-sensitivity in the present work were consistent with previous ERP studies.

Previous research has also demonstrated view-sensitive ERP repetition effects at various time windows. The earliest time window for view-sensitive repetition effects in the present work is that of the P1. Schendan and Kutas (2003) observed repetition effects as an enhanced P150 for repeated vs. unrepeated objects at fronto-centro electrode locations. These were larger for objects repeated in the same vs. different view, and therefore would appear to have been driven by view-based representations. The present results indicated that repetition effects were also modulated by view in a time window as early as the P150 in Experiments 6 and 7, although at different electrode sites to those of Schendan and Kutas.

The time window of the N1 locked to stimulus presentation has been linked with stored structural descriptions (e.g. Eimer & McCarthy, 1999; Penney et al, 2000), and as such was found to be sensitive to view-changes, for example picture inversion (Itier & Taylor, 2004). However, previous studies have indicated that the repetition effects in the time window of the N1 are not view-sensitive. For example, the study of Itier and Taylor (2004) compared the effects of upright, inverted and contrast-reversed faces at both initial presentation and upon their repetition. The N170 locked to the prime did exhibit view-sensitivity, however, the repetition effects in the time window of the N170 were not sensitive to view. In Experiment 6, the N1 was not view-sensitive (to split images), but in Experiment 7, the N1 was view-sensitive (to inverted images).

Itier and Taylor (2004) also observed repetition effects in the time window of the N250. The effect of the view was to change the time window at which repetition effects were manifested. Repetition effects were observed between 250-350 ms for upright faces, between 300-400 ms for inverted faces and between 250-400 ms for contrast-reversed faces. For all these time windows, the amplitude was more negative for repeated vs. unrepeated faces. Itier and Taylor suggested that the delay in time window reflected the increased difficulty in accessing stored representations for each case of view. Therefore, their study indicates that the time window is sensitive to view, however, other studies have demonstrated that view also modulates the amplitude of repetition effects.

Of particular relevance are the properties of the view-sensitivity displayed by the N250r. The N250r is insensitive to scale-changes (Bindemann et al, 2008; Zimmermann & Eimer, 2013), and to geometrical distortions of faces such as vertical and horizontal stretching (Bindemann et al, 2008), but sensitive to different images of the same person, such as from different facial expression, eye gaze, age, etc (Schweinberger et al, 2002). These particular properties of view-sensitivity are similar to those derived for the holistic route of the hybrid model, and are generally consistent with the pattern of view-sensitivity demonstrated by the experiments in this thesis.

Turning to the letter search experiments, both view-sensitive (to split and inverted images) repetition effects, manifested in the early time windows of P1 and N1, and view-insensitive repetition effects, manifested at the later time windows of N250, were observed[17]. The observation of both view-sensitive and view-insensitive repetition effects in one experiment is not easily explained under the holistic route of the hybrid model. It is not clear from the results whether both view-based and view-invariant representations exist in parallel, or whether one precedes the other in a serial processing model of object recognition.

When an object is unattended, only holistic representation is possible, and repetition effects would be expected to be view-sensitive. The presence of the view-insensitive repetition effects implies the activation of analytic processing, which is only possible under attention. Therefore, one explanation for the presence of view-insensitive repetition effects is that the objects were attended, and then the earlier view-sensitive repetition effects either reflect pre-attentive processing preceding view-invariance, or parallel processing. In the study of Schendan and Kutas (2003), in which all the objects were attended, both view-sensitive and much later (after 700 ms) view-insensitive repetition effects were observed, and took it this as support for a partially view-invariant model of

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[17] The view-sensitivity of the N1 repetition effect was different between experiments: In Experiment 6 the repetition effects were view-insensitive to split images, whereas in Experiment 7 the repetition effects were view-sensitive to inverted images.

object recognition, in which different networks were responsible for the early and late repetition effects.

The objects in Schendan and Kutas (2003) study were perceived under attention, however, it could be argued that the objects underwent both pre-attentive processing and that involving attentional resources. In their two-stage model of object recognition, Schendan and Kutas (2007) divide perceptual processing from post-perceptual processing from about 200 ms post-stimulus onset. Therefore, although the earlier repetition effects (before 200 ms) may be associated with pre-attentive processing such as figure-ground processing, those later would rather be associated with processing under attention.

To relate this suggested timing of pre-attentive vs. attended processing to the present results and the view-sensitive and view-insensitive repetition effects, there is some consistency with the early time window and view-sensitivity of the repetition effects (on the P1 for Experiments 6 and 7, and also on N1 for Experiment 7) for those associated with pre-attentive processing. The view-sensitivity of the repetition effects on P1 and N1 for Experiment 7 is consistent with holistic processing. The later view-insensitive repetition effects (on N1 and N250 for Experiment 6 and on the N250 for Experiment 7) are consistent in terms of the time window (at least the N250) and view-sensitivity that would be associated with processing under attention. The observed view-insensitivity is consistent with analytic processing

10.3.3 Summary of Implications for Object Recognition

The present results demonstrated view-sensitive repetition effects were found across experiments at a number of different time windows, from that of the P1 through to the N250. The properties of view-sensitivity that were demonstrated by the repetition effects observed in the spatial cuing experiments were consistent with those predicted for the holistic processing of unattended objects. That is, the repetition effects were found for scale changes, but not for split images. In contrast, in the letter search load experiments (6 and 7) not only were repetition effects observed that were sensitive to split or inverted images observed, but they were insensitive to split or inverted images. These view-insensitive repetition effects were not consistent with those predicted for the holistic route of recognition, but rather with those predicted for the analytic route. Attention is assumed to be required for analytic processing, and thus one explanation for the observation of view-insensitive repetition effects in the letter search experiments is that with this manipulation (but not in the spatial cuing paradigm) the task-irrelevant objects were receiving attention. The view-insensitive repetition effects in the letter search experiments were also load-insensitive (that is, they were observed under high and low load). The load-insensitivity of the repetition effects is discussed in Section 10.4 on the implications of the results for visual attention.

10.4. Implications for Visual Attention

The present results were consistent with other studies that have demonstrated visual processing without attention, for example found with priming and interference effects, and also from neuropsychological conditions such as visual neglect as discussed in Chapter 1. The differences in the properties of these repetition effects reveal how much visual processing was possible without attention (early vs. late selection) and how this was further influenced by the type of selection mechanism (endogenous or exogenous). The view-sensitivity of the repetition effects from the spatial cuing experiments was consistent with that predicted for the holistic route of the hybrid model. Another aspect of the holistic route is that it is assumed to be automatic. Whether the present results are also consistent with this assumption is discussed next.

10.4.1 Automatic and Pre-attentive Processing

The holistic route of the hybrid model is considered to be automatic, and thus fast, mandatory and capacity-free (Schneider & Chein, 2003; Schneider & Shiffrin, 1977). The presence of load-insensitive repetition effects in both spatial cuing and letter search experiments suggests that the processing of the objects had not been limited by capacity-constraints. The presence of repetition effects indicated the mandatory processing of the objects in two respects. Firstly, the repetition effects resulted without attention to the prime image, and despite the interruption from the visual mask that always followed the prime presentation here. Secondly, the repetition effects that were view-dependent indicated that the processing of unattended objects was only triggered by the "particular input configuration" (Schneider & Shiffrin, 1977, p.2) of intact and upright views of the prime objects. In the case of the letter search experiments, this view-dependence was only observed for the repetition effects of the earlier time windows.

Therefore, those present repetition effects that are consistent with the view-sensitivity predicted for the holistic route of the hybrid model are also consistent with the conditions of mandatory and capacity-free processing for automatic processing that is also expected of the holistic route. The implications of such automatic processing for early vs. late selection models is discussed next.

10.4.2 Early vs. Late Selection

The difference between early and late selection models has been described in terms of their predictions regarding the processing of unattended stimuli. For example (Wolfe, 2000) suggests that in early selection models preattentive processing is limited to that of basic features, whereas in late selection models preattentive processing advances further. He goes on to say that, " in early selection models, attention is needed to complete the act of perception. In late selection models, attention selects responses to fully processed stimuli" (p. 368).

In these terms, the present results speak to a late selection model in which unattended objects are visually processed sufficiently to allow recognition. The hybrid model is also a late selection model in such terms. In the hybrid model the holistic route of recognition is free of attentional capacity restraints (Stankiewicz & Hummel, 2002), and this is in contrast to the capacity-limited account of perceptual load theory. Repetition effects were observed in this thesis even under conditions of high perceptual load, again supporting a late selection account.

The presence of repetition effects under high perceptual load was in contrast to the finding of elimination of behavioural priming from peripheral objects under high perceptual load in the study of Lavie et al. (2009). Other ERP repetition effects have also been demonstrated to be resistant to high perceptual load, but for face-stimuli (Neumann et al., 2011). The observation of such repetition effects under high load suggest that attentional selection driven by perceptual load does not act in a purely bottom-up fashion. Similarly, it has been suggested by Xu et al. (2011) that selection via perceptual load relies both on bottom-up processing and top-down factors, and a number of studies have indicated that other factors, some interacting with perceptual load, also affect attentional selection. For example, Fu et al. (2008, 2009) suggested that voluntary and involuntary attention modulate the effects of load. Rorden et al. (2008) examined the task-relevance of the stimuli on load effects and Handy and Mangun (2000) suggested that other factors in addition to perceptual load, such as location expectancy, play a role in attentional selection. The possible influence of the saliency of stimuli and task-demand on attentional capture on the present results will be discussed in Section 10.4.3. However, one difference in the 'type' of late selection suggested by the load-insensitive repetition effects from the letter search experiments, and those from the repetition effects from the uncued objects in the spatial cuing experiments is highlighted here as follows.

The load-insensitive repetition effects from the letter search experiments were also view-insensitive. The view-insensitivity suggests that the distractor stimuli were processed equivalently, that is, the selection filter acted late and equivalently on all stimuli. However, in the case of the spatial cuing experiments the view-sensitivity of the repetition effects, which were limited to those elicited by identical (and scaled) views of the objects, thus indicated that the selectional filter did not act on all stimuli equivalently, that is, it only allowed the further processing of identical and scaled views of the objects. The images were of everyday objects, and so the identical and scale images can be conceived of as depicting familiar views of everyday objects, whereas split images are by definition unfamiliar views. In these terms, the attentional filter can be described as only allowing objects in familiar views to pass through for further processing. This is somewhat similar to the attenuation theory of Treisman (1960, 1964), in which the selection filter does not act to completely eliminate the processing of irrelevant stimuli, but rather reduces their signal to noise ratio.

These differences in the properties of the filter relate to the concepts of attentional spillage and leakage described by Lachter et al. (2004) and discussed in Section 1.13. That is, the filtering by the letter search manipulation of perceptual load appears to be ‘all or nothing’ and thus is consistent with the spillage of attention to task-irrelevant distractors under low load, and as proposed by perceptual load theory. In contrast, the filtering by the spatial cue appears to allow only familiar objects through and is thus consistent with a ‘leaky filter’. Lachter et al. suggest that evidence of leakage falsifies the idea of a completely selective filter. Therefore, the question of selection is not only whether it acts early or late but also what other influences affect how and when it acts.

In summary, the load-insensitive ERP repetition effects were consistent with those observed in previous studies involving face stimuli. The present results speak to a late selection account. What and how information is selected may depend on the experimental paradigm, and this suggests that it may not only be bottom-up processing that guides selection. For the letter search experiments, high load did not promote early selection as would have been expected by perceptual load theory. Rather, the observation of repetition effects under both conditions of load was consistent with late selection. In these experiments, the view-insensitivity of the repetition effects indicated that the selection filter acted equivalently on all views of the objects, and that selection of task-irrelevant stimuli may be due to attentional ‘spillage’. In contrast, for the spatial cuing experiments, the view-sensitivity of the repetition effects, suggested that the filter acted in a way more in line with the attenuation theory of Treisman (1960, 1964), allowing only familiar views of objects through the filter for further processing. However, the objects that ‘leaked’ through the filter would then be in receipt of attention, and so would not undergo the same automatic (without attention) processing that is associated with the holistic route of the hybrid model. How the results fit in with different selection mechanisms is discussed next.

10.4.3 Selection Mechanisms in Attention

The view-sensitivity of the repetition effects appeared in different patterns for the spatial cuing and letter search experiments. Indeed, the results indicate that the selection filter for the processing of irrelevant objects acts differently under the different paradigms. One difference between the spatial cuing and letter search paradigms is the selection mechanism for allocating attention. In Experiments 1-3 the spatial cue was presented 75 ms before the target and non-target (prime) images and thus, attention drawn exogenously by the onset of the cuing square. The cued target would then be selected through endogenous deployment of attention. However, the letter search experiments did not use a spatial cue and instead relied on the control of attention via the perceptual load of the letter search array. Perceptual load theory proposes bottom-up, exogenous selection driven by the perceptual demands of the display. However, the presence of load-insensitive repetition effects suggests that high perceptual load did not restrict the processing of irrelevant objects in the present work. The hybrid model is also a feed-forward model, but has a built-in automatic mandatory activation of the holistic route for familiar objects.

One difference between the letter search and spatial cuing paradigms is their potential for perceptual grouping effects. In the present experiments, the spatial cue is a cuing square that also encloses the target image, and thus may produce a grouping effect that is not as likely to occur in the letter search task. A study by Shomstein, Kimchi, Hammer & Behrmann (2010) found that perceptual grouping effects were possible even under high perceptual load for clinical patients showing hemispatial neglect, suggesting that at least some Gestalt processes may act before the spatial allocation of attention determined by perceptual load. Both grouping and predictability can change attentional effects even when perceptual load is used to control spatial attention as in Handy and Mangun (2000), Marciano and Yeshurun (2011) and Cosman et al. (2012).

Cosman et al. (2012) examined the effects of grouping on the influence of perceptual load by testing whether distractor influence was affected by presenting it outside of a superordinate object structure encompassing the letter search array. This structure was formed by splitting the screen into two sections side-by-side (rather similar to the spatial cuing square used in the present experiments). They found that even in high load, task-irrelevant flankers influenced performance on the central task if both were presented within the same object, however, in low load, the flanker exerted less influence when it was presented as a different object to that of the letter search. Cosman et al. (2012) suggested that their results could be predicted from the influence of object-based attention, specifically that features within an object are enhanced through the spreading of attention (object spreading enhancement accounts) as proposed by Han, Dosher and Lu (2003), Hollingworth et al. (2012), and Valdes-Sosa, Bobes, Rodriguez, & Pinilla (1998). It is also possible that rather than restricting the spread of attention, the spatial cuing paradigm did not allow the unattended object to appear as a unique and thus salient distractor image (the spatial cuing prime display always consisted of two images), which was the case in the letter search paradigm did. Therefore, a possible explanation for the load-insensitivity of the present results is that the saliency of the peripheral images caused them to capture attention (Forster and Lavie, 2008) despite high perceptual load at the letter search array. In this thesis, the N2pc was used as an indicator of the allocation of (or selection by) spatial attention (Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999) at the target during the prime presentation.

Typical experiments examining the N2pc use a visual search array where the target is presented amongst non-target stimuli, and in such experiments the non-targets are termed distractors. Thus, the current experiments are not typical in the presentation of stimuli for examination of the N2pc, and here the distractors relate to the peripheral images. The reasoning behind the use of the N2pc in the present work was only to index whether the presentation of 'distractor' images resulted in a change in the spatial attention allocated to the 'target'.

Under the distractor suppression model (Luck & Hillyard, 1994), the N2pc is only elicited when distractor information potentially interferes with target identification, that is, in attentionally demanding conditions. Therefore, in the present work a larger N2pc was associated with increased difficulty in suppressing the influence of the distractor images[18].

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[18] The main motivation behind using the N2pc to examine the allocation of attention was due to the concern that intact images would capture attention over split or inverted images. Although the

The load-insensitivity of the repetition effects was in contrast to the findings of Forster and Lavie (2008), described in Chapter 7, who suggested that attentional capture due to the salience of the distractor images was eliminated by high perceptual load. The observation of repetition effects under high load in the present experiments however indicate that in the present experiments the capture of attention was not eliminated. It is unlikely that the task-relevance of the images was responsible, as indicated by the distractor processing under high load in Experiment 5 in which the objects were never repeated.

In Experiments 6 and 7 a significant N2pc was elicited for low, but not high load, as would have been consistent with the notion that distractors are harder to suppress under low load. However, the finding that a significant N2pc was elicited at the target for split and inverted (and not intact, upright) flanker images respectively in both conditions of load, is difficult to interpret. When observed for Experiment 6, the finding led to the suggestion of the tuning of the visual system to promote more part-based processing due to the nature of the letter search task and thus the increase in saliency of split images (as discussed in Chapter 8). However, the inverted images that were not expected to benefit from such a processing bias, still elicited an N2pc in Experiment 7. It is difficult to explain why split and inverted images should be harder to suppress than intact, upright images.

The difficulty in suppressing distractor images observed in the letter search experiments was in contrast to the lack of modulation of the N2pc by either view (Experiment 2) or load (Experiment 3) in the spatial cuing experiments. One tentative interpretation is that the more endogenous control of attention through the spatial cue restricts the exogenous capture of attention by distractor images, whereas when attention is controlled only via exogenous means (perceptual load) other potentially salient stimuli also capture attention. Tsotsos et al. (2008) propose that top-down and bottom-up processing interact to ‘tune’ the visual system appropriately to task demands. In their Selective Tuning Model, they describe the stages of processing and tuning that begin with a stage of the guiding of

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difficulty in suppressing distractor information may not directly imply the capture of attention by the distractor, here the main aim was to look for differences in attentional allocation between conditions in order to substantiate the assumption that different views of objects received equivalent attentional allocation.

attention to e.g. a location by a cue or a specific visual feature. Therefore, this first stage may be the point at which the spatial cuing and letter search paradigms first differ, with the spatial cue guiding attention to a certain location, in contrast to a less location-specific and more feature-based guidance appropriate to the letter search task.

In summary, the present results indicate that the spatial cuing paradigm restricts attention more robustly than the letter search paradigm, and therefore adds support to the suggestion that unattended objects can be processed via the holistic route of the hybrid model. However, taking the results of the spatial cuing and letter search experiments together, suggests that top-down influences may also affect selection and thus the resulting processing of task-irrelevant distractor objects. This has implications on the bottom-up models of processing proposed by the hybrid model and perceptual load theory, and are discussed in the next section.

10.5. Integrating ERP Repetition Effects with the Hybrid Model of Object Recognition and Perceptual Load Theory

Taken together the present results are not compatible with either the hybrid model nor the perceptual load theory alone. That is, although the results of the spatial cuing Experiments 1, 2 and 3 demonstrate good support for the hybrid model, the results of letter search Experiments 4, 5, 6 and 7 show a more complicated pattern. Firstly, Experiments 6 and 7 showed both view-sensitive and view-invariant repetition effects, which are difficult to reconcile with the holistic route of the hybrid model. Secondly, Experiments 6 and 7 also demonstrated load-invariant repetition effects, which are difficult to reconcile with perceptual load theory.

Previously the only peripheral irrelevant images (distractors) that have been shown to be recognised under high perceptual load are faces (Lavie, 2005; Neumann et al., 2011). The latter of these studies was an ERP study that found that only images of faces (and not of houses or hands) exhibited an N250r under high perceptual load. However, there were other differences in experimental design that make a comparison difficult. The face-processing studies indicate that faces maintain their ‘special’ status in visual processing and are not restricted by the capacity-limits of the perceptual load theory (Bindemann et al., 2005; Jenkins et al., 2003, 2005). Faces are processed holistically[19] and somewhat automatically (e.g. Palermo & Rhodes, 2007; Young et al., 1986). Therefore, it can be speculated that this may indicate ‘space’ within the perceptual load theory for some automatic processing/recognition that is resistant to high load and possibly based on some form of holistic processing. However, it may be simply that faces employ their own domain-specific resources in a modular (Fodor, 1983) fashion as has been suggested by Bindemann, et al. (2008) and Thoma and Lavie (2013).

As has been mentioned, Lavie et al. (2009) suggested a difference between spatial cuing and perceptual load. This does appear to be the case, however, not in the way originally suggested (i.e. that cuing acts upon analytic processing, but perceptual load acts upon both analytic and holistic processing). Although the action of the spatial cue may indeed eliminate analytic processing for irrelevant peripheral images, high perceptual load does not always eliminate both analytic and holistic processing of them (Experiments 3, 4, 5, 6 and 7).

Both the presence of repetition effects under high load and the fact that they are view-invariant in Experiments 6 and 7 may indicate that there was attentional spillover even under high load in these studies. If it is assumed that the peripheral images thus became attended and could then benefit from analytic processing, the view-invariant and load-invariant repetition effects could be explained under the hybrid model. The N2pc results did indicate that split and inverted images were difficult to suppress, which may also support the notion that they received attention. The timing of the view-sensitivity of the repetition effects also offers support to the images receiving attention. In this case, one interpretation of the presence of both view-sensitive and view-insensitive repetition effects is that the view-sensitive repetition effects reflect the fast automatic processing of upright, intact images, but that the later view-insensitive repetition effects reflect slower analytic processing.

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[19] Although it must be noted that the definition of holistic can differ for face-recognition and object-recognition research.

One possible explanation for the presence of repetition effects under high load in the letter search task is that the load manipulation may simply not have been sufficiently strong. However, the paradigm used here was the same as in the Lavie et al. (2009) study and as used in many perceptual load experiments, see Lavie (2005) for a review.

Another possible explanation for the repetition effects under high load in the letter search experiments is that rather than manipulating perceptual load, that the letter search task manipulated working memory load. Working memory load has been demonstrated to increase distractor influence (e.g. de Fockert, Rees & Frith, 2001) and high cognitive load has been associated with spread of attention (de Fockert & Bremner, 2011). However, the letter search task would not seem particularly demanding of working memory, except that participants had to remember which letter they had pressed in response to the letter search task in order to respond to the naming of the subsequent probe image, but it is one difference to the spatial cuing experiments in which there was no memory between prime and probe display element at all. That is, upon naming the target image in the prime display, there was no requirement for them to remember it in order to make the response at the probe. Rather than a working memory explanation for distractor influence an alternative suggestion is that the recall of the letter provokes a representation in visual short-term memory of the prime display, as considered in Section 10.5.1.

The difficulties in the definition of perceptual load have been raised, and discussed, in Lavie and de Fockert (2003) and Lavie (2000, 2001), who have described a number of ways in which perceptual load can be manipulated. For example, perceptual difficulty through the relevant search set size or the similarity between target and non-targets in visual search. The processing requirements of similar stimuli may also be manipulated, for example contrasting response based on conjunction of features vs. single feature detection, or identification vs. detection, or even between a complex linguistic task vs. letter case discrimination. However, Khetrapal et al. (2010) discussed that perceptual load theory has not been without controversy (also Keysers & Perrett, 2002) and have suggested that perceptual load may be one (rather than the sole) factor that determines the level of irrelevant distractor processing.

Tsal and Benoni (2010a, 2010b) and Torralbo and Beck (2008) have argued for an alternative ‘dilution account’ in which both target and distractor are processed in a similar manner. However, in a case of ‘high perceptual load’, which is defined by a larger, more ‘cluttered’ display, the critical distractor must compete (cf. Desimone & Duncan, 1995) with a number of neutral non-target stimuli. In contrast, in the case of ‘low perceptual load’, the target does not compete with non-targets but can rather ‘pop-out’ (but Lavie & Torralbo, 2010b). Therefore, it is not that high load narrows attentional focus, eliminating the interference effect from the critical distractor, but rather, it is that the processing resources previously available for the critical distractor are diluted by the other stimuli in the visual array.

Tsal and Benoni (2010) argued, from the results of a number of behavioural tests, that if the load was controlled with respect to the dilution from other non-targets, that the interference effect was eliminated for both high and low load (unlike in the standard tests of perceptual load). However, Lavie has rebutted this claim (Lavie and Torralbo, 2010), and Lavie et al. (2009) have demonstrated perceptual load effects in an uncluttered display. Although the present experiments cannot discriminate between the effect of perceptual load or dilution as the types of target and distractor stimuli were not controlled in that way, (for example, in the letter search paradigm), Experiment 3 manipulated load without adding non-targets (or ‘clutter’) and found no effect of load on distractor processing. Furthermore, in Experiments 6 and 7, the non-target letters in high load arguably did not interfere with distractor perception, as repetition effects were found even for objects after view-changes.

In summary, the previous tests of the hybrid model and perceptual load theory have each relied on either spatial cuing or uncued perceptual load manipulations for the control of spatial attention respectively. As in previous research, the spatial cuing experiments provided support for the hybrid model from the presence of ERP repetition effects for unattended objects that are persistent after changes of scale and position, but sensitive to splitting the object image, and resistant to high perceptual load. However, the letter search experiments result in both view-sensitive and view-invariant repetition effects that are not easily accommodated in the hybrid model as it presently stands. Further, load-invariant repetition effects are also observed that are not easily accommodated by perceptual load theory. Thus the results from the letter search experiments (6 and 7) appear to demonstrate that there is some flexibility in the processing that is available to unattended objects. Options for interpreting these results include either that the hybrid model requires modification to allow for analytic processing within the unattended holistic route, or that top-down influences of saliency and ‘pre-tuning’ of the visual system (as suggested by Tsotsos et al., 2008) need also to be accommodated in the currently bottom-up hybrid model and perceptual load theory. One additional option to consider is that attention can be allocated at a time later than the initial prime presentation to allow for analytic processing. This is discussed briefly next where the possibility that the task-demands of letter search experiments used here promoted the backward access to a representation in visual short-term memory of the prime display as has been suggested by Astle et al. (2010) is considered.

10.5.1 The Role of Attention in Visual Short-Term Memory (VSTM)

It has been demonstrated that attention can be allocated to a topographic representation in visual short-term memory, VSTM, (Sperling, 1960) by the ERP study of Astle, Nobre & Scerif (2010). They presented participants either supraliminally (for 243 ms) or subliminally (for 63 ms) a display containing two objects, one each in the left or right visual field (the “memory array”). This was followed by a test probe, which could match one of the two objects in the memory array. The memory array was both forward and backward masked. Using the N2pc as a marker of spatial attention, they found that regardless of whether participants were aware of the memory array or not, when participants were presented with a test object that matched an item in the array, attention was drawn automatically to its original location in the memory array. This was in contrast to the view that storage in VSTM relies on intentional retention (Luria et al., 2010), and Astle et al. rather suggested that the storage was automatic and proceeded even though the memory array was task irrelevant and participants were not conscious of having seen any of the test probes previously. Astle et al. (2009) and Kuo et al. (2009) have also found that top-down attentional allocation from goal demands can bias the contents of

VSTM, and thus taken together the interaction between spatial attention and the contents of VSTM were considered bidirectional.

In the present letter search Experiments (6 and 7) participants had to remember the target letter (‘X’ or ‘Z’) found in the search task in order to respond with the same button press for the subsequent probe image. Though speculative, it is possible that the recall of the target letter may have provoked attentional allocation to the target location in the representation of the prime display in VSTM, similar to the suggestion of Astle et al. (2010). If attention spread to its surrounds (e.g. Driver, 2001), then this would allow for the inclusion of the neighbouring distractor image in the attentional window and so analytic processing would result in view-independent and load-independent repetition effects. In such a scenario, it may be expected that the view-independent repetition effects associated with analytic processing manifest later in the ERP waveform than those that are view-sensitive and are indicative of automatic processing. This would be consistent with the pattern of view-sensitivity along the time line that was found in Experiments 6 and 7.

Smith and Ratcliff (2009) have proposed a model of visual short-term memory, the integrated theory of attention and decision making (ITDM), where the strength of encoding is dependent on the allocation of attentional resources. Broadly, the theory describes how a stimulus first produces a sensory response (with a certain strength/intensity) and how spatial attention then controls how this is encoded into a “durable form” Smith and Ratcliff, 2009, p. 287) in VSTM. In the theory “attention is viewed as a time-dependent gradient of resources that can be flexibly allocated across space according to the demands of the task” (p. 308), which bears some similarity to the findings of Astle et al. (2010). Therefore, the dynamic nature of the elements of sensory response and spatial attention described by Smith and Ratcliff (2009) support a less rigid view of attentional allocation and of strength and longevity of object representation than currently included in the current versions of either the hybrid model or perceptual load theory.

10.6. Limitations and Further Work

It has been demonstrated that the results of the spatial cuing experiments are consistent with those predicted for the holistic route of the hybrid model. The results of the letter search experiments were difficult to explain under either the hybrid model or perceptual load theory. One difference between the paradigms could be grouping effects, therefore, it would be useful to use a test of perceptual load controlling for the grouping of central task and distractor (similar to one used by Cosman et al., 2012). If the grouping of the distractor images presented close to the unbounded letter search in the present studies was responsible for attention spilling over to the distractors even under high load, then this should be eliminated by presenting the perceptual load array and the distractor image in distinct bounded areas (groups).

The difference in task demands between the present letter search experiments and the original Lavie et al. (2009) study also requires follow up. This relates to the requirement to recall the target letter of the letter search task for probe response, which was not present in the original study, which used overt naming. Thus a task not requiring the recall of the correct letter for responses made at the prime in order to respond at the probe would not require the representation of the display and VSTM and so view-insensitive repetition effects would no longer be expected.

The factor of hemisphere was included in these present analyses, and the results included interactions with hemisphere and electrode site, but did not find any consistent pattern for the effects that might have linked the holistic route with the right and analytic with the left hemisphere as would have been expected by the previous work by e.g. Burgund and Marsolek (2000) and Laeng et al. (2007). Further work could investigate such hemispheric effects by controlling for e.g. the visual field of presentation.

Finally, only the ERP have been extracted and analysed from the EEG data here, and examination of the time-frequency characteristics, notably, gamma-band oscillations would provide more insight into the point of recognition of the objects (Martinovic et al., 2007, 2008, 2009). Also, source-localisation of the N1 and N250 repetition effects, would not only extend the topographic analysis comparing the effects for Experiments 1 and 2, but may indicate if the neural generators of the view-sensitive repetition effects could be localised to those implicated by e.g. the fMRI study of Thoma and Henson (2011) for holistic processing. This would be particularly useful in trying to link the repetition effects observed under the spatial cuing with letter search load paradigms, as would complementary ERP/fMRI or TMS studies.

Further work is required to examine whether and how perceptual load may control the temporal allocation of attentional resources as well as their spatial allocation. One possibility that arises from the present results is that high load delays, or de-prioritises, the recognition of irrelevant peripheral objects compared to low load, rather than eliminating it. The high load in the letter search Experiment 6 appears to delay the outcome of recognition even of intact, upright i.e. familiar views of objects and thus, the hybrid model in turn may require modification to allow for some capacity-restrictions even for holistic processing. At present, the hybrid model posits two independent and parallel routes for recognition modulated separately by attention. The results reported here indicate that the model may benefit from including the possibility of a more flexible allocation of attention that can be influenced by top-down as well as bottom-up factors.

10.7. Conclusions

ERP repetition effects were observed for unattended objects in this thesis. This was the case for different manipulations of attention, using a spatial cuing paradigm and a perceptual load paradigm. The repetition effects in the spatial cuing experiments provided support for a holistic route of object recognition in the hybrid model (Hummel, 2001). However, the repetition effects in the letter search experiments (uncued, perceptual load) indicated both view-sensitive and view-insensitive repetition effects for task-irrelevant, unattended objects, challenging the generality of findings on automatic, holistic representations. However, view-specific effects were robust early in the ERP time line. Perceptual load theory alone could not account for the load-insensitive repetition effects that were also observed.

In reaching conclusions on the effectiveness of the accounts of perceptual load theory and the hybrid model based on the results presented here however, it must be acknowledged that to best suit the purposes of this thesis, the predictions concerning the visual processing of unattended objects have been derived from rather strict interpretations of the models assuming a binary ('all or nothing') allocation of attention and thus the resultant mode of processing (early/late or holistic/analytic). That is to say that by allowing for some flexibility in this allocation, the present results may be more easily accommodated within the models. For example, an argument that high perceptual load decreases the prioritisation and so the allocation of attentional resources for processing rather than eliminating it completely could account for the observation of repetition effects for irrelevant objects under high perceptual load at the central task. In order to account for the observation of both view-dependent and view-independent repetition effects it might be argued that attention can be allocated to an irrelevant object even when it is presented alongside a target (rather than it being rendered completely 'unattended' as in the hybrid model as described here). Thus, instead of placing such emphasis upon the differences between the models, it is suggested that it is the interaction between the two models that requires unravelling further in order to reconcile them.

Wolfe (2000) has noted that it is difficult to distinguish the effects of "vision without attention" from "vision before attention". Indeed, he stated that, "All inattention is not created equal" with stimuli falling into three types: the explicitly attended, those that never receive any attention and those that do receive some processing, but "fail to leave any lasting impression on the observer" (p. 385)[20].

The present results indicate that objects are processed even when we have not attended to them in the first instance, but that their processing may depend more on the interaction of bottom-up and top-down influences than either perceptual load theory or the hybrid model currently allow.

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[20] See also Driver, 2001 and Smith & Ratcliff (2009) on the false dichotomisation of pre-attentive and attentive processes

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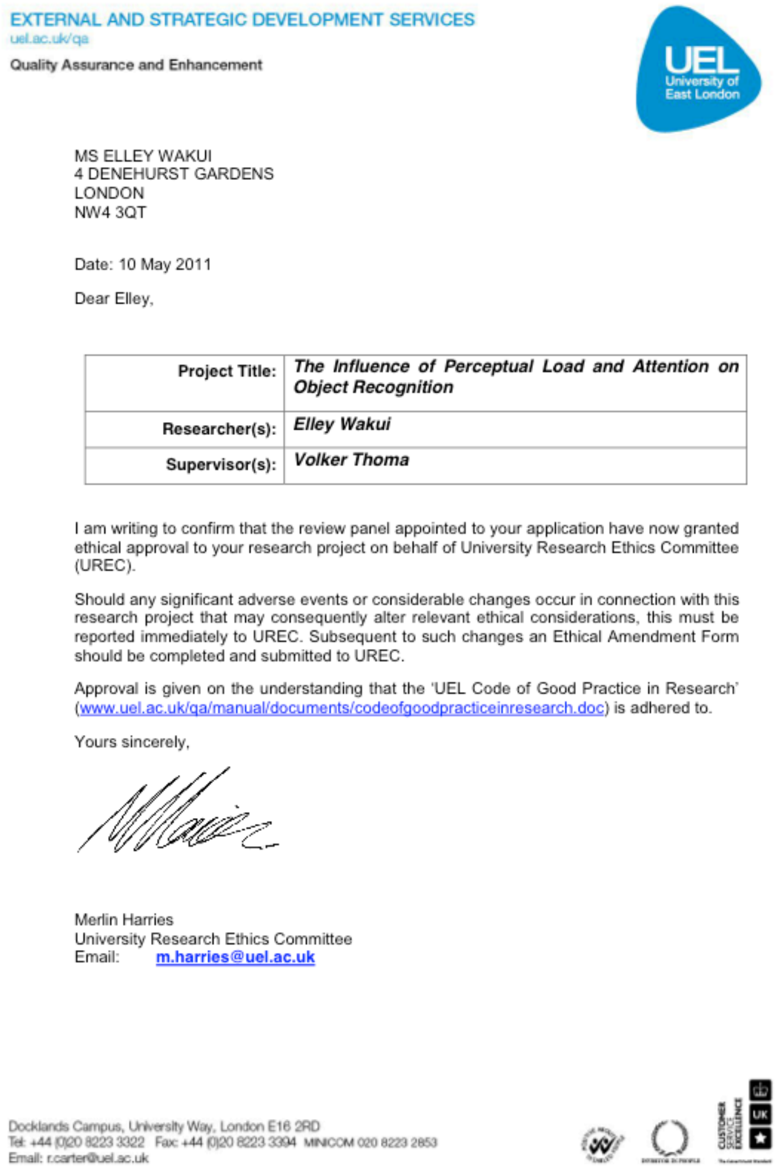
APPENDICES

Appendix I: Ethics and Examples of Participant Introduction Letter, Consent and Debrief Forms

Confirmation of UEL Ethics Approval



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UEL
University of East London

MS ELLEY WAKUI
4 DENEHURST GARDENS
LONDON
NW4 3QT

Date: 10 May 2011

Dear Elley,

Project Title:	***The Influence of Perceptual Load and Attention on Object Recognition***
Researcher(s):	***Elley Wakui***
Supervisor(s):	***Volker Thoma***

I am writing to confirm that the review panel appointed to your application have now granted ethical approval to your research project on behalf of University Research Ethics Committee (UREC).

Should any significant adverse events or considerable changes occur in connection with this research project that may consequently alter relevant ethical considerations, this must be reported immediately to UREC. Subsequent to such changes an Ethical Amendment Form should be completed and submitted to UREC.

Approval is given on the understanding that the 'UEL Code of Good Practice in Research' (www.uel.ac.uk/qa/manual/documents/codeofgoodpracticeinresearch.doc) is adhered to.

Yours sincerely,

Merlin Harries
University Research Ethics Committee
Email: **m.harries@uel.ac.uk**

Docklands Campus, University Way, London E16 2RD
Tel: +44 (0)20 8223 3322 Fax: +44 (0)20 8223 3394 MINICOM 020 8223 2853
Email: r.carter@uel.ac.uk

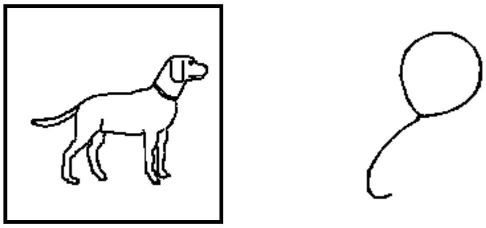
Example Introduction Letter, Consent Form, Debrief

Introduction to Experiment

Thank you for considering participating in this study.

This project is investigating how we represent pictorial information and how this may be influenced by the way it is presented. You will be shown some images briefly on a computer screen and asked to name them. An example is shown below:

Please name the picture in the square…



Now, please name this picture…

The study should cause no discomfort and will last for at most 40 minutes.

The only data recorded will be your response times and accuracies along with your age and gender. You will be asked to sign a consent form at which point you will be assigned a participant number. This document will be stored separately from your data, thus ensuring anonymity.

You are able to withdraw your data at any point up to six months from when you participate, at which point your consent form will be destroyed.

Individual results will not be discussed with anyone.

You are very welcome to contact the researcher again to discuss the study or its findings.

Consent to Participate

If, having read the introduction to the experiment, you would still like to participate, please fill in your details below.
I have the read the information leaflet relating to the above programme of research in which I have been asked to participate and have been given a copy to keep. The nature and purposes of the research have been explained to me, and I have had the opportunity to discuss the details and ask questions about this information. I understand what it being proposed and the procedures in which I will be involved have been explained to me.

I understand that my involvement in this study, and particular data from this research, will remain strictly confidential. Only the researchers involved in the study will have access to the data. It has been explained to me what will happen once the experimental programme has been completed. This confidential record of your participant number and name will be kept only in case you withdraw from the study at a later time and will be destroyed after six months.
I hereby freely and fully consent to participate in the study, which has been fully explained to me.

Having given this consent I understand that I have the right to withdraw from the programme at any time during the experiment or up to the time of full analysis of the complete participants' data set (typically six months) without disadvantage to myself and without being obliged to give any reason.

Participant Name:
Age:
Gender:

Participant Number:
Date:

Please now take a note of your participant number in case you wish to withdraw from the study at a later time.

Participant Debrief

Thank you for participating in this study. We are investigating how you pay attention to an object (the one you had to name first) may affect whether you can also notice a distracting object.
If you see an object and then see it again, you will generally be able to name it faster. Also, even if you are not aware of seeing it (as in the other object that you saw but did not have to name) you will also be able to name it faster. However, this depends on how the image is presented the second time you see it.

Your data will help us to understand the processes involved in naming objects and how important the way the object is presented may be.

If you are interested in any aspect of the study, please do not hesitate to contact me at e.wakui@uel.ac.uk, or on 020 8223 6227.

Elley Wakui
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School of Psychology
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Water Lane
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E15 4LZ

Invitation to participate in research collecting EEG data

Thank you for your interest in taking part in Electroencephalography (EEG) research. EEG is simply a technique for recording electrical signals at the scalp. In the study in which you are invited to participate, electrical signals will be recorded from many locations on your head while you perform an experimental task. This will enable us to investigate the relationships between the experimental stimuli, your responses, and the electrical activity in your brain. Please note that EEG is a crude measure of the total sum of electric signals generated in your brain and we will not be able to tell what you are thinking!

EEG recording is a very safe procedure that carries minimal risks to participants. However, there are some issues we would like to bring to your attention, so please read the following paragraphs carefully. If you have any questions, email [insert name here] and we can discuss your questions in more detail.

1. You will be asked to wear a cap consisting of 128 electrodes (small plastic rings) held together by plastic wire. The plastic wire causes slight pressure on your cheeks, forehead and chin, and although there is minimal discomfort, it is possible that there will be some marks on your face when you leave the laboratory. These are caused only by the pressure of the plastic wire and will fade naturally in a few minutes.
2. The electrodes contain small sponges, which will be soaked in a solution of warm salty water. You should be aware that when you leave the laboratory your hair may be damp and you may want to wash your hair when you get home. Your hair may also be a little messed up so please bring a hairbrush with you. We regret that for hygiene reasons we are unable to supply a hairbrush.
3. EEG recording is fairly time-consuming and you should allow around 2 ½ hours for the whole procedure.
4. You should have normal or corrected-to-normal vision, so if you wear glasses or contact lenses to read or work on a computer then please bring them with you.
5. We will ask for your permission to record some information about you, including your age and gender. We may also ask you for other information required for a particular study. Please note that the data we collect will be stored separately from your name. We will not disclose your name to any other person and it will not be possible for you to be identified from your data.

When you come to do your experiment we will run through these points again and make sure that you can give informed consent.

You may choose to withdraw from the study at any time before, during or after the collection of EEG data. The data you have contributed will be destroyed if you request this.

Finally, we need to ask you about a number of medical factors. If you answer "yes" to any of these questions then please contact [insert name here] to enquire whether you should take part in the EEG research. We will not disclose this information to any other person.

- Are you currently taking, or have you recently taken, any prescription or over-the-counter medicine?
- Have you ever suffered from epilepsy?
- Have you had surgery in which metal items have been placed in your head?
- Do you have a heart pacemaker fitted?
- Do you use any other medical device?
- Have you been feeling unwell over the last few days?
- Do you suffer from any chronic skin condition (e.g. dermatitis, eczema, psoriasis)?
- Do you suffer from any condition impairing blood clotting (e.g. haemophilia) or are you taking any medication that could affect blood clotting?
- Do you currently have any cuts or abrasions on your head?
- Please try to avoid consuming any alcohol or recreational drugs for the 24 hours before the EEG recording session

Please note that this letter is for your information so that you can decide whether you would like to participate in EEG research. This is not a consent form. When you come to do your experiment you will be reminded of the important points and ask to give your consent to participate in the research.

Your experimenter can give you more information about the actual experiment in which you are invited to participate.

Thank you for taking the time to read this carefully and we look forward to seeing you.

Consent to participate in research collecting EEG data

Thank you for your interest in taking part in Electroencephalography (EEG) research. If you have any questions, please ask them now. If you think of a question later you may ask the experimenter during the procedure.

We would like you to initial the boxes below to show that you consent to various aspects of the EEG recording procedure. Then sign the form at the bottom.

Please note that signing this consent form indicates your consent for EEG to be recorded. There will be a separate form to indicate your consent for the particular experiment in which you are participating.

☐ I confirm that I have read the "Invitation to Participate in research collecting EEG data" and I have asked questions of the researcher where necessary.

☐ I consent to wear the electrode cap. I understand that there may be some marks on my face, which will fade naturally in a few minutes.

☐ I understand that my hair may be damp and a little messy after the procedure.

☐ I understand that the procedure will take around 2 ½ hours.

☐ I have normal or corrected-to-normal vision.

☐ I consent for my age and gender to be recorded.

☐ I confirm that I have read the following medical questions.
If the answer to any question is "yes", I have discussed with the researcher, who has indicated that I may participate in the EEG study

- Are you currently taking, or have you recently taken, any prescription or over-the-counter medicine?
- Have you ever suffered from epilepsy?
- Have you had surgery in which metal items have been placed in your head?
- Do you have a heart pacemaker fitted?
- Do you use any other medical device?
- Have you been feeling unwell over the last few days?
- Do you suffer from any chronic skin condition (e.g. dermatitis, eczema, psoriasis)?
- Have you consumed any alcohol or recreational drug over the last 24 hours?
- Do you suffer from any condition impairing blood clotting (e.g. haemophilia) or are you taking any medication that could affect blood clotting?
- Do you currently have any cuts or abrasions on your head

Participant's declaration

I give my informed consent to participate in the EEG recording session. I am aware that my participation is voluntary and that I may withdraw at any time during the experiment, or have my data withdrawn at any time up to the full analysis of the completed data set (typically six months from participation), without giving a reason. I am aware that all information given by me or data recorded from me will be handled confidentially.

Participant signature ____

Date ____

Researcher's declaration

I believe the participant has been fully informed about the EEG recording procedure to the level necessary for the giving of informed consent. I have discussed all relevant aspects of the procedure with the participant, and answered all questions to their satisfaction. I have observed the participant initial all the appropriate sections of this EEG recording Consent to Participate form.

Researcher signature ____

Date ____

Name (print) ____

Debriefing after EEG recording session

Thank you for taking part in the EEG recording. We have now finished recording and we have a record of the electrical activity at various points on your scalp whilst you were doing the experimental tasks. We will collate this data with all of the other participants and then we will analyse the data. The information will help us to understand more fully the relationship between brain activity and behaviour.

We hope you have found the experiment interesting and relatively straightforward. If you have any further questions, you can ask now. If any questions occur to you over the next month you can contact the researcher as indicate on your Experiment debriefing sheet.

The risks associated with EEG recording are minimal. You may have marks where the plastic wires rested on your face but these will fade over the next few minutes.

Thank you for taking part in this research.

Appendix II: Experiment 7 Letter Search Experiment with Inverted Images Probe-locked ERP Analyses for N=13 participants

Probe-locked P1

The analysis of the amplitude of the P1 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes, revealed a significant interaction between View x Repetition x Hemisphere F(1,12) = 14.01, *p* = .003, η_p^2 = .54. There was also a significant interaction between Hemisphere x Electrode Site F(1,12) = 11.05, *p* = .006, η_p^2 = .48. The interaction between View x Electrode Site F(1,12) = 3.38, *p* = .091 was not significant. There were no other significant main effects or interactions in the main ANOVA, *ps* > .14.

In order to follow-up the interaction between View x Repetition x Hemisphere, two separate ANOVAs were performed on each hemisphere. In the right hemisphere, the interaction between View x Repetition was not significant F(1,12) = 4.34, *p* = .059. There were no significant main effects or interactions in the left hemisphere *ps* > 20.

Although the interaction between View x Repetition in the right hemisphere did not reach significance, as this as a key interaction, planned t-tests were performed and revealed that the amplitude for repeated objects (*M* = 1.76 µV, *SD* = 2.44) was almost significantly less than that for unrepeated objects (*M* = 2.19 µV, *SD* = 2.50) and that this was only the case for inverted objects, t(12) = 2.07, *p* = .031 (one-tailed), *d* = 0.58. The difference for upright objects, *p* = .07 (one-tailed).

The analysis of the amplitude of the P1 at the occipital (O1/2) electrodes revealed a significant interaction between View x Repetition x Hemisphere F(1,13) = 4.97, *p* = .04, 4, η_p^2 = .28. There were no other significant main effects or interactions, *ps* > .13. In order to follow up the three-way interaction, two separate ANOVAs were performed on each hemisphere. The only effect that had a significance value of less than .1 was the main effect of view F(1,13) = 3.66, *p* = .078 in the right hemisphere, all other *ps* > .39.

Probe-locked N1

The analysis of the amplitude of the N1 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a near significant interaction between View x Repetition F(1,12) = 3.59, *p* = .082, η_p^2 = .23. Follow-up paired t-tests revealed that only upright images resulted in significant repetition effects of an enhanced N1 for repeated (*M* = -6.02 µV, *SD* = 1.93) vs. unrepeated (*M* =

-5.55 µV, *SD* = 2.09) images, t(12) = 1.78, *p* = .05 (one-tailed), *d* = 0.49, inverted *p* > .35 (one-tailed). There were no other significant main effects or interactions, *ps* > .13.

The analysis of the amplitude of the N1 at the occipital (O1/2) electrodes revealed that none of the main effects or interactions reached significance, all *ps* > .19.

<u>Probe-locked N250: 200-240 ms</u>

This was the first of the two parts of the standard time window for the N250 that were separately analysed, based on visual inspection of the waveforms. The analysis of the amplitude of the early portion of the N250 at the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a near significant interaction between Load x Repetition F(1,12) = 4.52, *p* = .053, η_p^2 = .28. There was also a significant interaction between Repetition x Electrode Site F(1,12) = 6.09, *p* = .030, η_p^2 = .34. There were no other significant main effects or interactions, *ps* > .15.

The Load x Repetition interaction was followed up by paired t-tests, which revealed that for high load, the amplitude for repeated images (*M* = 0.18 µV, *SD* = 2.32) was more negative than for unrepeated (*M* = 0.72 µV, *SD* = 2.52), t(12) = 2.32, *p* = .019 (one-tailed), *d* = 0.64. Follow-up paired t-tests for the interaction between Repetition x Electrode Site found no significant repetition at either electrode site, *ps* > .095 (one-tailed).

The analysis of the amplitude of the early portion of the N250 at the occipital (O1/2) electrodes revealed an almost significant interaction between Load x Repetition F(1,12) = 4.57, *p* = .054, η_p^2 = .27. The interaction between Load x View was not significant F(1,12) = 3.31, *p* = .094. There were no other significant main effects or interaction in the main ANOVA, *ps* > .14. The follow-up paired t-tests for the interaction between Load x Repetition revealed that in high load, the amplitude for repeated images (*M* = 0.18 µV, *SD* = 1.87) was more negative than that for unrepeated (*M* = 0.73 µV, *SD* = 2.23), t(12) = 2.02, *p* = .033 (one-tailed), *d* = 0.56.

<u>Probe-locked N250: 240-270ms</u>

This was the second of the two parts of the standard time window for the N250 that were separately analysed. The analysis of the amplitude at this time window for the parietal (P7/8) and occipito-parietal (PO7/8) electrodes revealed a significant interaction between Repetition x Electrode Site F(1,12) = 6.09, *p* = .030, η_p^2 = .34. The interaction between Load x Repetition was near significant F(1,12) = 4.62, *p* = .053. There were no other significant main effects or interactions in the main ANOVA, *ps* > .11. Follow-up paired t-tests for the interaction between Repetition x Electrode Site revealed that for parietal electrodes P7/8 numerically, the amplitude for repeated objects (*M* = 0.32 μV, *SD* = 2.42) was more negative than that for unrepeated (*M* = 0.57 μV, *SD* = 2.65), but this was not significant p > .08 (one-tailed).

The analysis of the amplitude of the N250 at the occipital (O1/2) electrodes revealed only a near significant main effect of hemisphere F(1,12) = 4.14, *p* = .057, η_p^2 = .27, with the amplitude for the right hemisphere (*M* = -0.40 μV, *SD* = 2.83) more negative than that for the left hemisphere (*M* = 0.62 μV, *SD* = 3.26). There were no other significant main effects or interactions in the main ANOVA, *ps* > .10.

Appendix III: Probe-locked and Prime-locked ERP Latency Analyses for Experiments 1, 2 and 3

Experiment 1: Spatial Cuing Experiment with Scaled Objects

Probe-locked P1 Latency

The analysis of P1 latency revealed a near significant interaction between Hemisphere x Electrode, F(1,15) = 4.00, *p* = .064. There were no other significant main effects or interactions, all other *ps* > .11.

Probe-locked N1 Latency

The analysis of N1 latency revealed a near significant main effect of Repetition approached significance F(1,15) = 4.26, *p* = .057, which was modified by a significant three-way interaction Repetition x Hemisphere x Electrode F(1,15) = 4.90, *p* = .043. There were no other significant main effects or interactions, all other *ps* > .11. Follow up tests revealed that the effect of repetition was only significant at the parietal P78 electrode sites, where repeated images resulted in an earlier peak (151.3 ms), than unrepeated images (158.1 ms) t(15) = 2.26, *p* = .04.

Experiment 2: Spatial Cuing Experiment with Split Images

Probe-locked P1 Latency

The analysis of P1 latency revealed a statistically significant main effect of view F(1,13) = 6.937, *p* = .021, where the intact images produced an earlier peak at 96.4 ms, compared to split images peaking at 100.2 ms. There was also a significant effect of electrode site F(1,13) = 5.97, *p* = .03, with occipito-parietal PO7/8 sites peaking earlier (96.8 ms) than parietal P7/8 sites (99.9 ms). The interaction between View x Hemisphere interaction F(1,13) = 3.16, *p* = .099, was not significant, and there were no other significant main effects or interactions, all other *ps* > .16.

Probe-locked N1 Latency

The analysis of the N1 latency revealed a statistically significant main effect of view F(1,13) = 47.02, *p* < .001, with intact images producing an earlier peak at 153.0 ms compared to split images peaking at 161.7 ms. There was also a significant main effect of electrode site F(1,13) = 15.63, *p* = .002, with occipito-parietal PO7/8 sites peaking earlier at 156.6 ms compared to parietal P7/8 sites 158.0 ms. The main effect of hemisphere F(1,13) = 3.31, *p* = .092 did not reach significance. There were no other significant main effects or interactions, all other *ps* > .13.

Prime-locked P1 Latency

The analysis of the P1 latency revealed no significant main effects or interactions, *ps* > .12.

Prime-locked N1 Latency

The analysis of the N1 latency revealed a significant interaction between Hemisphere x Electrode Site, F(1,13) = 4.78, *p* = .048. There were no other significant main effects or interactions, all other *ps* > .27. Paired t-tests following up the interaction between Hemisphere x Electrode Site revealed no significant differences, *ps* > .086.

Experiment 3: Spatial Cuing with Perceptual Load

Probe-locked P1 Latency

The analysis of the P1 latency at the P7/8, PO7/8 electrodes, revealed no significant main effects or interactions, *ps* >.096.

The analysis of the P1 latency at the O1/2 electrodes revealed a significant main effect of hemisphere F(1,13) = 6.35, p=.026, with the P1 peaking earlier in the right hemisphere (89.1 ms) than left hemisphere (95.9 ms). There were no other significant main effects or interactions, all other *ps* > .52.

Probe-locked N1 Latency

The analysis of the N1 latency at the P7/8, PO7/8 electrodes revealed a near significant main effect of electrode site, F(1,13) = 4.34, *p* = .057, with the N1 for the occipito-parietal PO7/8 peaking earlier (150.0 ms) compared to the parietal P7/7 (154.4 ms).

There was a significant interaction between Load x Repetition, F(1,13) = 5.82, *p* = .031. Paired t-tests indicated that only the repetition effect for low load, with the N1 for repeated objects peaking later (153.5 ms) than unrepeated (149.1 ms) was near significance t(13) = 2.01, *p* = .065.

The analysis of the N1 latency at the O1/2 electrodes revealed a significant main effect of hemisphere F(1,13) = 6.53, *p* = .024, with the N1 peaking earlier in the right hemisphere (143.9 ms) than the left hemisphere (149.5 ms). There were no other significant main effects or interactions, all other *ps* > .29.

Prime-locked P1 Latency

The analysis of the P1 latency at P7/8, PO7/8 electrodes revealed a significant main effect of electrode site F(1,13) = 10.43, *p* = .007, and the interaction Hemisphere x Electrode Site F(1,13) = 3.91, *p* = .07 missed significance. In the right hemisphere, the P1 at the occipito-parietal electrode PO8 peaked earlier (88.5 ms) than the parietal P8 (102.4 ms), t(13) = 3.61, *p* = .003 (Bonferroni 4 comparisons *p* < .0125).

The analysis of the P1 latency at O1/2 electrodes revealed a near significant main effect of hemisphere missed significance F(1,13) = 4.26, *p* = .06, with the P1 peaking earlier in the right hemisphere (73.1 ms) than in the left (81.6 ms).

Prime-locked N1 Latency

The analysis of N1 latency at P7/8, PO7/8 electrodes revealed an almost significant interaction Load x Hemisphere just missed significance, F(1,13) = 4.57, *p* = .052. The follow up t tests indicated that there were no significant differences between levels of the factors.

The analysis of N1 latency at O1/2 electrodes revealed only a trend for an interaction between Load x Hemisphere F(1,13) – 3.4, *p* = .088.

Experiment 6: Letter search Experiment with Split Images

Probe-locked P1 Latency

The analysis of P1 latency at P7/8, PO7/8 electrodes revealed a significant interaction between Repetition x Hemisphere F(1,11) = 8.08, *p* = .016. There was a significant three-way interaction between Load x Repetition x Electrode Site F(1,11) = 5.05, p=.046. The interactions between Load x View x Hemisphere F(1,11) = 3.89, *p* = .074 and Repetition x Electrode Site F(1,11) = 3.36, *p* = .094 and towards the main effect of Electrode Site F(1,11) = 3.83, *p* = .093 were not significant.

There were no other significant main effects or interactions, all other *ps* > .14.

Follow up tests for the Repetition x Hemisphere interaction revealed that the effect of repetition was only significant in the left hemisphere such that the peak was earlier for unrepeated (100.3ms) vs. repeated (103.1ms) images, t(11) = 2.25, *p* = .046.

Follow-up ANOVAs for the Load x Repetition x Electrode Site interaction indicated that for Low Load the interaction between Repetition x Electrode site missed significance F(1,11) = 4.43, *p* = .059, where the peak of the P1 for unrepeated objects was earlier for the occipito-parietal PO78 (100.0 ms) than parietal P78 (104.0ms), t(11) =2.77, *p* = .018.

The analysis of the P1 latency at O1/2 electrodes revealed a significant three-way interaction between View x Repetition x Hemisphere F(1,11) = 5.51, p=.039. Load x View x Hemisphere F(1,11) = 8.06, p=.016. There were no other significant main effects or interactions, all other *ps* > .12.

Follow-up ANOVAs for the View x Repetition x Hemisphere interaction revealed a significant interaction between Repetition x Hemisphere F(1,11) = 8.11, *p* = .016 for split images only. The peak was earlier for unrepeated (97.3 ms) vs. repeated (105.5 ms) images in the left hemisphere, t(11) = 2.24, *p* = .046, and repeated images peaked earlier in the right hemisphere (97.5ms, SD = 14.2) than the left hemisphere, t(11) = 2.27, *p* = .044.

The separate follow-up ANOVAs for the Load x View x Hemisphere interaction did not reveal and significant main effects or interactions.

Probe-locked N1 Latency

The analysis of the N1 latency for P7/8, PO7/8 electrodes revealed a significant main effect of electrode site F(1,11) = 13.19, *p* = .004, which was qualified by a significant interaction between View x Electrode Site F(1,11) = 5.21, *p* = .043. The interaction between Load x View F(1,11) =

3.33, *p* = .095 was not significant. There were no other significant main effects or interactions, all other *ps* > .12.

Follow-up paired t-tests for the interaction between View x Electrode Site indicated that at the parietal P78 the N1 peaked significantly earlier for split (155.8 ms) vs. intact (179.4ms) images, t(11) = 24.1, *p* < .001. Also, for intact images, the N1 peaked earlier for occipito-parietal PO78 (152.3 ms) than at parietal P78, t(11) = 21.84, *p* < .001 (Bonferroni criterion for 4 comparisons *p* < .0125).

The analysis of the N1 latency for O1/2 electrodes revealed only a non-significant interaction between Load x Repetition F(1,11) = 3.34, *p* = .095. There were no other significant main effects or interactions, all other *ps* > .18.

Experiment 7: Letter Search Experiment with Inverted Images

Probe-locked P1 Latency

The analysis of the P1 latency at P7/8, PO7/8 electrodes revealed a significant main effect of electrode site F(1,13) = 10.71, *p* = .006, which was qualified by an interaction between Load x Hemisphere x Electrode Site F(1,13) = 5.71, *p* = .033. There were no other significant main effects or interactions, all other *ps* > .11.

The Load x Hemisphere x Electrode Site interaction was followed up by three sets of 2 x 2 ANOVAs. In low load, there was a significant interaction between Hemisphere x Electrode Site F(1,13) = 5.07, *p* = .042, and paired t-tests then indicated that the peak at occipito-parietal PO8 (89.3 ms) was earlier than at the parietal P8 (95.5 ms), t(13) = 3.02, *p* = .01 (Bonferroni 4 comparisons *p* < .0125).

The analysis of the P1 latency at O1/2 electrodes revealed a significant main effect of hemisphere F(1,13) = 5.98, *p* = .03, with the peak in the right hemisphere (79.5ms) earlier than in the left (86.0ms). There was also a significant interaction between Load x View x Repetition F(1,13) = 12.1, *p* = .004. There were no other significant main effects or interactions, all other *ps* > .13.

The Load x View x Repetition interaction was followed up with three sets of 2 x 2 ANOVAs. In low load, there was a significant interaction between View x Repetition F(1,13) = 4.86, *p* = .046, however, repetition effects were not significant for either view *ps* >.098. In high load, there was also a significant interaction between View x Repetition F(1,13) = 7.4, *p* = .018. Here the paired t-tests indicated that for inverted images, the peak was earlier for repeated (80.9 ms) than for unrepeated images (82.9 ms), t(13) = 2.32, *p* = .019 (one-tailed).

Probe-locked N1 Latency

The analysis of the N1 latency at P7/8,PO7/8 electrodes revealed a significant main effect of electrode site F(1,13) = 5.34, *p* = .038, and a significant interaction between Repetition x Hemisphere F(1,13) = 5.50, *p* = .036, but these were qualified by significant interaction between Load x Repetition x Hemisphere x Electrode Site F(1,13) = 6.18, *p* = .027.There were no other significant main effects or interactions, all other *ps* > .11.

The follow up ANOVA for the interaction between Load x Repetition x Hemisphere x Electrode Site at the level of the occipito-parietal Electrode Site PO7/8 showed no significant main effects or interactions, all *ps* > .11. However, at the level of the parietal Electrode Site P78, there was a significant interaction between Repetition x Hemisphere F(1,13) = 8.25, *p* = .013. Paired t-tests then indicated that the peak for repeated images (153.2 ms) was earlier than for unrepeated (157.2 ms) only for the left P7, t(13) = 2.32, *p* = .037.

The analysis of the N1 latency at the O1/2 electrodes revealed a significant interaction between Load x Repetition F(1,13) = 10.55, *p* = .006. There were no other significant main effects or interactions, all other *ps* > .24.

The paired t-tests to follow up the Load x Repetition interaction indicated that for low load, the peak for repeated images (147.8 ms) was earlier than for unrepeated images (151.1 ms), t(13) = 3.21, *p* = .007.

Appendix IV: Prime-locked ERP Analyses for P1 and N1 for Experiments 6 & 7

Experiment 6: Letter Search Experiment with Split Images

Prime-locked P1 Amplitude

The analysis of the P1 at P7/8, PO7/8 electrodes revealed a main effect of Electrode Site reached significance F(1,11) = 5.34, p = .041, with a more enhanced P1 at occipito-parietal PO78 (1.98 μV) vs. parietal P78 (1.25 μV) sites. There were no other significant main effects or interactions, all *ps* > .13.

The analysis of the P1 at O1/2 electrodes revealed a near significant interaction between Load x View x Hemisphere missed significance F(1,11) = 4.11, *p* = .068. There were no other significant main effects or interactions, *ps* > .11.

Follow-up ANOVAs for the interaction between Load x View x Hemisphere indicated that in the left hemisphere, there was a significant interaction between Load x View F(1,11) = 7.79, *p* = .018, for which paired t-tests then indicated for high load only was the P1 enhanced for split (1.53 μV) vs. intact (0.97 μV) images.

Prime-locked P1 Latency

The analysis of the P1 at P7/8, PO7/8 electrodes revealed no significant main effects or interactions, *ps* > .21.

The analysis of the P1 at O1/2 electrodes revealed non-significant interactions between View x Hemisphere F(1,11) = 3.88, *p* = .074 and Load x Hemisphere F(1,11) = 3.49, *p* = .089. There were no other significant main effects or interactions, *ps* >.29.

Prime-locked N1 Amplitude

The analysis of the N1 at P7/8, PO7/8 electrodes revealed an almost significant interaction between Hemisphere x Electrode Site just missed significance F(1,11) = 4.58, *p* = .052. The interaction between Load x View also near significance F(1,11) = 4.26, *p* = .063. The main effect of electrode site, F(1,11) = 3.33, *p* = .095, and the interaction between View x Hemisphere x Electrode Site F(1,11) = 3.32, *p* = .096 were not significant. There were no other significant main effects or interactions, *ps* > .11.

The follow up paired t tests for the Hemisphere x Electrodes Site interaction revealed a significantly enhanced N1 for PO7 (-5.96 µV) vs. P7 (4.58 µV), t(11) = 3.62, *p* = .004 (Bonferroni criterion for 4 comparisons p<.0125)..

Follow-up paired t-tests for the Load x View interaction indicated that for Intact images only, the N1 amplitude was enhanced for high (-6.42 µV) vs. low (-5.80 µV) load, t(11) = 2.32, *p* = .041.

The analysis of the N1 at O1/2 electrodes revealed a significant interaction between View x Hemisphere F(1,11) = 6.90, *p* = .024, where numerically, in the right hemisphere the N1 was enhanced for split (-5.05 µV) vs. intact (-4.73 µV) images, t(11) = 1.88, *p* = .087. The interaction between Load x View was near significance F(1,11) = 4.65, *p* = .054. There were no other significant main effects or interactions, *ps* > .27.

The follow up paired t tests for the Load x View interaction indicated that the N1 was numerically enhanced for high intact (-4.84 µV) vs. low intact (-4.2 µV) images, t(11) = 2.01, *p* = .069.

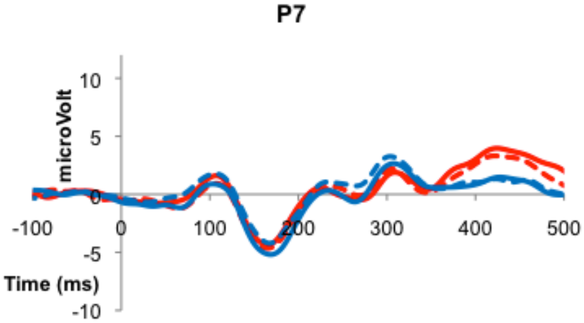
Prime-locked N1 Latency

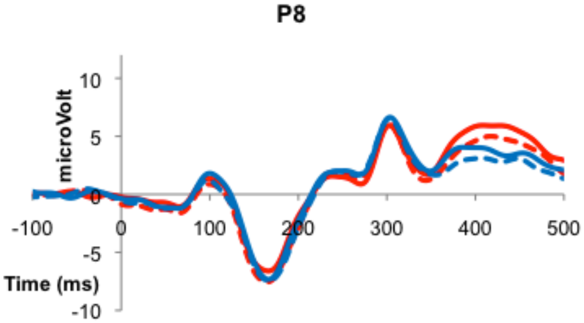
The analysis of the N1 at P7/8, PO7/8 electrodes revealed a significant main effect of load F(1,11) = 9.34, *p* = .011 that was qualified by a significant interaction between Load x View x Hemisphere x Electrode Site F(1,11) = 15.23, *p* = .002. There were no other significant main effects or interactions, *ps* > .14.

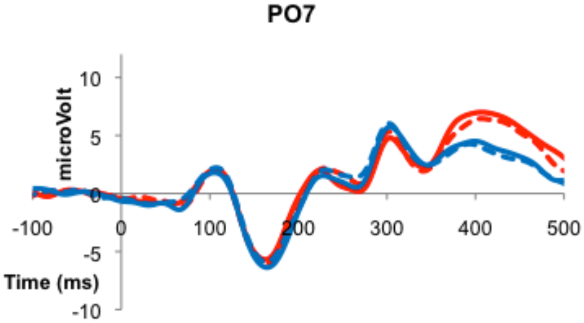
Follow-up ANOVAs for the Load x View x Hemisphere x Electrodes Site interaction indicated that for the occipito-parietal electrodes PO78 there was only a significant main effect of load F(1,11) = 5.56, *p* = .038, with the N1 peaking earlier for low (160.3 ms) vs. high (163.0 ms) load. For the parietal P78, the interaction between Load x View x Hemisphere was significant F(1,11) = 10.71, *p* = .007. Further follow-up ANOVAs indicated that there was a just significant main effect of load F(1,11) = 4.85, *p* = .05. For the right hemisphere the N1 peaked earlier for low (161.2 ms) vs. high (163.6 ms) load. For the left hemisphere, there was a significant interaction between Load x View F(1,11) = 5.99, *p* = .032, however, none of the paired t-tests showed significant differences (all *ps* >.19) although numerically, the peak was earlier for split vs. intact images and for low vs. high Load.

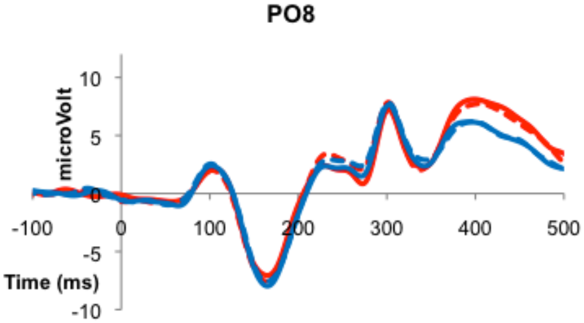
The analysis of the N1 at O1/2 electrodes revealed a significant main effect of load F(1,11) = 6.15, *p* = .031, with the N1 peaking earlier for low (159.0 ms) vs. high (161.6 ms) load. There were no other significant main effects or interactions, *ps* > .10.

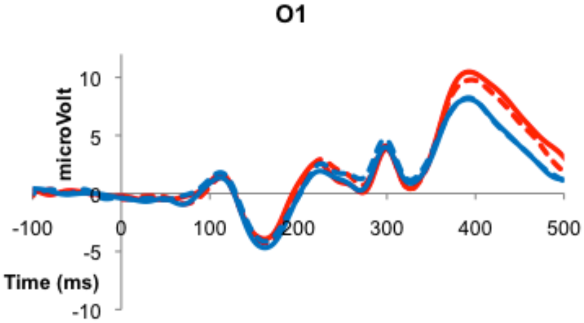
The grand-averaged prime-locked waveforms for each electrode site analysed are shown below:

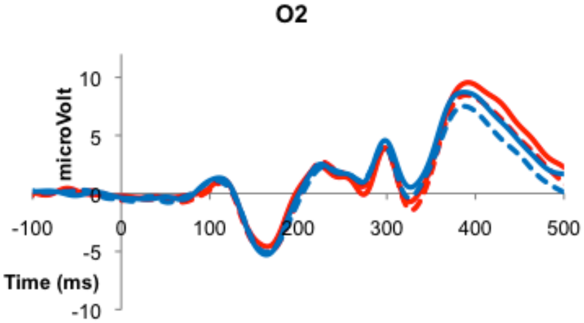

P7
microVolt
10
5
0
-5
-10
-100
0
100
200
300
400
500
Time (ms)


P8
microVolt
10
5
0
-5
-10
-100
0
100
200
300
400
500
Time (ms)


PO7
microVolt
10
5
0
-5
-10
-100
0
100
200
300
400
500
Time (ms)


PO8
microVolt
10
5
0
-5
-10
-100
0
100
200
300
400
500
Time (ms)


O1
microVolt
10
5
0
-5
-10
-100
0
100
200
300
400
500
Time (ms)


O2
microVolt
10
5
0
-5
-10
-100
0
100
200
300
400
500
Time (ms)

Experiment 7: Letter Search Experiment with Inverted Images

Prime-locked P1 Amplitude

The analysis of the P1 at P7/8, PO7/8 electrodes revealed non-significant main effect of electrode site, F(1,13) = 3.44, *p* = .086 and interaction between Load x View x Hemisphere F(1,13) = 3.51, *p* = .084. There were no other significant main effects or interactions, *ps* > .15.

The analysis of the P1 at O1/2 electrodes revealed no significant main effects or interactions, *ps* >.22

Prime-locked P1 Latency

The analysis of the P1 at P7/8, PO7/8 electrodes revealed no significant main effects or interactions, *ps* > 12.

The analysis of the P1 at O1/2 electrodes revealed no significant main effects or interactions, *ps* > 11.

Prime-locked N1 Amplitude

The analysis of the N1 at P7/8, PO7/8 electrodes revealed a significant main effect of load F(1,13) = 17.88, *p* = .001, where the amplitude for high load (-7.23 μV) was more negative than for low load (-6.34 μV). The main effect of view was near significance F(1,13) = 4.0, *p* = .067, where the amplitude for inverted images (-7.04 μV) was more negative than for Upright images (-6.53 μV). There were no other significant main effects or interactions, *ps* > .13.

The analysis of the N1 at O1/2 electrodes revealed a significant main effect of load F(1,13) = 15.45, *p* = .002, where the amplitude for high load (-6.32 μV) was more negative than for low load (-5.11 μV). There was also a significant main effect of view F(1,13) = 5.87, *p* = .031, where inverted images (-6.0 μV) had a more negative amplitude than upright images (-5.43 μV). There were no other significant main effects or interactions, *ps* > .28.

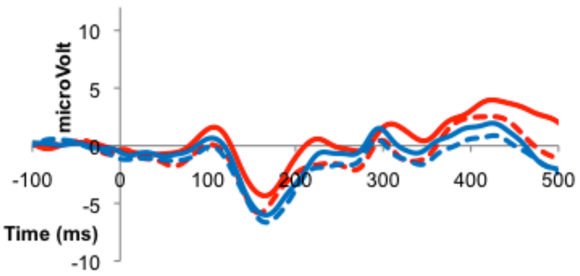
Prime-locked N1 Latency

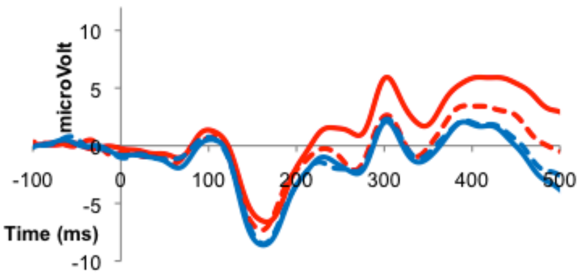
The analysis of the N1 at P7/8, PO/8 electrodes revealed a significant main effect of load F(1,13) = 5.04, *p* = .043, with high load (165.2 ms) peaking later than low load (159.2 ms). There were no other significant main effects or interactions, *ps* > .12.

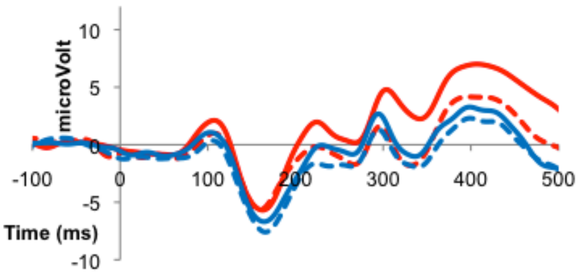
The analysis of the N1 at O1/2 electrodes revealed a significant main effect of load F(1,13) = 7.92, *p* = .015, where the peak for high load (165.1 ms) was later than for low load (160.3 ms).

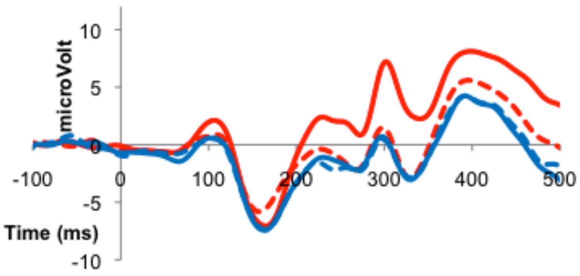
This was qualified by interaction between Load x Hemisphere F(1,13) = 4.87, *p* = .046. Follow up tests indicated that the load effect was only significant in the left hemisphere (O1) such that the peak for high load (165.2 ms) was later than for low load (158.8 ms) t(13) = 2.94, *p* = .012. There were no other significant main effects or interactions, *ps* > .17.

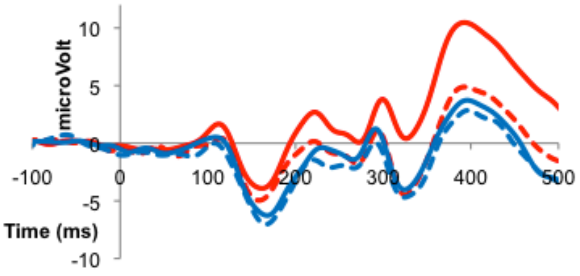
The grand-averaged prime-locked waveforms for each electrode site analysed are shown below:

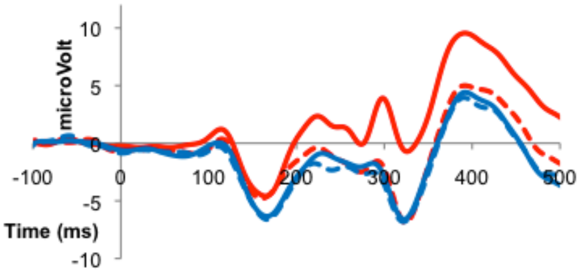

P7


P8


PO7


PO8


O1


O2

Appendix V: Stimulus Lists for Experiment 1

<u>Subset A:</u>

clamp, cot, wallet, trowel, thermometer, dart, blowfish, moon, pickaxe, tweezers, worm, compass, cymbals, pan pipes, exercise bike, button, baseball glove, coin, newspaper, tag, claw, chainsaw, skull, hotdog, belt, bone, shovel, planet, dice, ear, net, scroll, key, jam, magnifying glass, cutting board, ferris wheel, spiderweb, finger, tray, corn, fork, trombone, lamp, ruler, package, bag, strawberry, croissant, acorn, pencil sharpener, banjo, watch, tennisracket, cards, spoon, toe, sandwich, hand, zipper

<u>Subset B:</u>

peanut, avocado, chisel, coffee pot, rake, caterpillar, rope, thumb, paintroller, knife, eye, badge, scooter, pretzel, tyre, necklace, barrel, deckchair, letter, onion, balloon, rolling pin, hour glass, carrot, starfish, lollipop, dust pan, comb, dragonfly, bird cage

<u>Subset C:</u>

nailfile, scarf, artichoke, hook, clothes line, rifle, lettuce, lobster, bow and arrow, rooster, envelope, plug, grave, pillow, yarn, handcuffs, torch, lemon, syringe, triangle, magnet, flipflops, bookcase, razor, horseshoe, sailboat, door, orange, traffic light, saw

<u>Subset D:</u>

ring, yoyo, paddle, walnut, wall, rug, pinecone, peach, screw, arm, spaghetti, hamburger, sword, radiator, snake, bales, pizza, box, cherry, baseball bat, horseshoe, horn, sailboat, paintbrush, french horn, plug socket, cigarette, door, sweets, knitting

Table i: Mean Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for each stimulus subset of Experiment 1 based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Subset	**Percentage Name agreement***	**Visual complexity ***	**Familiarity***	**Age of Acquisition in years ****
A	0.83	2.75	4.10	2.6
B	0.82	2.78	3.40	3.0
C	0.86	2.94	3.40	2.6
D	0.86	2.78	3.42	2.3

Appendix VI: Stimulus Lists for Experiment 2

Subset A:

car, mixer, aerosol, stapler, tricycle, armour, frying pan, barbeque, bench, treasure chest, bomb, baseball cap, coffee maker, handbag, chair, unicycle, tap, helmet, cane, van, ladle, backpack, ship, bucket, dress, stroller, sofa, spinning wheel, gravy boat, filing cabinet, tripod, bulldozer, barn, blender, chimney, slingshot, fishbowl, well, fire extinguisher, telephone, exercise bike, drill, swimming pool, kettle, hanger, blouse, windmill, arch, microphone, desklamp, violin, guitar, vulture, antlers, penguin, beaver, bat, beetle, bread, popcorn, lion, rubber duck, soldier, foot, tiger, mushroom, ant, hyena, knight, dolphin, rhino, kangaroo, parrot, dinosaur, grapes, alligator, horse, frog, rocking horse, bird, trainer, bookcase, vest, sock, helicopter, safe, clipboard, igloo, table, broom, fan, birdhouse, crown, pump, bowtie, camera, sandal, boat, briefcase, pipe, forklift, bathtub, walrus, headphones, thermos, stove, firetruck, cannon, drawer, glue, submarine, medal, carriage, robot, bell, paint, mask, hose, mobile phone, weather vane, maracas, baby bottle, tractor, canoe, excavator, hot air balloon, grater, refridgerator, bus, wineglass, basket, lamppost, hippo, broccoli, tortoise, owl, dog, cat, dragon, koala, turkey, peacock, bull, scorpion, ice cream, apple, hoof, rabbit, flower, pumpkin, armadillo, cockroach, doll, cake, leopard, swan, fish, brain, squirrel, chick

Subset B:

pepper mill, swimsuit, fence, computer, harp, traffic cone, lock, sink, highchair, stethoscope, toilet, microscope, garbage can, king, seal, cactus, skunk, flamingo, monkey, bear, trolley, camcorder, baby carriage, wagon, bottle, slide, whistle, saxophone, glass, bicycle, saucepan, anchor, camper van, monk, jellyfish, fly, man, butterfly, dove, christmas tree

Subset C:

teeshirt, snowman, laptop, suit, skirt, colander, house, step ladder, monitor, wheelbarrow, shed, kennel, clock, llama, pelican, pig, ostrich, tomato, toucan, cow, electric razor, parachute, funnel, cup, train, crane, coat, cable car, cleaver, sewing machine, piano, spinning top, toaster, tree, giraffe, mountain, grasshopper, lizard, raccoon, wolf

Subset D:

gun, carousel, mop, anvil, tent, bridge, hat, lawnmower, stool, television, space shuttle, tank, dresser, chef, bee, platypus, skeleton, elephant, nose, camel, radar dish, fishing rod, skateboard, candle, iron, rocking chair, vase, ink, whisk, toilet roll, telescope, swing, fire hydrant, palmtree, ladybird, panda, goose, girl, salt, zebra

Subset E:

stairs, urn, typewriter, wardrobe, ironing board, apron, blowdryer, truck, vacuum cleaner, cap, washing up liquid, trousers, shoe, fox, eggs, leg, pineapple, prawn, seahorse, calculator, trophy, cot, shirt, easel, wellington boots, binoculars, jug, roller skate, boot, tissues, mousetrap, spray bottle, train wagon, unicorn, chicken, butter, gorilla, clown, milk, fruit basket

Subset F:

iceskate, motorcycle, desk, mirror, wheelchair, can, projector, suitcase, plane, umbrella, lipstick, washing machine, shield, sheep, swordfish, duck, celery, teddybear, donkey, mouse, pyramid, corkscrew, tape measure, record player, watering can, bowl, bed, cashtill, rosette, mailbox, totem, glasses, skittles, boy, lamb, diver, buffalo, moose, lungs, eagle

Subset G:

hole punch, ashtray, sled, jar, bra, radio, castle, sack, sweater, scales, lighter, golf club, tie, baby, fairy, witch, rose, deer, goat, whale, teapot, perfume, lantern, flag, globe, church, grandfather clock, shower, balcony, jacket, lighthouse, xylophone, roof, piggybank, ghost, hedgehog, pear, shark, snail, astronaut

Table ii: Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for each stimulus subset of Experiment 2 based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Subset	**Name agreement***	**Visual complexity***	**Familiarity***	**Age of Acquisition****
A	0.84	3.22	3.33	2.6
B	0.88	3.12	3.07	1.6
C	0.86	3.27	3.33	3.0
D	0.85	3.18	3.26	2.7
E	0.85	3.38	3.15	2.1
F	0.80	3.31	3.53	2.4
G	0.86	2.87	3.33	2.6

Appendix VII: Stimulus Lists for Experiment 3

Subset A:

jar, jug, lamp, net, pool, pump, sack, salt, scales, shed, shield, ship, shirt, shoe, sled, slide, soap, church, crane, fence, fire, gate, suitcase, sweater, swimsuit, teapot, teeshirt, telephone, tissues, toaster, toilet, tractor, trainer, tripod, trolley, trophy, television, wardrobe, wheelchair, windmill, wineglass, apron, easel, faxmachine, forklift, fountain, helmet, highchair, microscope, milkbottle, mobilephone, motorcycle, piano, projector, pyramid, radio, placesetting, radardish, rollerskate, submarine, wateringcan, radiator, recordplayer, exercisebike, filingcabinet, ant, bat, bear, bed, bird, boy, bread, cat, chef, clown, cow, lung, skunk, baby, butter, cactus, camel, chicken, christmastree, donkey, dragon, eagle, pirate, racoon, waiter, alligator, dinosaur, elephant, flamingo, fruitbasket, rubberduck

Subset B:

bench, blouse, boat, book, boot, bowl, box, bra, bus, cake, can, cap, car, chair, chest, clock, coat, sofa, crown, safe, sink, skirt, doghouse, drawer, firetruck, fishbowl, funnel, glasses, hanger, headphones, hourglass, icecream, igloo, iron, jacket, kettle, laptop, lighter, lighthouse, lightning, saucepan, lamppost, anvil, ashtray, binder, birdnest, blender, bookcase, tricycle, typewriter, unicycle, vacuumcleaner, weathervane, wheelbarrow, bulldozer, aerosol, balcony, blowdryer, cablecar, carousel, ironingboard, cyclehelmet, excavator, fireextinguisher, milk, moose, mouse, nose, owl, pig, prawn, queen, rose, shark, sheep, fern, giraffe, hedgehog, lion, monkey, mushroom, palmtree, panda, parrot, peacock, penguin, walrus, antlers, grasshopper, hamburger, kangaroo, koala, leopard, pelican, platypus, caterpillar

Subset C:

cup, desk, doll, dress, drill, drum, fan, glass, globe, grave, gun, spinningtop, harp, hat, heel, house, ink, stairs, hose, mosque, road, roof, lipstick, lunchbox, medal, mirror, mixer, mountain, trousers, computer, handbag, rainbow, rosette, saddle, sailboat, scooter, skittles, slingshot, stapler, stroller, teepee, thermos, totem, turnstile, wagon, window, taxi, lantern, shower, barbeque, camera, colander, dressinggown, fryingpan, garbagecan, gravyboat, microphone, trainwagon, volcano, xylophone, chandelier, firehydrant, picnictable, sewingmachine, washingmachine, deer, dog, duck, eggs, fish, fox, frog, ghost, girl, goat, horse, hair, hoof, logs, fairy, flower, pumpkin, rabbit, rhino, robot, seahorse, beaver, lizard, llama, ostrich, gorilla, skeleton, teddybear, unicorn, buffalo, armadillo

<u>Subset D:</u>

stool, stove, suit, swing, table, tank, tap, tent, tie, train, truck, vase, vest, well, wine, bag, bathtub, cot, arch, barn, bridge, gas, aeroplane, babycarriage, backpack, baseballcap, basket, bicycle, birdhouse, bottle, bowtie, bucket, candle, cannon, cashregister, chesspiece, cradle, curtains, deckchair, desklamp, castle, chimney, briefcase, crutches, dresser, earring, refridgerator, camper, carriage, rockingchair, rockinghorse, spinningwheel, spraybottle, telescope, toiletroll, trafficlight, triangle, coffeemill, ferriswheel, lawnmower, calculator, coffeemaker, grandfatherclock, helicopter, hotairballoon, skull, snail, swan, tree, witch, wolf, king, knight, lamb, man, beard, brain, bull, calf, popcorn, snowman, soldier, squirrel, tiger, turtle, zebra, rooster, toucan, turkey, vulture, piggybank, icelolly, scorpion, hyena, leprechaun, hippopotamus

<u>Subset Ea:</u>

kite, knife, knot, pipe, scarf, spoon, tyre, watch, wheel, axe, dart, torch, horn, nail, rocket, scissors, shovel, toothbrush, trombone, trowel, whistle, zipper, banjo, button, hammer, handcuffs, paddle, safetypin, baseballbat, envelope, tennisracket, peas, shell, snake, sun, tomato, bride, monk, carrot, lemon, lobster, pizza, butterfly, onion, spiderweb, ladybird, pineapple, dragonfly

<u>Subset Eb:</u>

ball, brush, peg, coin, comb, dice, flag, fork, key, pen, saw, sword, wand, whisk, yarn, anchor, bandaid, broom, corkscrew, guitar, notebook, planet, palette, paintbrush, pillow, pliers, razor, toothpaste, trumpet, yoyo, rollingpin, protractor, bone, cheese, crab, leaf, pear, grapes, nut, worm, acorn, apple, sandwich, starfish, banana, brocolli, octopus, dove

Table iii: Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for each stimulus subset of Experiment 3 based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Subset	**Name agreement***	**Visual complexity***	**Familiarity***	**Age of Acquisition****
A	3.95	3.32	3.29	2.3
B	0.83	3.03	3.35	2.5
C	0.84	3.20	3.31	2.6
D	0.85	3.34	3.29	2.6
Ea	0.91	2.73	3.52	2.5
Eb	0.89	2.49	3.62	2.8

Appendix VIII: Stimulus Lists for Experiment 4

Subset A:

anchor, belt, watering can, penguin, toothpaste, kangaroo, lobster, desk, zipper, candle, dolphin, guitar

Subset B:

tree, fox, walrus, rifle, clock, comb, crown, barbecue, glass, glasses, hat, seahorse

Subset D:

light switch, camel, apple, banana, piano, sofa, stapler, fire extinguisher, fishbowl, trombone, hippopotamus, kite

Subset E:

ant, bandaid, baseball bat, bed, boot, igloo, cat, crane, lipstick, elephant, frog, house

Subset F:

axe, barrel, basket, key, bow, rocket, garbage can, dinosaur, eagle, crab, spoon, flower

Subset G:

typewriter, toothbrush, trolley, toiletroll, table, goat, teeth, alligator, clothespin, bathtub, bird house, cheese

Subset J:

sewingmachine, squirrel, coat, cot, donkey, globe, lightbulb, lion, lock, syringe, wolf, pipe

Subset K:

scorpion, bear, fly, telephone, microscope, bird, bucket, car, chair, washing machine, fishhook, flag

Subset C:

baseball glove, brain, chest, cleaver, croissant, cymbals, deckchair, doll, dragon, easel, toucan, golf club, harmonica, racoon, lawnmower, magnifying glass, match, paint, paintroller, piggybank, rocking horse, rooster, cherry, slingshot

Subset H:

prawn, koala, thermos, thimble, tractor, flamingo, whip, whisk, mop, net, fairy, maracas, radar dish, hyena, highchair, sled, trowel, porcupine, clamp, jar, celery, boomerang, turkey, panda

Table iv: Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for each stimulus subset of Experiment 4 based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Subset	**Name agreement***	**Visual complexity***	**Familiarity***	**Age of Acquisition****
A	0.92	3.13	2.85	2.5
B	0.89	3.21	3.39	3.0
D	0.83	2.63	3.61	3.0
E	0.92	3.08	3.59	3.0
F	0.89	3.09	3.21	3.0
G	0.81	2.73	3.31	2.3
J	0.9	2.98	3.20	2.0
K	0.84	3.41	3.72	3.0
C	0.74	3.63	3.29	2.8
H	0.77	3.38	3.47	2.4

Appendix IX: Stimulus Lists for Experiment 5

Stimulus List:

accordion, boomerang, bow, calipers, celery, cherry, chisel, clamp, cleaver, clipboard, cloud, compass, cork, corn, croissant, cymbals, door, drumstick, feather, flip flops, flute, frame, moth, hand, hinge, hoe, horseshoe, lettuce, light switch, magnet, magnifying glass, mattress, necklace, oil drum, orange, package, paintroller, peach, peanut, pencil, pencil sharpener, pickaxe, pillar, pitchfork, plug, plunger, propeller, rake, reel, ring, ruler, scoop, screw, screwdriver, seal, sheriff badge, spool, sweets, syringe, tambourine, tape measure, tennisball, thimble, toe, towel, tray, tweezers, wall, wallet, watermelon, whip, wrench

Table v: Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for Experiment 5 stimuli based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Name agreement*	**Visual complexity***	**Familiarity***	**Age of Acquisition****
0.81	2.82	3.33	2.85

Appendix X: Stimulus Lists for Experiment 6

Subset A:

anchor, belt, bowl, bowtie, calculator, canoe, dart, desk, can, candle, dolphin, guitar, kangaroo, microphone, penguin, ring, scroll, suitcase, sun, watering can, windmill, tomato, torch, swan, arrow, backpack, chicken, cow, watch, gorilla, hair, horseshoe, ladle, leg, lobster, orange, plate, pyramid, ruler, saddle, saxophone, shark, strawberry, swimming pool, zipper, toothpaste, tie, wheel

Subset B:

tree, fox, carrot, chimney, clock, comb, crown, fence, glass, glasses, hat, potato, lamb, wheel barrow, pear, pelican, pepper, pincers, rifle, seahorse, seal, spatula, scale, salt, wall, walrus, window,trousers, tap, truck, balloon, barbecue, barn, bee, binder, blow dryer, bottle, butterfly, castle, door, dust pan, hand, leaf, lighthouse, mousetrap, mushroom, parachute, iron

Subset D:

bone, camel, apple, banana, corn, sofa, eye, fire extinguisher, fishbowl, foot, hippopotamus, kite, light switch, logs, mask, piano, pot, rolling pin, screw, shield, shirt, stairs, stapler, wagon, whale, trombone, zebra, tank, ashtray, blimp, book, box, bus, cannon, church, coin, dog, fan, hammer, helicopter, lamp, feather, moose, mouse, nail, onion, screwdriver, stove

Subset E:

ant, bandaid, baseball bat, bed, boot, button, cat, crane, doorknob, elephant, frog, house, jacket, nose, owl, pig, mountain, sailboat, scarf, scissors, shower, telescope, teeshirt, vacuum cleaner, well, teapot, ball, bird cage, brush, chain, corkscrew, duck, envelope, igloo, ironing board, lipstick, pineapple, plane, rabbit, refridgerator, rhino, roof, sack, shell, shoe, snail, sword, thumb

Subset F:

axe, barrel, basket, panda, bow, stag, cigar, dinosaur, eagle, ear, finger, flower, fork, french horn, frying pan, witch, hanger, key, knife, handcuffs, necklace, peanut, plug, Spear, cactus, sock, swordfish, tent, traffic light, cane, baby carriage, bench, bicycle, clipboard, ladybird, crab, garbage can, giraffe, horse, hotair balloon, ladder, pumpkin, rocket, rose, shovel, ski, spoon, stool

Subset G:

octopus, toothbrush, trolley, toiletroll, table, goat, teeth, alligator, arm, bathtub, bird house, cheese, clothespin, vulture, rake, sheep, sink, slide, saw, scorpion, toilet, trophy, umbrella, bell, baby, beetle, acorn, trumpet, whistle, typewriter, dragonfly, lemon, peacock, pillow, swim suit, skateboard, spider, swing, vase, harp, chainsaw, asparagus, radio, pencilsharpener, mitten, doghouse, headphones, ostrich

Subset H:

sewingmachine, squirrel, coat, cot, donkey, globe, lightbulb, lion, lock, mailbox, artichoke, pipe, jug, firetruck, suit, syringe, lips, worm, tiger, turtle, broom, cap, magnet, cup, deer, laptop, tape measure, razor, walnut, wineglass, train, wolf, sandwich, leopard, spinning wheel, milk, tennisball, thermometer, mattress, binoculars, carriage, ghost, lantern, bridge, pliers, fish, unicorn, cashtill

Subset K:

telephone, dice, bird, bucket, car, chair, eggs, fishhook, flag, football, grasshopper, gun, kettle, lettuce, lizard, moon, rat, robot, rocking chair, ship, skirt, snake, star, violin, washing machine, tennisracket, television, bat, bear, bread, camera, scoop, dress, fire hydrant, fly, grapes, microscope, monkey, motorcycle, paintbrush, paperclip, computer, pen, handbag, roller skate, rope, spade, wheelchair

Subset C:

accordion, avocado, bag, baseball glove, beard, blender, blouse, bra, brain, caterpillar, chest, cigarette, cleaver, compass, croissant, cutting board, cymbals, deckchair, toe, doll, dragon, drawer, dresser, easel, eel, excavator, ferris wheel, first aid kit, fishingpole, glove, golf, harmonica, racoon, hour glass, lawnmower, magnifying glass, match, nut, paint, paintroller, piggybank, projector, recorder, rocking horse, rooster, safe, cherry, slingshot, rubber duck, boots, hamburger, popcorn, towel, unicycle, tissues, badge, cloud, arch, rainbow, trainer, wood, moth, reel, lightning, newspaper, shed, chesspiece, pizza, nailfile, snowman, claw, cable car, spool, chisel, hose, ice cream, needle, bird nest, map, volcano, stroller, tag, frame, bales, rosette, pretzel, milkbottle, hotdog, mirror, hoe, spiderweb, boy, llama, clown, king, toucan

Subset N:

staplegun, sweater, tambourine, thermos, thimble, tractor, tripod, weather vane, wellingtons, whip, whisk, wrench, yarn, helmet, mop, wand, net, ink, colander, maracas, urn, flute, stethoscope, radar dish, anvil, highchair, sled, trowel, cork, wardrobe, clamp, coffemaker, plunger, wallet, christmas tree, jar, celery, jellyfish, protractor, boomerang, gravy boat, butter, film, carousel, plug socket, fire, totem, forklift, propellor, skull, jumprope, teepee, record player, submarine, triangle, tray, package, top, safetypin, rug, balcony, skittles, planet, lighter, pencil, radiator, road, bomb, medal, tweezers, filing cabinet, pump, pickaxe, knight, peach, prawn, platypus, fairy, pinecone, porcupine, koala, monk, hyena, bride, flamingo, blowfish, ray, armadillo, turkey, jaw, pirate, lung, hoof, starfish, chef, anteater

Table vi: Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for each stimulus subset of Experiment 6 based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Subset	**Name agreement***	**Visual complexity***	**Familiarity***	**Age of Acquisition****
A	0.89	2.87	3.39	2.4
B	0.88	3.01	3.40	3.0
C	0.84	3.06	3.23	2.6
D	0.88	2.89	3.51	2.8
E	0.89	2.91	3.42	2.4
F	0.87	2.91	3.52	2.8
G	0.85	3.13	2.95	2.1
C	0.77	3.11	3.37	3.0
H	0.80	3.28	3.34	2.8
K	0.85	3.14	3.45	2.9

Appendix XI: Stimulus Lists for Experiment 7

Subset A:

rhino, chick, zebra, elephant, duck, camel, lamb, helmet, fire hydrant, hat, boat, bicycle, spinning wheel, camper van, helicopter, tricycle, roller skate, sandal, pepper mill, table, bride, clothes line, llama, robot, petrol pump, prawn, seal, dove, pipe, triangle, whisk, colander, beetle, hose, hand fan, glasses

Subset B:

brain, fountain, goat, moose, cake, cat, sheep, pig, skateboard, vacuum cleaner, chimney, forklift, basket, lighthouse, globe, crane, typewriter, sled, bench, fire extinguisher, man, lantern, porcupine, leopard, closet, hoof, strawberry, mushroom, skirt, life jacket, sofa, sack, rosette, binoculars, spinning top, golf club

Subset C:

hippo, unicorn, chicken, tiger, dragon, swan, milk, telephone, rocking chair, microphone, bridge, projector, tank, suit, cashtill, boot, wheelchair, trophy, highchair, birdhouse, king, sink, turkey, fairy, bus, blowfish, pine cone, grapes, tie, fishing rod, wardrobe, grater, ashtray, trowel, bell, battery

Subset D:

platypus, skeleton, rubber duck, bull, monkey, pumpkin, doll, firetruck, deckchair, calculator, toilet, cot, carriage, jar, scooter, hot air balloon, stapler, bucket, wagon, camera, chef, saddle, buffalo, lizard, car jack, treasure chest, bat, tomato, pan pipes, mobile phone, mousetrap, hanger, rifle, anchor, van, jacket

Subset E:

tortoise, scorpion, volcano, dolphin, camcorder, frog, butter, barn, spray bottle, cable car, sewing machine, ship, telescope, dress, windmill, blender, heel, igloo, briefcase, barbeque, toilet roll, drawer, radar dish, trousers, gate, grandfather clock, apron, lollipop, armour, mixer, whistle, saxophone, sock, baby bottle, shield, ice skate

Subset F:

mouse, peacock, owl, vulture, cactus, snowman, alligator, sweater, wheelbarrow, submarine, coffee maker, radio, backpack, coat, scales, swimming pool, chesspiece, bird table, house, handbag, policeman, filing cabinet, cockroach, tree, refridgerator, dragonfly, pineapple, hedgehog, wine glass, suitcase, swing, laptop, salt, lamppost, shower, road

Subset G:

dinosaur, lion, koala, parrot, skull, rabbit, dog, candle, lawnmower, watering can, tap, stroller, pyramid, clock, gravy boat, tissues, tent, piano, television, trolley, clown, pencil sharpener, bottle, toucan, dresser, ice cream, butterfly, lungs, urn, flag, bomb, tape measure, lipstick, perfume, vase, blowdryer

Subset H:

raccoon, squirrel, witch, skunk, pelican, piggybank, mask, truck, grave, fishtank, harp, garbage can, frying pan, slide, stool, fan, boy, totem, bed, baseball cap, knight, safe, armadillo, nose, dentist, pear, hole punch, swordfish, ladle, cap, pot, arch, flower, gun, can, glass

Subset J:

eggs, penguin, snail, christmas tree, popcorn, fox, palmtree, parachute, shirt, cup, well, balcony, anvil, car, stairs, desklamp, step ladder, kennel, blouse, ink, santa, roof, hyena, pheasant, soldier, astronaut, whale, leg, headphones, fence, trainer, magnet, paint, jellyfish, washing up liquid, monitor

Subset K:

raccoon, squirrel, witch, skunk, pelican, piggybank, mask, truck, grave, fishtank, harp, garbage can, frying pan, slide, stool, fan, boy, totem, bed, baseball cap, knight, safe, armadillo, nose, dentist, pear, hole punch, swordfish, ladle, cap, pot, arch, flower, gun, can, glass

Subset L:

exercise bike, beaver, rocking horse, giraffe, wolf, deer, ostrich, train, plane, jug, vest, bra, mailbox, castle, pump, church, baby carriage, panda, grasshopper, xylophone, pirate, pinball, fish, diaper, monk, glue, celery, octopus, stethoscope, plunger, lock, bow tie, clipboard, foot, cane, traffic cone

Subset M:

seahorse, birdnest, gorilla, eagle, ant, donkey, bird, record player, thermos, carousel, easel, motorcycle, mirror, toaster, crown, excavator, teapot, microscope, cannon, chair, waiter, turnstile, fire, goose, girl, shark, electric razor, logs, ladybird, corkscrew, lighter, cleaver, fly, maracas, tiara, iron

Table vii: Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition for each stimulus subset of Experiment 7 based on available norms from (*) Snodgrass and Vanderwart (1980) and Cycowicz, Friedman and Rothstein (1997) and (**) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

Subset	**Name agreement***	**Visual complexity***	**Familiarity***	**Age of Acquisition****
A	0.83	3.17	2.82	2.7
B	0.90	3.20	3.08	2.5
C	0.87	3.39	3.28	2.5
D	0.84	2.87	3.36	2.3
E	0.90	3.24	3.15	2.3
F	0.82	3.31	3.39	2.4
G	0.82	3.25	3.54	2.6
H	0.86	2.86	3.63	2.6
J	0.77	3.05	3.20	2.6
K	0.86	2.86	3.63	2.6
L	0.82	3.48	3.22	2.6
M	0.83	3.56	3.05	2.8

Appendix XII: Stimulus Norms for all Experiments

Table viii: Available norms for Percentage Name Agreement, Visual Complexity rating, Familiarity rating and Age of Acquisition collated for all stimuli based on norms in (blue) Snodgrass and Vanderwart (1980), (red) Cycowicz, Friedman and Rothstein (1997) and (black) the International Picture Naming Project (IPNP) as described by Szekely et al (2004).

	Percentage Name Agreement	**Visual Complexity (Mean)**	**Visual Complexity (SD)**	**Familiarity (Mean)**	**Familiarity (SD)**	**Age of Acquisition in years**
accordion	0.88	4.68	0.61	2.15	1.2	-
acorn	0.83	9198	-	-	-	3
alligator	0.6	4.08	0.10	1.65	0.82	-
anchor	0.93	2.58	0.70	1.6	0.83	-
ant	0.81	3.92	0.82	2.62	1.11	-
anteater	0.67	3.72	0.88	2.57	1.3	-
anvil	0.6	2.67	0.92	2.83	1.37	-
apple	0.98	1.82	0.67	3.98	1.08	-
apron	-	-	-	-	-	-
arch	0.47	2.3	1.09	3.43	1.28	-
arm	0.9	2.15	0.61	4.75	0.58	-
armadillo	0.67	3.86	0.88	3	1.41	-
armour	-	-	-	-	-	-
arrow	0.98	1.05	0.31	3.38	1.23	-
artichoke	0.52	3.72	0.77	2.29	1.45	-
ashtray	1	2.25	0.89	3.56	1.37	-
asparagus	0.69	3.32	0.79	2.68	1.38	-
astronaut	-	-	-	-	-	-
avocado	0.57	2.6	1.16	3.73	1.28	-
axe	0.9	2.48	0.74	2.28	1.1	-
baby	0.94	18598	-	-	-	1
baby bottle	0.9	8529	-	-	-	1
baby carriage	0.52	3.42	0.1	2.72	1.14	-
backpack	1	31598	-	-	-	3
badge	0.68	15109	-	-	-	3

bag	0.84	18014	-	-	-	3
balcony	0.65	35416	-	-	-	3
bales	-	-	-	-	-	-
ball	0.93	2.28	0.81	3.2	1.21	-
balloon	1	1.55	0.59	2.58	1.02	-
banana	1	1.32	0.47	3.65	1.04	-
bandaid	0.92	13392	-	-	-	3
banjo	0.87	17479	-	-	-	3
barbecue	0.9	12302	-	-	-	3
barn	0.69	3.3	0.98	2.38	1.06	-
barrel	1	3.32	0.93	2.02	1.13	-
baseball bat	0.52	1.2	0.4	3.68	1.15	-
baseball cap	-	-	-	-	-	-
baseball glove	0.5	3.47	0.97	4.3	0.95	-
basket	0.9	4.3	0.84	2.18	0.97	-
bat	1	3.23	0.82	3.93	1.14	-
bathtub	0.78	18067	-	-	-	1
battery	-	-	-	-	-	-
bear	0.88	3.68	0.9	1.98	1.01	-
beard	0.96	30362	-	-	-	3
beaver	0.74	11319	-	-	-	3
bed	1	2.85	0.79	4.72	0.77	-
bee	0.6	4.75	0.49	2.68	1.19	-
beetle	0.5	3.65	0.82	1.88	1	-
bell	1	2.62	0.66	2.2	0.93	-
belt	0.98	2	0.59	4.12	1.05	-
bench	-	-	-	-	-	-
bicycle	0.88	3.85	0.11	3.78	1.04	-
binder	1	18762	-	-	-	-
binoculars	1	18262	-	-	-	3
bird	0.88	3.25	0.73	3.62	1.16	-
bird cage	0.73	3.77	1.01	4.13	3.77	-
bird house	-	-	-	-	-	-
bird nest	-	-	-	-	-	-
bird table	-	-	-	-	-	-
blender	-	-	-	-	-	-
blimp	0.81	9051	-	-	-	3
blouse	0.43	3.1	0.66	4.18	0.97	-
blow dryer	-	-	-	-	-	-

blowfish	0.4	3	1.04	2.79	1.52	-
boat	0.71	11180	-	-	-	2
bomb	0.9	6984	-	-	-	3
bone	1	14370	-	-	-	3
book	1	2.1	0.66	4.75	0.54	-
bookcase	-	-	-	-	-	-
boomerang	-	-	-	-	-	-
boot	0.88	2.45	0.7	3.38	1.24	-
bottle	0.95	1.68	0.79	3.72	1.05	-
bow	0.74	2.75	0.86	2.25	1.18	-
bow and arrow	-	-	-	-	-	-
bowl	0.95	1.82	0.8	4.18	0.92	-
box	0.88	1.38	0.76	2.88	1.31	-
boy	0.9	15675	-	-	-	1
bra	1	11410	-	-	-	3
brain	0.77	4	0.79	4.37	0.93	-
bread	0.83	1.95	0.67	4.4	0.83	-
bride	0.86	14046	-	-	-	3
bridge	0.98	27543	-	-	-	3
briefcase	-	-	-	-	-	-
broccoli	-	-	-	-	-	-
broom	1	2.42	0.8	3.42	1.14	-
brush	0.83	2.82	0.74	3.8	1.08	-
bucket	-	-	-	-	-	-
buffalo	-	-	-	-	-	-
bull	-	-	-	-	-	-
bus	1	3.95	0.1	4.5	0.74	-
butter	0.96	15536	-	-	-	1
butterfly	1	4.25	0.77	2.92	1.17	-
button	0.98	2.02	0.76	3.85	1.26	-
cable car	-	-	-	-	-	-
cactus	0.93	2.37	0.89	4	1.17	-
cake	1	16237	-	-	-	1
calculator	-	-	-	-	-	-
calipers	-	-	-	-	-	-
camcorder	-	-	-	-	-	-
camel	0.83	2.88	0.68	2.08	1.06	-
camera	1	16408	-	-	-	2
camper van	-	-	-	-	-	-

can	0.63	2.59	0.78	4.47	0.9	-
candle	1	2.48	0.9	3.08	1.15	-
cane	0.96	5668	-	-	-	3
cannon	0.9	3.92	0.82	1.52	0.63	-
canoe	0.62	27029	-	-	-	3
cap	0.86	2.18	0.74	3.12	1.12	-
car	0.81	4.05	0.95	4.7	0.6	-
car jack	-	-	-	-	-	-
cards	-	-	-	-	-	-
carousel	0.6	32489	-	-	-	3
carriage	-	-	-	-	-	-
carrot	1	2.95	0.77	3.55	0.97	-
cashtill	-	-	-	-	-	-
castle	1	22746	-	-	-	3
cat	1	3.25	0.94	4.22	0.88	-
caterpillar	0.79	3.58	0.1	1.72	0.81	-
celery	0.76	4.25	0.86	3.4	1.11	-
chain	0.98	2.55	0.97	2.82	1	-
chainsaw	-	-	-	-	-	-
chair	1	2.05	0.7	4.58	0.86	-
cheese	0.53	2.17	0.79	4.53	0.68	-
chef	-	-	-	-	-	-
cherry	0.83	1.6	0.62	3.38	1.18	-
chesspiece	-	-	-	-	-	-
chest	0.63	20690	-	-	-	3
chick	-	-	-	-	-	-
chicken	0.67	3.48	0.9	2.42	1.09	-
chimney	1	9730	-	-	-	3
chisel	0.33	3.12	0.75	2.46	1.24	-
christmas tree	-	-	-	-	-	-
church	0.93	3.28	0.11	3.38	1.34	-
cigar	1	3.58	0.97	2.35	1.26	-
cigarette	0.98	2.25	0.77	3.65	1.41	-
clamp	0.5	8045	-	-	-	3
claw	-	-	-	-	-	-
cleaver	-	-	-	-	-	-
clipboard	-	-	-	-	-	-
clock	0.98	2.68	0.88	4.38	0.99	-
closet	-	-	-	-	-	-

clothes line	-	-	-	-	-	-
clothespin	0.81	2.82	0.92	2.8	1.47	-
cloud	0.95	2.12	0.87	3.82	1.19	-
clown	0.95	4.5	0.81	2.6	1.16	-
coat	0.79	2.55	0.67	3.88	1.19	-
cockroach	-	-	-	-	-	-
coffee maker	-	-	-	-	-	-
coffee pot	-	-	-	-	-	-
coin	-	-	-	-	-	-
colander	-	-	-	-	-	-
comb	0.93	2.38	0.83	4.52	0.87	-
compass	0.83	3.67	0.96	3.97	0.89	-
cork	0.85	18503	-	-	-	3
corkscrew	0.5	11421	-	-	-	3
corn	0.81	3.58	0.86	3.3	1.05	-
cot	0.84	13719	-	-	-	1
sofa	0.67	2.28	0.84	4.4	0.74	-
cow	0.93	3.85	0.96	2.42	1.2	-
crab	0.9	3.93	0.94	3.9	1.18	-
cradle	-	-	-	-	-	-
crane	-	-	-	-	-	-
croissant	-	-	-	-	-	-
crown	1	4.25	0.77	1.52	0.81	-
cup	0.93	1.78	0.52	4.4	0.83	-
cutting board	-	-	-	-	-	-
cymbals	0.4	3.3	1.15	2.97	1.59	-
dart	1	3.3	1.21	4.17	1.12	-
deckchair	-	-	-	-	-	-
deer	0.76	3.55	0.77	2.22	1.21	-
dentist	0.88	14931	-	-	-	3
desk	0.95	3.05	0.84	4.32	0.9	-
desklamp	-	-	-	-	-	-
diaper	0.48	17126	-	-	-	1
dice	-	-	-	-	-	-
dinosaur	0.8	3.3	0.95	3.83	1.21	-
diver	-	-	-	-	-	-
dog	1	3.38	0.73	4.6	0.7	-
doghouse	0.93	2.67	0.96	4.13	1.11	-
doll	0.71	4.12	0.93	2.92	1.14	-

dolphin	0.98	9949	-	-	-	3
donkey	0.86	3.35	0.69	1.88	0.87	-
door	0.98	3.22	0.69	4.68	0.79	-
doorknob	0.9	2.68	0.61	4.25	0.92	-
dove	-	-	-	-	-	-
dragon	-	-	-	-	-	-
dragonfly	0.47	4.03	0.85	3.4	1.19	-
drawer	1	16141	-	-	-	1
dress	1	2.65	0.65	3.62	1.46	-
dresser	0.36	2.95	0.89	4.52	0.77	-
drumstick	-	-	-	-	-	-
duck	0.95	3.32	0.82	2.75	1.11	-
dust pan	0.69	17095	-	-	-	3
eagle	0.76	4.18	0.74	2.42	1.3	-
ear	0.95	2.68	0.82	4.5	0.7	-
easel	0.8	3.23	1.01	3.72	1.22	-
eel	0.83	2.6	0.81	3.07	1.31	-
eggs	-	-	-	-	-	-
electric razor	-	-	-	-	-	-
elephant	1	4.12	0.78	2.35	1.04	-
envelope	0.98	1.42	0.59	4.12	0.93	-
excavator	-	-	-	-	-	-
exercise bike	-	-	-	-	-	-
eye	0.98	3.48	1.1	4.88	0.4	-
fairy	-	-	-	-	-	-
fan	0.98	9104	-	-	-	3
feather	0.98	21626	-	-	-	3
fence	0.74	2.55	1	3.02	1.06	-
ferris wheel	-	-	-	-	-	-
filing cabinet	-	-	-	-	-	-
film	-	-	-	-	-	-
finger	0.71	2.3	0.95	4.78	0.79	-
fire	0.96	52543	-	-	-	3
fire extinguisher	-	-	-	-	-	-
fire hydrant	0.71	25793	-	-	-	3
firetruck	0.65	41094	-	-	-	1
first aid kit	-	-	-	-	-	-
fish	-	-	-	-	-	-
fishbowl	0.67	3.43	1.1	4.17	0.95	-

fishhook	-	-	-	-	-	-
fishingpole	0.53	5685	-	-	-	3
fishtank	-	-	-	-	-	-
flag	0.95	1.88	0.46	2.9	1.28	-
flamingo	0.63	3.23	0.9	3.63	1.13	-
flip flops	-	-	-	-	-	-
flower	0.93	3.25	0.94	3.88	1.19	-
flute	0.88	4.15	0.85	2.45	1.22	-
fly	0.76	4.1	0.92	3.02	1.06	-
foot	0.95	2.18	0.89	4.78	0.69	-
football	1	2.28	0.71	3.55	1.24	-
fork	1	2.62	0.94	4.78	0.47	-
forklift	-	-	-	-	-	-
fountain	0.86	32442	-	-	-	3
fox	0.74	4.3	0.87	1.95	0.84	-
frame	-	-	-	-	-	-
french horn	0.57	4.3	0.87	2	1.05	-
frog	1	3.42	1.05	2.48	1.05	-
fruit basket	-	-	-	-	-	-
frying pan	0.6	2.05	0.67	4.15	0.96	-
funnel	0.97	6468	-	-	-	3
garbage can	0.88	2.58	0.74	-	-	-
gate	-	-	-	-	-	-
ghost	1	23538	-	-	-	-
giraffe	0.95	4.65	0.73	1.8	0.95	-
girl	0.92	15540	-	-	-	1
glass	0.98	1.82	0.74	4.78	0.52	-
glasses	0.64	2.85	0.85	4	1.3	-
globe	0.98	24454	-	-	-	-
glove	0.98	3.02	0.76	3.38	1.06	-
glue	-	-	-	-	-	-
goat	0.86	3.18	0.77	1.92	1.06	-
golf	-	-	-	-	-	-
goose	-	-	-	-	-	-
gorilla	0.76	3.62	0.86	2.05	1.18	-
grandfather clock	-	-	-	-	-	-
grapes	0.9	3	0.92	3.65	1.04	-
grasshopper	0.71	4.4	0.8	2.42	1.07	-
grater	-	-	-	-	-	-

grave	0.62	21614	-	-	-	3
gravy boat	-	-	-	-	-	-
guitar	0.98	4	0.92	3.58	1.09	-
gun	0.74	3.52	0.81	2.68	1.19	-
hair	0.9	2.88	0.78	4.59	0.74	-
hamburger	0.77	3.03	0.93	4.5	0.94	-
hammer	1	2.6	0.7	3.48	1.16	-
hand	0.93	2.98	0.91	4.82	0.67	-
hand fan	-	-	-	-	-	-
handcuffs			-	-	-	3
hanger	0.86	1.2	0.56	4.52	0.67	-
harmonica	0.83	4.25	0.89	3.69	1.31	-
harp	0.93	4.05	0.81	1.88	1.08	-
hat	0.98	2.35	0.79	3.18	1	-
headphones	-	-	-	-	-	-
hedgehog	-	-	-	-	-	-
heel	0.88	14448	-	-	-	3
helicopter	0.95	3.8	0.95	2.55	1.12	-
helmet	0.96	15650	-	-	-	3
highchair	0.87	19638	-	-	-	1
hinge	-	-	-	-	-	-
hippo	0.55	12429	-	-	-	3
hoe	0.77	6124	-	-	-	3
hole punch	-	-	-	-	-	-
hoof	0.92	13837	-	-	-	3
hook	1	10144	-	-	-	3
horn	-	-	-	-	-	-
horse	1	3.82	0.7	3.55	1.14	-
horseshoe	0.93	2.1	0.86	3.97	1.3	-
hose	0.96	26130	-	-	-	2
hot air balloon	-	-	-	-	-	-
hotdog	-	-	-	-	-	-
hour glass	-	-	-	-	-	-
house	0.95	3.9	0.94	4.38	1.04	-
hyena	0.47	3.86	0.79	2.76	1.35	-
ice cream	0.52	7742	-	-	-	3
ice skate	-	-	-	-	-	-
igloo	1	2.7	0.88	3.83	1.32	-
ink	-	-	-	-	-	-

iron	0.95	3.25	0.89	3.65	1.08	-
ironing board	0.83	2.05	0.63	3.5	1.07	-
jacket	0.81	3.25	0.8	4	1.07	-
jam	-	-	-	-	-	-
jar	0.7	2.5	1.17	4.53	0.73	-
jaw	-	-	-	-	-	-
jellyfish	-	-	-	-	-	-
jug	0.58	8789	-	-	-	3
jumprope	0.84	11207	-	-	-	3
kangaroo	1	3.98	0.88	1.92	1.15	-
kennel	-	-	-	-	-	-
kettle	0.4	2.4	0.74	3.8	1.17	-
key	1	1.92	0.76	4.85	0.42	-
king	1	31165	-	-	-	3
kite	1	2.85	0.69	2.48	1.14	-
knife	0.9	1.92	0.68	4.45	0.84	-
knight	0.88	15019	-	-	-	3
knitting	-	-	-	-	-	-
koala	0.53	3.67	1.06	3.83	1.15	-
ladder	0.98	2.32	0.61	3.35	1.15	-
ladle	0.83	2.2	0.89	3.87	1.36	-
ladybird	0.87	3.31	0.76	4	0.98	-
lamb	0.73	3.13	0.9	3.67	1.12	-
lamp	0.93	1.85	0.61	4.2	0.95	-
lamppost	-	-	-	-	-	-
lantern	-	-	-	-	-	-
laptop	-	-	-	-	-	-
lawnmower	0.96	18238	-	-	-	2
leaf	0.9	2.52	0.77	4.3	0.75	-
leg	0.81	2.55	0.84	4.65	0.82	-
lemon	1	1.85	0.69	3.25	1.22	-
leopard	0.76	4.28	0.81	1.92	0.93	-
letter	0.68	40467	-	-	-	3
lettuce	0.74	3.48	0.92	3.42	1.24	-
life jacket	-	-	-	-	-	-
light switch	0.67	2.52	0.77	4.58	0.63	-
lightbulb	0.86	2.75	0.94	4.18	0.8	-
lighter	-	-	-	-	-	-
lighthouse	0.94	31692	-	-	-	3

lightning	0.84	30782	-	-	-	3
lion	0.93	4.3	0.87	2	1.07	-
lips	0.93	1.85	0.88	4.5	0.81	-
lipstick	1	2.97	1.07	4.23	1.14	-
lizard	0.7	2.9	0.82	3.5	1.17	-
llama	0.77	3.1	0.96	3	1.31	-
lobster	0.9	4.48	0.81	2.58	1.24	-
lock	0.88	2.22	0.69	3.18	1.18	-
logs	-	-	-	-	-	-
lollipop	-	-	-	-	-	-
lung	0.8	3.5	0.94	3.77	1.14	-
magnet	0.96	23234	-	-	-	3
magnifying glass	-	-	-	-	-	-
mailbox	0.84	19211	-	-	-	3
man	0.94	15791	-	-	-	1
map	1	41029	-	-	-	3
maracas	-	-	-	-	-	-
mask	0.98	13078	-	-	-	3
match	1	13078	-	-	-	3
mattress	-	-	-	-	-	-
medal	0.89	21541	-	-	-	3
microphone	0.9	9962	-	-	-	3
microscope	0.84	20349	-	-	-	3
milk	-	-	-	-	-	-
milkbottle	-	-	-	-	-	-
mirror	1	11938	-	-	-	3
mitten	0.76	2.35	0.69	3.1	1.22	-
mixer	0.39	18578	-	-	-	3
mobile phone	-	-	-	-	-	-
monitor	-	-	-	-	-	-
monk	-	-	-	-	-	-
monkey	0.95	3.9	0.7	2.58	0.97	-
moon	0.62	1.02	0.16	3.98	1.01	-
moose	0.63	3.34	0.86	3.28	1.25	-
mop	0.94	14393	-	-	-	2
moth	-	-	-	-	-	-
motorcycle	0.95	4.78	0.47	3.25	1.09	-
mountain	0.9	2.8	1.05	2.7	1.19	-
mouse	0.79	3.28	0.87	2.45	1.02	-

mousetrap	0.65	18345	-	-	-	3
mushroom	0.98	3.12	0.71	2.88	1.23	-
nail	0.98	1.8	0.68	3.28	1.2	-
nailfile	0.67	3.18	1	3.15	1.39	-
necklace	0.6	1.78	0.88	2.7	1.31	-
needle	0.81	1.55	0.74	3.4	1.14	-
net	0.96	9970	-	-	-	3
newspaper	-	-	-	-	-	-
nose	0.98	1.6	0.92	4.52	0.87	-
nut	0.64	2.3	0.56	2.55	1.28	-
octopus	0.93	3.6	0.89	3.5	1.22	-
oil drum	-	-	-	-	-	-
onion	0.95	2.85	0.96	3.32	1.31	-
orange	0.81	2.12	0.71	3.34	1.26	-
ostrich	0.86	3.7	0.81	1.52	0.67	-
owl	1	4.22	0.72	2.22	1.06	-
package	0.94	29767	-	-	-	3
paddle	-	-	-	-	-	-
paint	0.57	11757	-	-	-	3
paintbrush	0.74	2.58	0.95	2.78	1.24	-
paintroller	-	-	-	-	-	-
palmtree	0.86	18577	3	-	-	3
pan pipes	-	-	-	-	-	-
panda	0.47	3.17	1.05	4.03	1.13	-
pants	0.88	2.22	0.7	4.55	0.86	-
paperclip	0.81	21555	-	-	-	3
parachute	0.6	25199	-	-	-	3
parrot	0.79	18115	-	-	-	3
computer	-	-	-	-	-	-
peach	0.74	2.55	0.81	2.9	1.02	-
peacock	0.79	4.75	0.43	2.05	1.05	-
peanut	0.93	2.82	0.95	3	1.02	-
pear	1	1.15	0.36	3.55	1.14	-
pelican	0.83	3.83	0.83	3.33	1.21	-
pen	0.95	3.15	0.94	4.78	0.72	-
pencil	1	2.32	0.91	4.42	1	-
pencil sharpener	0.84	19617	-	-	-	3
penguin	0.9	2.82	0.7	1.7	0.93	-
pepper mill	0.67	2.48	0.95	2.92	1.29	-

perfume	-	-	-	-	-	-
petrol pump	-	-	-	-	-	-
pheasant	-	-	-	-	-	-
piano	0.81	4.58	0.77	3.42	1.48	-
pickaxe	-	-	-	-	-	-
pig	0.9	3	0.81	2.18	0.97	-
piggybank	0.94	24489	-	-	-	3
pillar	-	-	-	-	-	-
pillow	1	16592	-	-	-	1
pinball	-	-	-	-	-	-
pincers	-	-	-	-	-	-
pine cone	0.73	10484	-	-	-	3
pineapple	1	4.35	1.01	2.95	1.3	-
pipe	0.98	1.88	0.71	2.9	1.14	-
pirate	0.88	37716	-	-	-	3
pitchfork	0.65	6158	-	-	-	3
pizza	1	40526	-	-	-	1
plane	0.7	16810	-	-	-	1
planet	-	-	-	-	-	-
plate	0.94	21533	-	-	-	1
platypus	-	-	-	-	-	-
pliers	0.88	2.2	0.6	3.38	1.13	-
plug	0.88	2.25	0.7	4.18	0.77	-
plug socket	-	-	-	-	-	-
plunger	-	-	-	-	-	-
handbag	0.57	2.7	0.78	3.95	1.28	-
policeman	214.28	-	-	-	-	3
popcorn	1	26185	-	-	-	2
porcupine	0.98	20053	-	-	-	3
pot	0.81	2.22	0.69	4.22	0.96	-
potato	0.9	2.2	1.1	3.46	1.17	-
prawn	-	-	-	-	-	-
pretzel	0.97	2.53	1.07	4.23	1.14	-
projector	-	-	-	-	-	-
propeller	0.77	2.7	1.15	3.4	1.28	-
protractor	-	-	-	-	-	-
pump	-	-	-	-	-	-
pumpkin	0.98	2.6	0.7	3.08	1.35	-
pyramid	1	2.21	0.9	3.8	1.3	-

rabbit	1	3.28	0.84	2.95	1.07	-
raccoon	0.79	4.4	0.83	2.2	1.23	-
radar dish	-	-	-	-	-	-
radiator	-	-	-	-	-	-
radio			-	-	-	1
rainbow	0.98	32529	-	-	-	3
rake	0.98	5156	-	-	-	3
rat	0.83	3.5	1.01	4.17	0.99	-
ray	0.27	3.2	0.89	2.63	1.27	-
razor	0.94	14404	-	-	-	3
record player	0.5	3.32	0.93	4.4	0.86	-
recorder	-	-	-	-	-	-
reel	-	-	-	-	-	-
refridgerator	0.93	2.2	0.6	4.68	0.65	-
rhinoceros	0.77	18320	-	-	-	3
rifle	0.71	9010	-	-	-	3
ring	0.98	2.55	0.8	3.48	1.28	-
road	0.92	26797	-	-	-	3
robot			-	-	-	3
rocket	0.9	18164	-	-	-	3
rocking chair	0.9	3.58	0.92	3.25	1.3	-
rocking horse	-	-	-	-	-	-
roller skate	0.52	4.08	0.93	2.25	1.11	-
rolling pin	0.71	1.52	0.5	2.22	1.08	-
roof	0.94	13178	-	-	-	2
rooster	0.76	4.12	0.9	2.22	1.08	-
rope	1	34568	-	-	-	3
rose	0.76	245742	-	-	-	3
rosette	-	-	-	-	-	-
rubber duck	-	-	-	-	-	-
rug	0.68	13474	-	-	-	3
ruler	0.98	1.85	0.94	3.58	0.95	-
sack	-	-	-	-	-	-
saddle	1	10307	-	-	-	3
safe	0.8	10940	-	-	-	3
safetypin	0.53	13291	-	-	-	3
sailboat	0.93	3.58	0.92	2.92	1.17	-
saltshaker	0.83	3	0.92	4.18	0.92	-
sandal	-	-	-	-	-	-

sandwich	1	3.42	0.86	4.45	0.97	-
santa	-	-	-	-	-	-
saucepan	-	-	-	-	-	-
saw	0.98	2.25	0.62	2.92	1.19	-
saxophone	0.87	4.31	0.76	3.93	1.23	-
scales	0.56	14308	-	-	-	3
scarf	0.98	24187	-	-	-	2
scissors	0.98	2.15	0.65	3.98	0.99	-
scoop	-	-	-	-	-	-
scooter	-	-	-	-	-	-
scorpion	0.57	3.97	0.76	3.3	1.42	-
screw	0.93	3.25	0.99	3.2	1	-
screwdriver	0.98	2.35	0.73	3.42	1.14	-
scroll	-	-	-	-	-	-
seahorse	0.88	4.5	0.71	1.5	0.89	-
seal	0.88	2.9	0.74	1.62	0.73	-
sewing machine	0.98	29901	-	-	-	3
shark	0.93	2.67	1.06	4.1	1.03	-
shed	-	-	-	-	-	-
sheep	0.67	3.8	0.75	1.85	0.82	-
shell			-	-	-	3
sheriff badge	-	-	-	-	-	-
shield	-	-	-	-	-	-
ship	-	-	-	-	-	-
shirt	1	3.08	0.79	4.56	0.7	-
shoe	0.95	3.38	0.86	4.62	0.7	-
shovel	1	11955	-	-	-	1
shower	0.84	20173	-	-	-	2
sink	0.96	26500	-	-	-	1
skateboard	1	14225	-	-	-	3
skeleton	-	-	-	-	-	-
ski	0.95	20764	-	-	-	3
skirt	0.98	1.4	0.58	3.64	1.53	-
skittles	-	-	-	-	-	-
skull	0.77	3.73	0.91	4.3	1.02	-
skunk	0.98	16683	-	-	-	3
sled	0.98	3.05	0.84	2.8	1.03	-
slide	1	20613	-	-	-	1
slingshot	0.82	25531	-	-	-	3

snail	0.86	3.4	0.8	1.85	1.06	-
snake	0.98	4.52	0.81	1.9	1.04	-
snowman	1	2.52	0.59	3.15	1.04	-
sock	1	1.62	0.62	4.52	0.84	-
soldier	0.69	9301	-	-	-	3
spaghetti	0.94	32766	-	-	-	1
spatula	0.83	2.68	1.16	4.55	0.69	-
Spear	-	-	-	-	-	-
spider	0.88	3.68	0.85	2.28	1.1	-
spiderweb	0.57	3.1	1.06	4.2	1.03	-
spinning wheel	0.5	4.25	0.92	1.18	0.54	-
spool	0.55	3.18	0.97	3.12	1.14	-
spoon	0.98	2.02	0.82	4.5	0.89	-
spray bottle	-	-	-	-	-	-
squirrel	0.93	3.75	0.97	3.82	0.89	-
stag	-	-	-	-	-	-
stairs	0.74	27602	-	-	-	1
staplegun	-	-	-	-	-	-
stapler	-	-	-	-	-	-
star	1	1.05	0.22	3.35	1.33	-
starfish	1	3.41	1.12	3.63	1.13	-
step ladder	-	-	-	-	-	-
stethoscope	1	2.97	0.93	4.23	0.86	-
stool	0.98	2.32	0.72	3.98	1.13	-
stove	0.76	4.02	0.94	4.65	0.65	-
strawberry	0.9	3.38	0.91	3.2	1.29	-
stroller	0.49	17135	-	-	-	1
submarine	0.88	12481	-	-	-	3
suit	-	-	-	-	-	-
suitcase	0.79	3.6	0.86	3.65	0.91	-
sun	1	1.2	0.46	4.9	0.3	-
swan	0.83	2.9	0.77	1.97	0.83	-
sweater	0.95	2.72	0.97	4.48	0.74	-
sweets	-	-	-	-	-	-
swim suit	-	-	-	-	-	-
swimming pool	0.73	28244	-	-	-	1
swing	0.95	2.72	0.97	3.02	1.24	-
sword	0.92	10243	-	-	-	3
swordfish	0.77	3.4	0.97	2.93	1.31	-

syringe	-	-	-	-	-	-
table	0.95	1.72	0.77	4.35	0.88	-
tag	-	-	-	-	-	-
tambourine	-	-	-	-	-	-
tank	0.9	11180	-	-	-	3
tap	-	-	-	-	-	-
tape measure	-	-	-	-	-	-
teapot	0.44	35631	-	-	-	3
teepee	0.7	15294	-	-	-	3
teeshirt	-	-	-	-	-	-
teeth	0.79	8898	-	-	-	3
telephone	0.86	3.52	0.97	4.8	0.51	-
telescope	0.98	21547	-	-	-	3
television	0.52	3.22	0.96	4.82	0.38	-
tennisball	-	-	-	-	-	-
tennisracket	0.86	3.25	0.94	3.62	1.3	-
tent	1	16963	-	-	-	3
thermometer	0.97	2.8	1.1	4.5	0.73	-
thermos	0.87	5251	-	-	-	3
thimble	0.83	3.35	0.82	2.48	1.12	-
thumb	0.98	2.38	0.97	4.72	0.74	-
tiara	-	-	-	-	-	-
tie	0.69	4.62	0.8	3.8	1.03	-
tiger	0.93	4.62	0.8	2.1	0.92	-
tissues	-	-	-	-	-	-
toaster	1	2.78	0.85	4.08	0.9	-
toe	0.55	1.98	0.82	4.48	0.81	-
toilet	1	22049	-	-	-	3
toilet roll	-	-	-	-	-	-
tomato	0.88	1.98	0.57	3.78	1.06	-
toothbrush	0.98	2.42	0.77	4.62	0.73	-
toothpaste	-	-	-	-	-	-
top	0.86	2.65	0.82	1.88	0.98	-
torch	-	-	-	-	-	-
tortoise	1	14768	-	-	-	1
totem	0.9	4.27	0.87	3.63	1.3	-
toucan	0.5	3.8	0.85	3.13	1.25	-
towel	0.8	24097	-	-	-	1
tractor	0.87	9518	-	-	-	2

traffic cone	-	-	-	-	-	-
traffic light	0.67	3.45	0.84	4.55	0.8	-
train	0.86	4.32	0.88	4.15	0.88	-
train wagon	-	-	-	-	-	-
trainer	-	-	-	-	-	-
tray	-	-	-	-	-	-
treasure chest	-	-	-	-	-	-
tree	1	3.7	0.81	4.68	0.61	-
triangle	-	-	-	-	-	-
tricycle	-	-	-	-	-	-
tripod	0.79	13049	-	-	-	3
trolley	-	-	-	-	-	-
trombone	-	-	-	-	-	-
trophy	-	-	-	-	-	-
trowel	-	-	-	-	-	-
truck	0.9	2.75	0.86	4.02	0.91	-
trumpet	0.79	3.58	0.92	2.6	1.26	-
turkey	0.97	4.07	1.01	4.2	1.06	-
turnstile	-	-	-	-	-	-
turtle	0.95	3.62	0.89	2.4	1.14	-
tweezers	0.91	7308	-	-	-	3
typewriter	1	28850	-	-	-	3
tyre	0.9	14920	-	-	-	3
umbrella	1	3	1.05	3.95	0.92	-
unicorn	1	12749	-	-	-	3
unicycle	0.81	20238	-	-	-	3
urn	-	-	-	-	-	-
vacuum cleaner	0.82	34257	-	-	-	1
van	-	-	-	-	-	-
vase	0.95	3.15	0.66	2.78	1.26	-
vest	0.96	10103	-	-	-	3
violin	0.86	4.1	0.86	2.68	1.21	-
volcano	1	54995	-	-	-	3
vulture	0.73	3.83	0.75	3.2	1.24	-
wagon	0.79	3.35	0.91	2.5	1.22	-
waiter	0.85	27418	-	-	-	3
wall	-	-	-	-	-	-
wallet	0.77	10594	-	-	-	3
walnut	0.62	30661	-	-	-	3

walrus	0.93	3.3	1.09	3.43	1.3	-
wand	-	-	-	-	-	-
wardrobe	0.86	30610	-	-	-	2
washing machine	0.83	4.17	0.83	4.6	0.62	-
washing up liquid	-	-	-	-	-	-
watch	0.9	3.4	1.04	4.58	0.73	-
watering can	0.55	2.78	0.79	2.72	1.5	-
watermelon	0.98	9982	-	-	-	3
weather vane	-	-	-	-	-	-
well	0.86	2.28	0.92	1.45	0.7	-
wellington boots	-	-	-	-	-	-
whale	0.73	3.17	0.91	3.57	1.3	-
wheel	0.93	2.42	0.83	2.22	1.04	-
wheelbarrow	0.86	20045	-	-	-	3
wheelchair	1	33755	-	-	-	3
whip	0.83	2.67	1.32	3	1.46	-
whisk	-	-	-	-	-	-
whistle	1	2.55	0.84	2.45	0.92	-
windmill	0.98	4.62	0.76	1.8	1	-
window	0.95	3.18	0.86	4.4	0.86	-
wine glass	0.5	1.85	0.79	4.02	1.11	-
witch	1	27723	-	-	-	3
wolf	0.87	3.07	1.05	3.77	1.19	-
wood	0.55	17090	-	-	-	3
worm	0.43	2.76	0.84	3.83	1.18	-
wrench	0.76	2.02	0.79	2.72	1.28	-
xylophone	-	-	-	-	-	-
yarn	-	-	-	-	-	-
yoyo	0.96	8066	-	-	-	3
zebra	0.98	4.55	0.7	1.6	0.83	-
zipper	1	5830	-	-	-	2