PhD Thesis

# The effect of cognitive load on the processing of hierarchical visual information

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PhD in Psychology

## Certificate of Originality

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# ABSTRACT

The visual world is organised hierarchically from global structure to local detail or from the 'forest' to the 'trees' (Navon, 1977; Palmer, 1975). The present thesis explores the effect of cognitive load on the processing of hierarchical visual information; specifically, we distinguish between the effects of cognitive load on i) whether observers are biased toward prioritising global structure or local detail; ii) the ability to select local and global information, as relevant to tasks or behavioural goals.

The main contributions of this thesis are to show that cognitive load i) affects perceptual bias by making observers less global and more local or, in other words, less likely to see the 'forest' for the 'trees', and ii) makes it more difficult to selectively attend to the least salient level of hierarchical information. These effects of cognitive load are likely exerted through separate mechanisms. With respect to perceptual bias, we suggest that cognitive load alters relative hemispheric activation and with it the relative priority afforded to global structure and local detail. With respect to selection, we suggest that cognitive load impairs cognitive control and makes it harder to prevent the processing of irrelevant-yet-salient hierarchical information.

Taken together, the findings presented in this thesis suggest that cognitive load exerts significant effects on hierarchical processing, whether through effects on global-local perceptual bias or attentional selection of hierarchical information. As the visual world is

structured hierarchically, whether it be the global scene as a whole or individual hierarchical structures such as words or faces, cognitive load – which can vary from person-to-person and within an individual circumstantially – could fundamentally affect how observers ‘see’ the visual world.

# ACKNOWLEDGMENTS

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# CHAPTER ONE – GENERAL INTRODUCTION

Perception results from a continuous interaction between top-down and bottom-up factors, so that our experience of the world can be affected by the behavioural relevance of visual stimuli as well as physical properties of the environment (e.g., Corbetta & Shulman, 2002; Egeth & Yantis, 1997). The visual world is structured hierarchically, from the local details up to the global scene as a whole (Palmer, 1975) – or from the 'trees' to the 'forest' – and ordinarily we can choose to focus on either the local detail or global structure, depending on task demands (Navon, 1977, 1981; Treisman, 2006). Cognitive resources must be available for this kind of goal-directed behaviour, so that task-relevant information can be held, prioritised and manipulated in working memory. However, our cognitive resources are often engaged in other tasks – resulting in *cognitive load* – and in these situations behavioural priorities become harder to maintain and vulnerability to distraction is increased (e.g. Baddeley, 1986; Caparos & Linnell, 2010; de Fockert, Rees, Frith & Lavie, 2001; Lavie, Hirst, de Fockert & Viding, 2004). Although the processing of hierarchical information is of fundamental importance to how we understand the world, little evidence exists to suggest what effect cognitive load might have on understanding of hierarchical visual information. This thesis seeks to provide a better understanding of this issue. Specifically, we distinguish between i) whether cognitive load affects the extent to which people are *biased* toward prioritising either global structure or local detail, and ii) whether cognitive load affects the *ability* to select local and global information if the task demands it. As top-down and bottom-up mechanisms interact, we also explore how the effects of cognitive load are modulated by the salience of local and global information.

Hierarchical information is potentially ambiguous, as it can be understood in terms of either its local detail or its overall global structure. In general, some people prioritise global structure while others prioritise local detail; in other words, some people are more likely to see the forest while others are more likely to perceive the trees. We refer to this as *perceptual bias*. This describes how individuals weight local detail and global structure, and suggests the existence of a 'default setting' with which observers approach visual information (Dale & Arnell, 2013). However, expressing a bias towards one hierarchical level of representation over the other does not necessarily mean that the other is more difficult to process (Caparos, Linnell, Bremner, de Fockert & Davidoff, 2013); as observers, we can choose to selectively attend to a single tree while ignoring the forest, or appreciate the forest as a whole while ignoring individual trees (Treisman, 2006). We refer to this as *selection*. In this thesis we explore the effect of cognitive load on both perceptual bias and on selection and consider the ways in which the effects may be related. When we refer to processing of hierarchical information without distinguishing between bias and selection we use the term *hierarchical processing.*

People in the Western world have been shown to prioritise global structure over local detail (e.g., Davidoff, Fonteneau & Fagot, 2008). They have also been shown to be better at selecting global structure than they are at selecting local detail (e.g., Navon, 1977; see Kimchi, 1992, for a review). Thus, all else being equal (Kimchi, 1992), Westerners are disposed to 'see' the forest over the trees. However, whether global structure or local detail is ultimately most "salient in the final percept" (p. 26; Kimchi, 1992) is determined by an interaction between person-driven factors such as perceptual bias on the one hand and stimulus-driven factors such as *goodness of form* on the other. The outcome of this interaction denotes the relative strength of local and global information and in the present thesis we refer to this as local-global *salience* (Figure 1a depicts this schematically). For example, individual differences in local-global 'default setting' (e.g., Dale & Arnell, 2013) affect the extent to which individuals represent hierarchical information in terms of global structure and local detail; individuals whose setting is positioned towards the global end will be more likely to represent hierarchical information in terms of its global structure than individuals whose setting is positioned more towards the local end. Nevertheless, global salience will be stronger for stimuli with good form than those with bad form, regardless of default setting; if stimuli have particularly bad global form, then even individuals with a strong global bias will represent global structure as being less salient than local detail and will likely be worse at selecting global than local information. In the present thesis we explore the effect that cognitive load has on hierarchical processing but also consider the influence that stimulus-driven local-global salience has on whether local or global information is ultimately more salient.

Recent evidence has shown that cognitive load improves performance in a global-selection task and impairs performance in a local-selection task (Ahmed & de Fockert, 2012). It was concluded that cognitive load prompts a "shift towards global processing" (p. 1404); however, we note that this research i) fails to distinguish between perceptual bias and attentional selection; and ii) neglects the role that stimulus-driven factors play in modulating the effect of cognitive load. In the present thesis we extend the work of Ahmed and de Fockert. We first explore how cognitive load affects perceptual bias and consider the mechanism that may underlie this effect (Chapter 2). We show that cognitive load reduces global salience and enhances local salience. We then consider the effect of cognitive load on selection of hierarchical information and explore the extent to which this effect is modulated by stimulus-driven factors which affect local-global salience. We suggest that cognitive load should make it more difficult to ignore irrelevant-yet-salient hierarchical information (Chapters 3-6; see Figure 1b for a schematic representation). We show that cognitive load does not always enhance global processing – as suggested by Ahmed and de Fockert – but can have the opposite effect and *impair* global selection when local salience is strong.

We suggest that cognitive load will not simply make people more global or more local but that its effects will depend on both i) whether the paradigm addresses perceptual bias or attentional selection; and ii) stimulus-driven factors that modulate local-global salience. In the present chapter we provide a brief overview of research into hierarchical processing. We see that – all else being equal –global structure is more salient than the local detail out of which it is composed (Kimchi, 1992). We review evidence which suggests that global salience depends on both individual differences and physical stimulus factors. We then consider the effect that cognitive load might have on both perceptual bias and attentional selection. Finally, we provide an overview of the paradigms that we will use to explore our question and briefly preview our key findings.

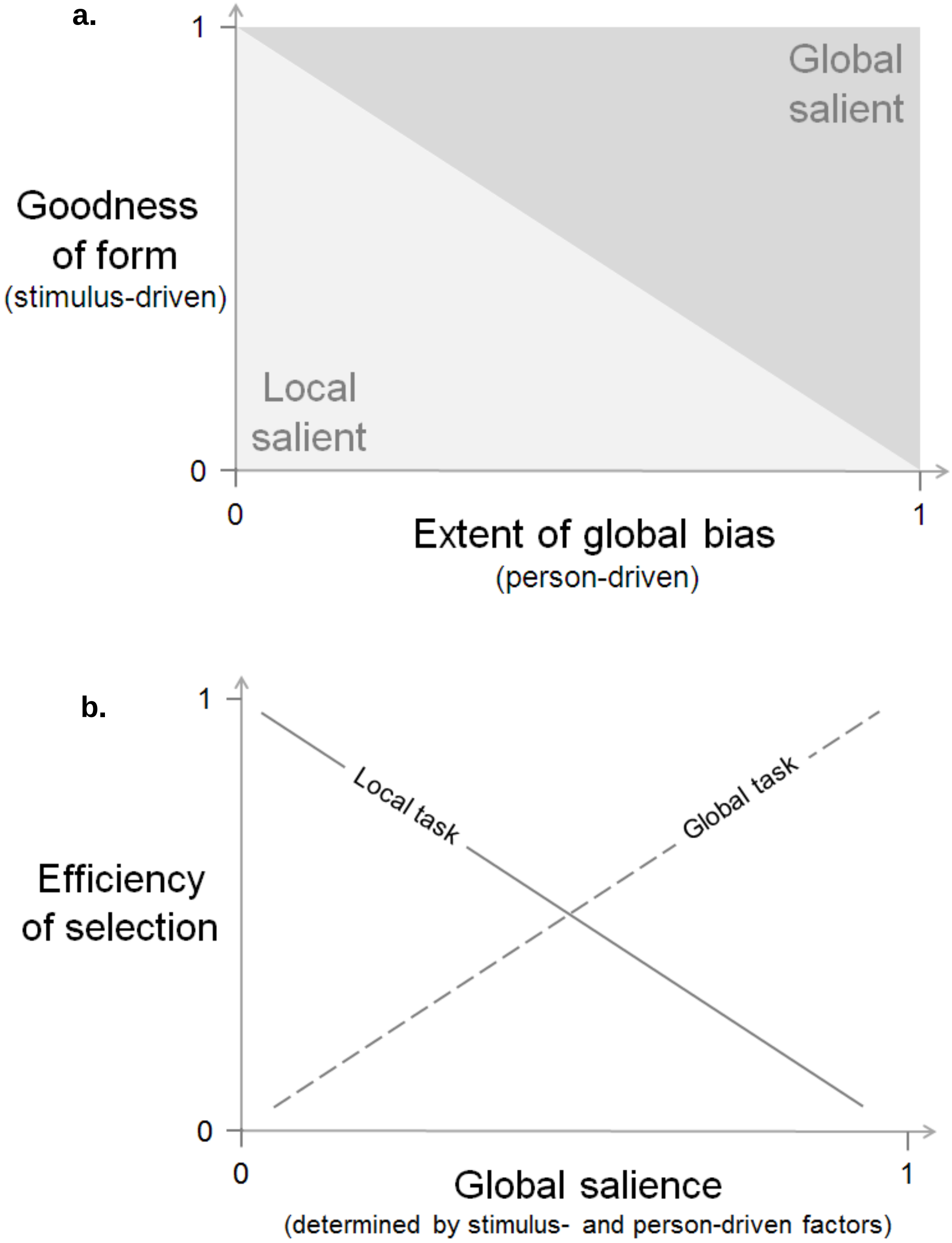



**Figure 1a**. *The interaction between extent of global bias (0 = never prioritise global structure over local detail, 1 = always prioritise global structure over local detail) and goodness of form (0 = poor global form, 1 = perfect global form) determines the salience of global and local information.* **1b**. *Global salience (0 = local most salient, 1 = global most salient) determines efficiency of selection of both local and global information. High global salience will benefit selection of global information whereas low global salience (corresponding to high local salience) will benefit selection of local information.*

## 1.1 Hierarchical information

We begin with a brief overview of what is meant by *hierarchical information*. When we view the world we perceive an organised collection of objects arranged as a coherent scene. Physiologically, though, what the brain receives is a continuous stream of retinal activation which must then be parsed and segregated into discrete perceptual units (e.g., see Kimchi, 2009, for a review). How exactly perceptual organisation is achieved has been the subject of investigation for over a century, beginning with the Gestalt school of psychology. The Gestaltists (e.g., Wertheimer, 1923/1938) proposed a series of perceptual 'laws', such as the Law of Proximity, the Law of Similarity, The Law of Closure and the Law of Continuity (see Wagemans, Elder, Kubovy, Palmer, Peterson, Singh & von der Heydt, 2012; Wagemans, Feldman, Gepshtein, Kimchi, Pomerantz & van der Helm, 2012, for recent reviews of Gestalt grouping principles), to explain how stable percepts could emerge from apparent chaos. Their view was that the "whole is other than the sum of its parts" (Koffka, 1935/1955).

This view has been explored extensively in the time since. Introspection provides compelling support for the Gestaltists' argument that global form is qualitatively different than a summation of individual parts, as whole scenes are remarkably easy to understand despite the amount of information that they contain; for instance, Potter (1975, 1976) demonstrated that participants could correctly identify a target scene embedded in amongst a rapid-serial-visual-presentation (RSVP) stream of stimuli 80-

90% of the time when the presentation duration of each stimulus was only 250 ms. The instant categorisation of scenes is referred to as scene ‘gist’ (e.g. see Oliva, 2005; Oliva & Torralba, 2006, for reviews) and illustrates that global structure – defined by the spatial arrangement of its constituent parts – is processed before local detail (e.g., Oliva & Schyns, 2000; Schyns & Oliva, 1994). Thus, global scene attributes seem to be dominant in early visual processing and seem to be of fundamental importance in how we understand the world.

Although scenes are the most naturalistic form of hierarchical display the relationship between elements in a scene is difficult to control because individual element identities are typically heterogeneous and may indicate the identity of the global whole (Navon, 2003). For example, an individual tree may prime the global construct of ‘forest’ as we know that trees are integral parts of forests. Global-local processing has therefore been most frequently investigated with hierarchical patterns (Kinchla, 1974; Navon, 1977; see Figure 2), stimuli where many local elements are arranged to form a global structure but local detail and global structure can be manipulated independently. For instance, the small ‘S’s in Figure 2a are arranged to form a large ‘S’ but in Figure 2b the small ‘S’s have been replaced with ‘H’s, while the spatial layout remains the same. Similarly, it would be possible to arrange small ‘S’s to form a large ‘H’ or small ‘H’s to form a large ‘H’. Hierarchical patterns provide simple and easily-to-manipulate stimuli with which to investigate global-local processing of visual information.

The original, and most widely-cited, study with hierarchical patterns was conducted by Navon (1977) using a selective-attention paradigm. Navon's goal was to test the assumption that the global form is rapidly accessible and must be elaborated on in order to perceive local details. Navon likened this idea to *Aktualgenese* – termed *microgenesis* in English texts (Flavell & Draguns, 1957; Werner, 1956) – which suggests that percepts progress through qualitatively different stages of development. In the selective-attention hierarchical-patterns paradigm, participants have to selectively attend to either the local detail or global structure of briefly-presented hierarchical patterns. Navon suggested that global information should be available earlier than local information, which should mean that i) responses are faster to global targets than to local ones; and ii) irrelevant global information interferes with selective attention to local detail, whereas irrelevant local information does not affect global-level responses. The latter should be evident in slowing on trials in which the local and global levels of a pattern are 'incompatible' with each other; responses to local detail (e.g., 'H') should be slowed if the identity of local elements is incompatible with the identity of the global structure (e.g., 'S' as opposed to 'H', see Figure 2b) but responses to global structure should not be affected if its identity is incompatible with the identity of its local elements (e.g., if the local elements become 'S'; see Figure 2a). The data conformed to this pattern and were interpreted as evidence that global structure is more salient than local detail in the early stages of visual processing.

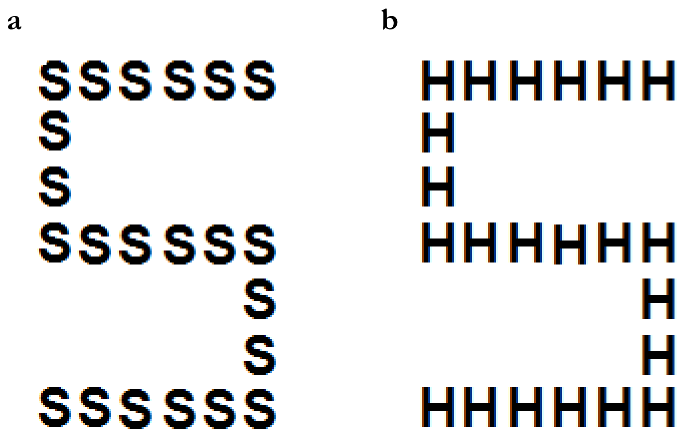



**Figure 2.** *An example of two hierarchical patterns:* **a.** *Both the global and local levels are compatible with each other ('S');* **b.** *The global configuration ('S') is incompatible with the local elements ('H'; note that the local element 'H' in this example is still a global configuration of two vertical lines and one horizontal line; however, it is lower in the hierarchy than the large 'S' which the 'H's comprise).*

In the present thesis we use the term *global advantage* to refer to circumstances in selective-attention hierarchical-patterns tasks where global information is responded to faster, and with less interference, than local detail. We align this with Kimchi's (1992) use of the term in her review of the hierarchical-patterns literature. Similarly, when we discuss occasions where local detail is selected more efficiently than global structure we use the term *local advantage*. In situations where a global advantage is observed it is reasonable to assume that global information is more salient than local information, whereas a local advantage would suggest that local detail is more salient than global structure. It can be suggested that decreased global salience is associated with increased local salience and the point at which local detail becomes more salient than global structure is determined by both person-driven factors such as perceptual bias and stimulus-driven factors such as goodness of form which together determine local-global salience. This conceptualisation of local-global salience is compatible with the idea that salience lies on a continuum; specifically, salience results from the relative weight given to hierarchical information by both person-driven and stimulus-driven factors. Whereas salience varies continuously on a single dimension, it is likely determined by interactions between several independent local-global processing mechanisms; the local-global processing mechanisms that determine salience are not therefore situated on a single dimension. In other words, whereas salience is on a continuum, the processes which interact to determine salience are not.

The majority of research into hierarchical processing has focused on stimulus-driven factors that can affect local-global salience. In a review of the hierarchical-patterns literature, Kimchi (1992) summarised a host of stimulus factors that could affect global salience and, in the time since then, many more have been identified. Global salience (as determined by the extent of global advantage) has been found to depend on: whether stimuli are presented foveally or peripherally (e.g., Grice, Canham & Boroughs, 1983; Kimchi, 1988; Lamb & Robertson, 1988; Pomerantz, 1983); the size of the stimulus (or visual angle; e.g., Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; McLean, 1978/1979; Navon & Norman, 1983); goodness of form (e.g., Hoffman, 1980; Sebrechts & Fragala, 1985); element density and number (e.g., Kimchi, 1988; Kimchi & Palmer, 1982; Martin, 1979; Navon, 1983); and exposure duration (e.g., Hughes, Layton, Baird & Lester, 1984; Kimchi, 1988; Luna, 1993; Miller, 1981; Paquet & Merikle, 1984; Paquet & Merikle, 1988; Pomerantz, 1983, Qiu, Fu and Luo, 2009; Wandmacher & Arend, 1985), amongst many other factors. Thus, any number of changes in the relationship between individual elements, the identity of the elements themselves, the position in the visual field or size, or the amount of processing time can impact on the salience of local and global information.

In this thesis we consider stimulus-driven determinants of local-global salience when we explore the effect of cognitive load on hierarchical processing. When considering the effect that cognitive load might have on perceptual bias, we acknowledge that – although cognitive load may affect the extent to which global structure is prioritised over local detail – whether local detail or global structure is ultimately most salient will also be influenced by stimulus-driven factors. When considering the effect of cognitive load on selection of hierarchical information, stimulus-driven factors which affect local-global salience will also determine whether local or global information is most difficult to ignore. In the present thesis, our investigation specifically focuses on exposure duration and density of hierarchical patterns as stimulus-driven factors that can determine global salience.

Global salience has been shown to increase as the number and relative density of the local elements that constitute global structure increases (e.g., Kimchi & Palmer, 1982;

see Figure 3). Kimchi (1998, 2000) has demonstrated that local elements are more likely to be perceived as individual entities when there are relatively few of them in a given configuration; as local elements within a pattern become more numerous and more dense, however, they become less categorisable as individual elements and more akin to a *texture* which defines global structure. Accordingly, this affects the salience of local and global information: "When the pattern is composed of a few relatively large elements, the elements are salient as figural parts of the overall form. When the number of elements increases and they become part of the texture, the global configuration is more salient than the individual elements" (p.525; Kimchi & Palmer, 1982). Thus, not all hierarchical patterns are equal in terms of global salience; Kimchi (1998, 2000) has demonstrated that high-density stimuli initially have strong global salience which decays with time whereas low-density stimuli initially have low global salience (and high local salience). Thus, not only is global salience determined by density, but density-driven global salience is affected by exposure duration.

**Figure 3.** *An illustration of how pattern density can determine local and global salience. The pattern on the left is more likely to be represented in terms of its local elements while the pattern on the right is more likely to be defined by its global structure (Kimchi & Palmer, 1982).*

Exposure duration is an important stimulus-driven factor to consider as a determinant of global salience, as the selective-attention hierarchical-patterns task (Navon, 1977), which is often used to index local-global salience, is a speeded-response measure in which patterns are usually presented for a limited duration. In general, global salience of hierarchical patterns has been shown to be strong initially but weaken over time (e.g. Hibi, Takeda & Yagi, 2002; Ninose & Gyoba, 2003; Paquet & Merikle, 1984; Qui et al., 2009; see). This suggests that strong global salience is a fleeting phenomenon in hierarchical patterns and is determined by the abrupt common-onset of the elements comprising a hierarchical pattern. This is important as the length of time that patterns are presented for varies between studies; some studies present patterns for just a few tens of milliseconds whereas others present stimuli until response (which can be in the region of 600 ms). Thus, global salience may differ between paradigms simply because of variations in exposure duration.

The fleeting nature of global salience was demonstrated by Paquet & Merikle (1984) when they ran a version of Navon's (1977) selective-attention hierarchical-patterns task but varied the exposure-duration of the stimuli between 10, 40, and 100 ms. It was found that unidirectional global-to-local interference was observed when stimuli were presented for 10 ms but that at longer exposure durations (40 and 100 ms) both global-to-local and local-to-global interference was observed to the same extent. Qiu et al. (2009) replicated these findings in a divided-attention task in which participants had to indicate whether a target letter appeared at either the local or the global level of a hierarchical pattern. According to the logic of the paradigm, quicker responses to targets at the global level indicate that the global level is more salient than the local level, whereas quicker responses to local targets suggest that the local level is more salient than the global level. Patterns were presented for either 80 ms or for an unlimited duration. There was a global advantage in the limited-exposure condition – indicating stronger global than local salience – but global- and local-level reaction times were identical at unlimited-exposure durations. These data suggest that global-level information is more salient than local detail for an initial but limited period of time and that at longer exposure durations local and global salience is more equally matched.

The decay of global salience on a selection task has also been shown to have real-world consequences. There is a well-known effect amongst Chinese and Japanese readers that prolonged viewing of Chinese characters or Japanese kanji results in a loss of perceptual coherence and makes it more difficult to tell whether or not the characters are orthographically correct. This is referred to as *orthographic satiation* of Chinese characters (Cheng & Wu, 1994) or *Gestaltzerfall* for Japanese kanji (Ninose & Gyoba, 1996, 2002, 2003) and describes the fact that characters are initially represented as global wholes with strong global salience before an uncertainty gradually emerges about orthographic correctness, indicating reduced global salience. These findings have been replicated using Navon-type hierarchical patterns (Ninose & Gyoba, 2003); evidently then, the decay in global salience over time can cause confusion about real-world stimuli.

In light of this evidence that exposure duration is important in affecting local-global salience, it is perhaps unsurprising that a global advantage was observed in Navon's (1977) original selective-attention hierarchical-patterns study, as he used hierarchical patterns which were both high in density and were presented for a limited duration (40 ms) and would thus be likely to possess strong global salience. In the present thesis we use exposure duration, in addition to pattern density, to manipulate global salience in hierarchical patterns when we explore the effect of cognitive load on both perceptual bias and on attentional selection.

Although the majority of research has focused on stimulus-driven determinants of local-global salience, recent research has also begun to explore the effect that the disposition of the perceiver can have on hierarchical processing. The present thesis adds to this line of research by exploring the effect that cognitive load – which occurs when excessive demand is placed on cognitive processes and can vary both within and between individuals – can have on hierarchical processing; specifically, we distinguish between the effect of cognitive load on local-global perceptual bias and its effects on attentional selection. However, much of the previous research into how perceiver-driven differences may affect hierarchical processing has tended to treat perceptual bias and attentional selection as reflecting the same underlying process. We now briefly discuss research on individual differences in hierarchical processing and illustrate how perceptual bias and selection are often conflated. It is important to state that we do not automatically equate differences in hierarchical processing with differences in cognitive load. However, appealing to individual differences in hierarchical processing is a useful illustration of the effect that person-driven factors can have on hierarchical processing.

Recently it has been demonstrated that an array of individual differences in many different – and varied – groups of people can affect hierarchical processing: people living in remote areas are more locally-biased than urban dwellers (Davidoff et al., 2008); Buddhists show a stronger global advantage than atheists on a selection task (Colzato, Hommel, van der Wildenberg & Hsieh, 2010), who are in turn more global than Calvinists (Colzato, van den Wildenberg & Hommel, 2008); individuals with obsessive-compulsive disorder (OCD) are more local than controls (Rankins, Bradshaw & Georgiou-Karistianis, 2005; Yovel, Revelle & Mineka, 2005); homosexuals are more local than heterosexuals (Colzato, Hooidonk, van der Wildenberg, Harinck & Hommel, 2010); and East Asians show a stronger global advantage than Americans (Kitayama, Duffy, Kawamura & Larsen, 2003; McKone, Davies, Fernando, Aalders, Leung, Wickramariyaratne & Platow, 2010). Different experimentally-manipulated motivational and mood states have also been shown to affect hierarchical processing, such as approach motivation (Gable & Harmon-Jones, 2008), happy and sad moods (Gasper & Clore, 2002), whether participants have been primed with either a local or global processing style (McCrae & Lewis, 2002) and whether they feel as though they have power over a situation (Guinote, 2007). Interestingly, whether participants have performed a cryptic crossword or Sudoku puzzle just prior to a hierarchical processing task has been shown to affect performance (Lewis, 2006).

A widespread assumption in the hierarchical-processing literature is that performance on local-global processing tasks relates to how individuals approach hierarchical information in the real world; it seems plausible that individual differences in local-global processing exist because a particular hierarchical processing style is more useful to the perceiver's behavioural goals. For instance, to explain why homosexuals have a less global processing style than heterosexuals, Colzato et al. (2010) suggest that homosexuals have a chronic attentional bias to local detail resulting from the need "to detect perceptual cues indicative of homosexual orientation, which … facilitates finding like-minded, social peers, and potential friends and sex mates" (p. 4). Similarly, the more global processing style of East Asians and more local style of Americans is said to reflect the interdependent and individualistic nature of these cultures respectively (e.g., Kitayama et al., 2003; Masuda & Nisbett, 2006). According to this view, the focus on collectivism in East Asian cultures promotes a focus on global context at the expense of local detail, whereas the focus on autonomy and independence in American culture leads to a more analytic processing style where objects are analysed in isolation from their context (Masuda & Nisbett, 2006; Nisbett, Peng, Choi & Norenzayan, 2001; Uskul, Kitayama & Nisbett, 2008).

It seems reasonable to assume that individual differences in perceptual bias and attentional selection are the same: a tendency to prioritise global structure over local detail when approaching hierarchical information in the absence of task demands should also mean that global structure is easier to select than local detail (as long as the same stimuli are used in both of these measures, to minimise the influence of stimulus-driven factors in determining local-global salience). We have already seen that this seems to be the case for Westerners, who show both a global bias on a measure of perceptual bias (Davidoff et al., 2008) and global advantage on a measure of attentional selection (e.g., Navon, 1977). However, there is reason to believe that perceptual bias and attentional selection may be governed by two separate mechanisms; thus, although perceptual bias and attentional selection may usually be aligned, cognitive load could potentially affect the operation of these mechanisms in different ways. Evidence that perceptual bias and selection are governed by separate mechanisms comes from Caparos et al. (2013) who showed that members of the Himba, a remote population in Namibia who show a markedly local bias (Caparos, Ahmed, Bremner, de Fockert, Linnell & Davidoff, 2012; Davidoff et al., 2008) were better at selecting both local and global hierarchical information in comparison to their Western counterparts (students at a London, UK, university) who show a global bias. Caparos et al. (2013) proposed that the Himba may "have superior attentional control than Westerners" (p. 211) and suggest that perceptual bias and attentional selection should be distinguished from each other when exploring hierarchical processing.

The evidence discussed here (Caparos et al., 2013) is compatible with the idea that cognitive load affects attentional selection by placing demands on the cognitive control network and by making it more difficult to ignore salient irrelevant hierarchical information. The way in which it may affect perceptual bias, however, is less clear as the propensity to prioritise global structure over local detail does not immediately suggest the involvement of cognitive control. In the following section we review evidence concerning the effect of cognitive load on visual processing and discuss the ways in which it may affect the processing of hierarchical visual information in particular, both in terms of bias and in terms of attentional selection. We preview some of the findings observed in the present thesis. We also discuss the extent to which perceptual bias may feed into selection and discuss the importance of accounting for stimulus-driven factors when exploring hierarchical processing.

## 1.2 Cognitive load

Cognitive control processes are responsible for actively maintaining behavioural goals and allocating priority of processing to behaviourally relevant stimuli to ensure that behaviour is coherent and efficient (e.g., Baddeley, 1986, 1996; Engle & Kane, 2004; Kane & Engle, 2003; Lavie et al., 2004; see Baddeley, 2012, for a recent review). With regard to the selection of hierarchical information, therefore, the function of cognitive control is to ensure that information from the relevant hierarchical level is processed without interference from information at the unattended level. For example, in a task of local selection it is important that irrelevant global structure is ignored, whereas local detail must be ignored when the task requires that global information is attended. The efficiency of selection is dependent on the availability of cognitive resources. When cognitive resources are engaged in secondary tasks – resulting in cognitive load – cognitive processing is impaired and it becomes more difficult to deploy attention in a manner consistent with top-down behavioural goals and to avoid distraction from task-irrelevant information. In selection tasks, high cognitive load is therefore associated with longer response latencies and lower accuracy in response (e.g., de Fockert et al., 2001; Lavie et al., 2004; Yi, Woodman, Widders, Marois & Chun, 2004).

The fact that imposing a cognitive load impairs maintenance of task goals and makes it more difficult to ignore behaviourally irrelevant stimuli (e.g., Lavie et al., 2004) suggests that cognitive control is a limited-capacity system with a finite pool of resources. Previous research has suggested that *working memory* is the cognitive-control process responsible for the maintenance of task priorities (e.g., Baddeley, 1986, 1996, 2012; Engle & Kane, 2004). In the majority of the experiments presented in this thesis we manipulate cognitive load by having participants perform a secondary task that loads on working memory at the same time as performing a primary hierarchical processing task; specifically, participants are required to remember digit strings at the same time as performing a task of local-global processing. The digit-rehearsal task is designed to engage working memory which would otherwise be engaged in performance of the primary task; thus, imposing cognitive load during performance of a local-global processing task can indicate how cognitive load could affect hierarchical processing.

The effect that cognitive load may have on processing of hierarchical information is important as the modern world is full of cognitive distractions, and while under varying amounts of cognitive load individuals are having to navigate through and interact with the hierarchically-organised environment which surrounds them. Cognitive load can vary both inter- and intrapersonally; some individuals may generally be under more cognitive load than others, but the extent of the cognitive load that any individual is under will also vary circumstantially (for examples, mobile phones are ubiquitous in modern life but impose a very high cognitive load; e.g., see Nasar & Troyer, 2013). Thus, if cognitive load affects how hierarchical information is processed, this could have profound implications for how visual information is represented and manipulated.

It has been argued that one function of cognitive control is to vary the focus of the *attentional window* (e.g., Belopolsky, Zwaan, Theeuwes & Kramer, 2007; Theeuwes, 1994, 2004, 2010; Theeuwes, Kramer & Kingstone, 2004). This is a spatial resource which can be either widely distributed or narrowly focused and according to this view everything that falls within the window is perceptually processed. A narrow window should benefit local selection whereas deploying attention more widely should benefit global processing at the expense of processing local detail (Treisman, 2006). Indeed, global processing has been linked with a wide attentional window (e.g., Kitayama et al., 2003; Srivastava, Kumar & Srinivasav, 2010); thus the fact that – all else being equal – Westerners express a global perceptual bias (Davidoff et al., 2008) and are better at selecting global information than local information (e.g., Navon, 1977), means that it is possible that Westerners approach the world with the attentional window in a distributed state.

Recently it has been shown that cognitive load defocuses the attentional window (Caparos & Linnell, 2010; Linnell & Caparos, 2011). If cognitive load always defocuses attentional resources, and if a wide attentional window facilitates global processing, then global processing may become more efficient under high cognitive load (Ahmed & de Fockert, 2012). Caparos and Linnell used a variant of the flanker task (Eriksen & Hoffman, 1972, 1973) – a local selection task which measures the ability to select task-relevant stimuli in the face of distracting information presented in the periphery – to demonstrate that high cognitive load spreads the spatial focus of perceptual resources. In the flanker task, target stimuli are presented in conjunction with distractor items which are to be ignored. These items can be response compatible with the target (e.g., an 'E' when the target is an 'E') or response incompatible (e.g., an 'E' when the target is an 'F'). The extent to which attention can be constrained to the target without interference from the distractor is assessed by subtracting reaction times on trials with compatible distractors from reaction times on trials with incompatible distractors. This difference quantifies the extent of *interference.* The more distractors are perceptually processed, the more interference increases.

To explicitly measure the distribution of attention, Caparos and Linnell (2010; Linnell & Caparos, 2011) used a version of the flanker task in which the spatial separation between the target and distractor varied (Müller, Mollenhauer, Rösler & Kleinschmidt, 2005); by extracting the amplitude of interference as a function of separation, the focus of attention can be derived. Research with this paradigm has demonstrated that the spatial profile of attention can be likened to a 'Mexican hat', where distractor interference first decreases with separation from the target but then *increases* again, before finally tapering off (Bahcall & Kowler, 1999; Cutzu & Tsotsos, 2003; Hopf, Boehler, Luck, Tsotsos, Heinze & Schoenfeld, 2006; Müller et al, 2005; Slotnick, Hopfinger, Klein & Sutter, 2002). The point at which distractor interference stops decreasing and starts increasing again (the 'turning point') can be used as an index of the focus of attention. When the turning point occurs at a small separation, attention is focused; when it occurs at a large separation, attention is defocused. Caparos & Linnell (2010) had participants perform the task under conditions of high (remembering six digits) and low (remembering one digit) cognitive load. Their data showed that the turning point of the attentional profile occurred at a larger separation in the high cognitive load condition, compatible with attentional resources having spread and defocused.

The separation-flanker task is arguably a task of local selection, as a central target is to be isolated and identified and competing information in the periphery is to be ignored. However, Ahmed and de Fockert (2012) interpreted Caparos and Linnell's (2010) finding to infer that high cognitive load always causes a widening of the attentional window, even when the task does not involve local selection. If a wide attentional window is associated with global processing, then high cognitive load should always result in a processing style which favours the processing of global structure in a hierarchical-patterns task. They tested this assumption by having participants perform a selective-attention version of the hierarchical patterns task (Navon, 1977) under low or high cognitive load. In the local task, participants were required to respond to the identity of local elements and to ignore the global structure. In the global task, local detail was to be ignored whilst global structure was attended. Just as for the flanker task, the amount of interference from the irrelevant information was determined by the difference in reaction times to compatible trials from those on compatible trials. Ahmed and de Fockert demonstrated that high cognitive load increased interference from irrelevant global information on a local-selection task but decreased interference from irrelevant local information on a global-selection task. They suggested that their data confirmed a “shift towards global processing with [high cognitive] load” (p. 1404).

The aim of the present thesis is to more thoroughly explore the effect of high cognitive load on hierarchical processing. The focus of our investigation was twofold. Firstly, we distinguished between perceptual bias and selection, and explored the effect that cognitive load might have on the way in which hierarchical information is prioritised when there is no selection task to perform. Thus, our first question is “does cognitive load have an impact on perceptual bias?” If a spread in attentional resources equates to a shift towards global processing and if cognitive load invariably leads to defocused attention then it is possible that people under high cognitive load will show a stronger global bias than those under low cognitive load. Secondly, the claim that high cognitive load is associated with a “shift towards global processing” (Ahmed & de Fockert, 2012) suggests that high cognitive load should *always* favour the global level of selection at the expense of the local level. We explore this assumption in more depth and explore the extent to which the observation of Ahmed and de Fockert was determined by strong global salience in their stimuli. In a series of experiments, the present thesis explores and challenges the assumptions that i) increasing cognitive load leads to a stronger global bias, and ii) cognitive load always facilitates global selection and impairs local selection.

We explore the first assumption by investigating the effect of high cognitive load on perceptual bias. If high cognitive load causes the attentional window to defocus, then this should enhance the representation of global structure and participants should show a stronger global bias under high than low cognitive load. However, we will now preview our own findings – which we present in Chapter 2 – to suggest that cognitive load may in fact *reduce* the global bias.

In order to explain the mechanistic underpinnings of hierarchical processing, several theorists have proposed that local-global processing is underpinned by two separate local and global processing mechanisms. For example, Förster and Dannenberg (2010) have proposed that when processing information, the most appropriate hierarchical processing mechanism is activated to execute the task at hand. Support for separate local-global processing mechanisms at a neural level comes from evidence which suggests that processing of local and global information in the brain is lateralised, with the left hemisphere dominant for processing of local and the right dominant for processing of global information (e.g., Fink, Halligan, Marshall, Frith, Frackowiak & Dolan, 1996, 1997; Martinez, Moses, Frank, Buxton, Wong & Stile, 1997; Van Kleeck, 1989). Lateralisation of local and global information is linked to the observation that the left and right hemispheres process relatively high and low spatial frequency information respectively (LaGasse, 1993; Shulman, Sullivan, Gish & Sakoda, 1986), and that high spatial frequency information defines local detail whereas low spatial frequency information denotes global structure. It has been suggested that identification of either the local or global level of a hierarchical pattern activates the relevant level-specific lateralised mechanism (termed the *mechanism activation hypothesis*; Lamb, London, Pond & Whitt, 1998; Lamb & Yund, 1996). Indeed, Ivry and Robertson (1998) proposed that both the left and right hemispheres receive the same spatial frequency information and that the left and right hemispheres are responsible for amplifying the high and low spatial frequency information respectively.

We suggest that it is plausible that the resting activation of these two lateralised systems – and thus the extent to which low and high spatial frequency information is amplified – may determine the relative weight given to local and global information and thus may determine the perceptual bias. For example, if the resting activation of the right-lateralised global mechanism is higher than the left-lateralised local mechanism then global structure will receive priority of processing over local detail and a global perceptual bias will be observed. This could contribute to why, all else being equal, global structure is more salient than local detail (e.g., Kimchi, 1992). There is evidence to support this assertion. Global-dominant right hemisphere activation is higher than (local-dominant) left hemisphere activation when participants are preparing to respond to visual information (Duschek & Schandry, 2003; Helton, Hollander, Tripp, Parsons, Warm, Matthews & Dember, 2007; Hitchcock, Warm, Matthews, Dember, Shear, Tripp, Mayleben & Parasuraman, 2003; Stronbant & Vingerhoets, 2000). Hemispheric asymmetry for the processing of hierarchical information is most pronounced in divided-attention tasks, when both levels of representation must be attended to (Yovel, Yovel & Levy, 2001) and the relative activation of the left and right hemispheres is thought to represent the ‘preferred’ level of hemispheric activation for anticipating hierarchical information (Hübner, Volberg & Studer, 2007). Thus, perceptual bias may reflect the relative activation of the cerebral hemispheres when prioritising hierarchical information; higher right activation than left activation would result in a global bias, while higher left activation than right activation would result in a local bias.

In the present work, we explore the idea that cognitive load might change the relative activation of the cerebral hemispheres thus affecting the relative weight given to local and global information and with it perceptual bias. There is evidence to suggest that activation of the right hemisphere is only higher than activation of the left hemisphere when the task is easy; when task difficulty increases and imposes a high cognitive load, activation of the right hemisphere decreases and hemispheric activation becomes more bilateral (Helton, Warm, Tripp, Matthews, Parasuraman & Hancock, 2010). Thus, under low cognitive load global-dominant right hemisphere activation is higher than local-dominant left hemisphere activation and a global perceptual bias is observed. Under high cognitive load, however, both hemispheres may be activated to the same extent with the result that processing of global information is no longer prioritised over the processing of local information and the global bias is reduced.

We investigated the effect of cognitive load on perceptual bias in Chapter 2 by using a similarity-matching version of the hierarchical patterns task (Kimchi & Palmer, 1982; see Figure 4). In our version of the task, participants are presented with three hierarchical patterns simultaneously. One of these is a target pattern and the other two are comparison patterns, one of which matches the target at the local level while the other matches it at the global level. The participant must indicate which comparison pattern they perceive as most resembling the target pattern. The proportion of global matches indicates the strength of global salience; as global salience increases, so will the proportion of global matches. By comparing the proportion of global matches when the task is performed under low and high cognitive load (remembering one and six digits respectively) we can explore whether high cognitive load strengthens or weakens global salience.

To preview our findings, we found that participants under high cognitive load made significantly fewer global matches than participants under low cognitive load. This suggests that high cognitive load weakens the global bias and decreases the salience of global structure (and enhanced the salience of local detail). This effect was found only when stimuli were presented for an unlimited duration. When exposure durations were limited there was no effect of cognitive load; we suggest that the sudden onset of hierarchical patterns meant that global salience was strong at limited exposure durations (see earlier in this chapter) and thus compensated for the effect of cognitive load on perceptual bias. Exposure duration was not the only stimulus-driven factor to affect global salience. We also show that pattern density affects the likelihood that patterns will be matched according to global structure, with high-density patterns being more likely to be matched at the global level than low-density patterns (Kimchi & Palmer, 1982). Therefore, although high cognitive load reduces global salience, the likelihood of a global match is still dependent on stimulus-driven factors that determine global salience.

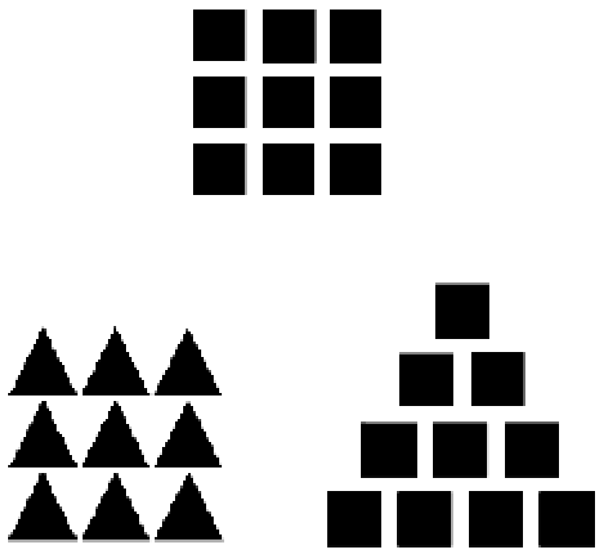


**Figure 4**. *An example of a similarity-matching version of the hierarchical patterns task. Participants are asked whether the pattern at the top 'looks most like' the pattern on the bottom left or bottom right. In the example above, a 'left' response would indicate a match at the global level whereas a 'right' response would indicate a local match.*

From Chapter 3 onwards we explore the effect of cognitive load on task-driven selection of hierarchical information. Ahmed and de Fockert (2012) showed that high cognitive load impaired local selection and improved global selection. However, we suggest that these findings were driven by the strong global salience of their stimuli, evidenced by the fact that participants were faster to respond to the global level than the local level of their patterns. It has been suggested that "the more obvious the form, the more it resists alteration by an observer" (p. 45; Katz, 1951) and in Ahmed and de Fockert's study it is likely that cognitive load made it more difficult to ignore high-salient global information when performing a local-selection task. We suggest that the opposite effect should be observed when local salience is strong. In this instance, high cognitive load should make it more difficult to ignore high-salient local information and performance on a task of global selection should be impaired.

In the present thesis, with respect to the effect of cognitive load on selection of hierarchical information, we aimed to extend the work of Ahmed and de Fockert (2012) and show that high cognitive load does not always favour the selection of global-level information, but can benefit local processing when local salience is strong. The vast majority of studies into local-global processing use some variant of the selective-attention hierarchical-patterns task (Navon, 1977) to explore selection of hierarchical information as it allows investigation into how easily either local or global information can be selected in the face of incompatible and distracting information at the other level. Selective-attention tasks are typically limited-exposure paradigms. We have already discussed evidence which suggests that global salience is strongest at limited exposures and our experiments in Chapter 2 showed that high cognitive load does not influence global salience at limited exposures while it did reduce global salience at unlimited exposures. In Experiments 4 and 5 (presented in Chapter 3) we ran a selective-attention version of the hierarchical-patterns task under low (remember one digit) and high (remember six digits) cognitive load. Using exposure duration as a manipulation of global salience, we predicted that the effect of cognitive load on perceptual bias at unlimited exposures would feed into the effect of cognitive load on selection when exposures were unlimited. By using stimuli in which local salience becomes stronger than global salience under high cognitive load, we predicted that it should become more difficult to ignore local information on a global-selection task when under high cognitive load. Thus we predicted that high cognitive load should impair global selection at unlimited exposures, when local salience is strong. This effect should however be absent for limited exposures.

We saw a trend in this direction but it was not significant. We reasoned that extending exposure duration was not an appropriate manipulation of global salience in the selective-attention version of the hierarchical-patterns task given that the latter is designed as a speeded-response task aimed at addressing the initial stages of visual processing. In Chapter 4 we present two experiments in which we enhanced local salience by manipulating the density of hierarchical patterns. Global salience in hierarchical patterns has been shown to increase as the number and relative density of the local elements increases (Kimchi & Palmer, 1982). Thus in Experiments 6 and 7 we ran a standard limited-exposure version of the selective-attention hierarchical-patterns task but compared the effect of high cognitive load on selection of low-density (high local salience) and medium-density (equal global and local salience) patterns. We manipulated cognitive load by having participants perform a task switching version of the selective-attention hierarchical-patterns task. In this version of the task, participants are told at the beginning of each trial whether they are to perform the local- or global-selection task. If the task to-be-performed is the same as the task on the previous trial this is a ‘no-switch’ trial, whereas if the task to-be-performed is different to the task on the previous trial this is a ‘switch’ trial. Task switching is cognitively demanding (e.g., Yeung & Monsell, 2003) and allows us to explore the difference between selection under high cognitive load (switch trials) and low cognitive load (no-switch trials) in the same block of trials. We demonstrated that high cognitive load increased interference from irrelevant local detail on a global-selection task but *only* with low-density patterns where local salience was strong.

## 1.3 Beyond hierarchical patterns

In the experiments presented in Chapters 5 and 6 we moved our investigation beyond hierarchical patterns. The overwhelming majority of research on global-local processing has been conducted with hierarchical patterns, and indeed the discussion of hierarchical information so far has centred on these stimuli. However, hierarchical patterns lack certain grouping properties – such as closure and connectedness – that are present in real-world objects. Arguably, it is erroneous to class them as objects and they can more reasonably be thought of as object clusters (Navon, 2003). Indeed, Navon has argued that hierarchical patterns are object formations, and that local elements are not features of the object but are individual discrete objects; the spatial positioning of these individual objects in relation to each other determines the overall global form. By focusing only on hierarchical patterns, and ignoring stimuli in which elements are connected to form an integral whole, we may fail to observe effects of cognitive load on hierarchical processing that may not necessarily be apparent with hierarchical patterns. Furthermore, closed and connected objects present us with another grouping principle to manipulate in order to vary global salience.

For this reason, in the experiments presented in Chapter 5 we focused our investigation on the Framed Line Test (Kitayama et al., 2003), a task with closed and connected figures in which local detail forms an integral part of the global whole. The FLT is a task designed to address the extent to which local detail can be isolated from or integrated into its surrounding context. We used it here to investigate how cognitive load might affect selection of hierarchical information. In this task, participants are shown a square frame with a line descending from the top and are required to redraw the line, from memory, in a differently-sized empty test frame (see Figure 5 for a schematic representation of the task). There are two different tasks to perform: the *absolute task* and the *relative task.* In the absolute task, participants are required to redraw the line the same absolute length as it was in the original frame, regardless of the size of the test frame. Even if the test frame is bigger or smaller than the first the line must be drawn the same absolute size as it was when it was originally presented. This assesses the ability to isolate the local line from its global context, and is in essence a local selection task. We align the absolute task with the local-selection hierarchical-patterns task. In the relative task, participants are required to redraw the line in proportion to the frame; that is, if the test frame is bigger than the first then the line should be drawn proportionally longer. This is in essence a task of global selection as successful performance depends on the ability to integrate the line element into its global context. We align the relative task with the global-selection hierarchical-patterns task.

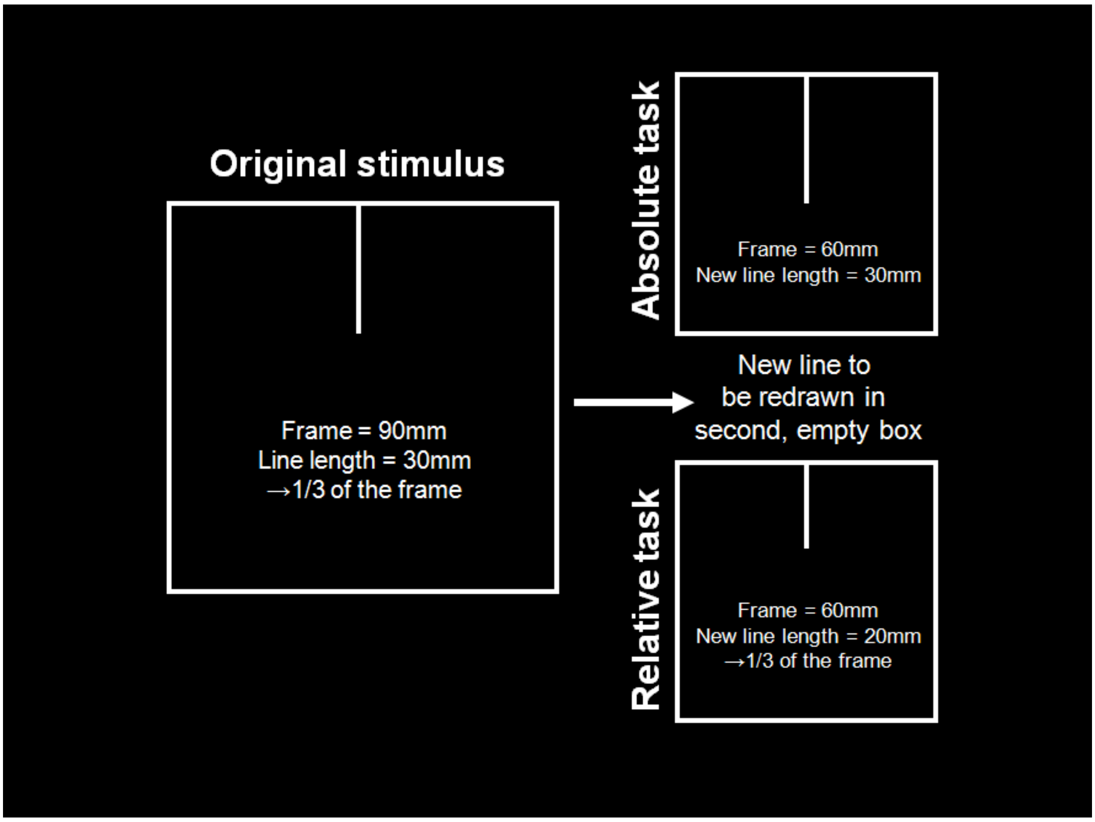



**Figure 5.** *Schematic illustration of the Framed Line Test (FLT; Kitayama et al., 2003). Frame dimensions are for illustrative purposes only. In the absolute task (top right), the new line has been redrawn in the frame exactly the same length as the first line was in the first frame (original stimulus on left), which in this instance measures 30 mm. In the relative task (bottom right), the new line has been redrawn in the same proportion to the new frame as the first line was to the first frame, namely as one third of the height of the frame in this instance.*

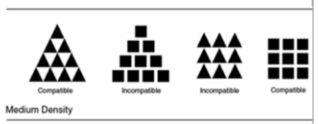
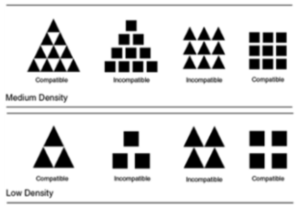
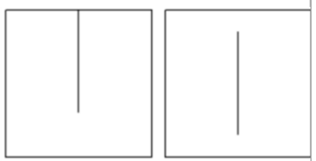
Global salience in the FLT is strong (Zhou, Gotch, Zhou & Liu, 2008; although see Kitayama et al., 2003). This is likely to be because the local line element is physically connected to the frame and thus the local detail and global context form a single entry-level perceptual unit (Palmer & Rock, 1994). We reasoned that we could reduce global salience and enhance local salience by disconnecting the local line element from the frame. Thus, we had two versions of the FLT: one connected version with strong global salience and the other disconnected version with strong local salience. In Chapter 5, we report a series of experiments in which we ran both versions of the FLT under low and high cognitive load. In the original version of the FLT – where the line is connected to the frame and global salience is strong – we showed that high cognitive load made it more difficult to ignore irrelevant global information and impaired performance on the absolute task. We aligned this with the results from Ahmed and de Fockert's (2012) study with global-salient hierarchical patterns. In the version of the FLT where the line is disconnected from the frame – and local salience is strong – high cognitive load however impaired performance on the relative task. These studies provide further evidence to suggest that the effect of cognitive load on selection of hierarchical information depends on stimulus-driven factors which determine local-global salience and does not always cause a "shift towards global processing" (Ahmed & de Fockert, 2012).

We concluded our investigation with a single experiment in Chapter 6 in which we explored how cognitive load might affect performance on a drawing task. While participants were under high or low cognitive load we compared performance on a task copying 'impossible' figures, where attending to global structure would be detrimental to performance, compared with performance on a task copying 'possible' figures. Participants copied pictures of both 'possible' objects – 2-dimensional drawings of 3-dimensional objects that can exist in 3D space – and 'impossible' objects – 2D drawings of 3D objects that *cannot* exist in 3D space – under both low and high cognitive load. We demonstrated that high cognitive load makes it more difficult to ignore a strong yet confusing global context and slows performance when copying confusing impossible objects. We suggest that cognitive load could potentially make the world more confusing, if irrelevant hierarchical information interferes with selection of relevant information.

## 1.4 Outline summary of thesis

In the present thesis, we investigate the effect of cognitive load on the processing of hierarchical information. Across a series of experiments (see Table 1 for an overview of experiments), we show that cognitive load affects both perceptual bias and attentional selection and that its effects are modulated by stimulus-driven factors that determine local-global salience. In Chapter 2, we explore the effect of cognitive load on perceptual bias and present evidence to suggest that cognitive load reduces the global bias and the salience of global information. In Chapters 3-6, we explore the effect of cognitive load on selection of hierarchical information and show that cognitive load can increase interference from local detail on a global-selection task when local salience is strong as well as increase interference from irrelevant global structure when global salience is strong. Thus, the present thesis suggests that cognitive load may not simply make people 'more global' or 'more local'; rather, the effect of cognitive load depends on an interaction between the bias and goals of the perceiver with the physical properties of the environment.

**Table 1:** *Overview of studies presented in the thesis*

| Experiment | Salience manipulation | Stimuli | | Effect of cognitive load: summary of findings |
|---|---|---|---|---|
| **Chapter 2**<br>**E1 – E3:**<br>Similarity match | **Hierarchical patterns:**<br>Exposure duration,<br>Pattern density |  | **Bias** | Cognitive load reduces global salience and enhances local salience of hierarchical patterns when exposure durations are unlimited. |
| **Chapter 3**<br>**E4 – E5:**<br>Selective attention | **Hierarchical patterns:**<br>Exposure duration |  | **Selection** | No effect of cognitive load on selection of hierarchical information: exposure duration is an ineffective manipulation of salience in a speeded-response hierarchical patterns task. |
| **Chapter 4**<br>**E6 – E7:**<br>Task switching | **Hierarchical patterns:**<br>Pattern density |  | **Selection** | Cognitive load makes it more difficult to ignore irrelevant local information when local salience is strong: cognitive load does not *always* make hierarchical processing more global. |
| **Chapter 5**<br>**E8 – E11:**<br>Framed Line Test (FLT) | **FLT:**<br>Connected/<br>disconnected<br>line |  | **Selection** | Cognitive load makes it more difficult to ignore the most salient level of hierarchical information. Effect of cognitive load on selection of hierarchical information is not limited to hierarchical patterns. |
| **Chapter 6**<br>**E12:**<br>Graphic construction | **Impossible/possible objects:**<br>Possibility of object |  | **Selection** | Cognitive load makes it more difficult to ignore confusing hierarchical information and could potentially make the visual world more confusing. |

# CHAPTER TWO – COGNITIVE LOAD AND PERCEPTUAL BIAS

## 2.1 Introduction

In the General Introduction we distinguished between the possible effects that cognitive load could have on perceptual bias and on selection of hierarchical information. Whereas selection describes the ability to select hierarchical information that is most relevant to task demands, perceptual bias is analogous to a default setting with which observers approach hierarchical visual information. For example, people in London, UK are more likely than members of the Himba, a remote culture in Namibia, Africa, to interpret visual information in terms of its global structure rather than local detail (Davidoff et al., 2008). In the present chapter we explore the effect of cognitive load on this perceptual bias and the extent to which it affects the salience of local and global information. Recent evidence has shown that high cognitive load causes a “shift towards global processing” (Ahmed & de Fockert, 2012); if cognitive load always shifts processing towards the global level then we should see global salience increase under high cognitive load. However, in the present chapter we discuss evidence to suggest that cognitive load may in fact *reduce* global salience. We present a series of experiments which explore whether cognitive load makes it more or less likely that global-level information will be prioritised over local detail. We use a paradigm which measures hierarchical perceptual bias to explore whether cognitive load increases or decreases the salience of local and global information.

Hierarchical perceptual bias denotes the relative processing priority given to global structure or local detail. All else being equal, in the urbanised world there is a global bias so that global structure is more salient than local detail (e.g., Davidoff et al., 2008); that is, if local elements and global structure are equally recognisable, the global form is the preferred level of representation (Kimchi, 1992; Navon, 2003). Navon (2003) has suggested that this makes adaptive sense, saying that “an old-time hominid would be liable to pay dearly, had s/he failed to recognise a pair of glowing dots in the bush at dark as the eyes of a predator, mistaking it for two fireflies” (p. 281; see Wagemans et al., 2012a, 2012b, for recent reviews of Gestalt grouping principles). When we explore the effect of cognitive load on perceptual bias we are effectively exploring whether it impacts on the likelihood that a pair of glowing dots will be classed as ‘eyes’ or ‘two fireflies’, or that we will see the ‘forest’ or the ‘trees’.

There is little extant evidence to suggest how cognitive load might affect hierarchical processing and furthermore the evidence that does exist concerns attentional selection rather than perceptual bias. As has been previously discussed, Ahmed and de Fockert (2012) have suggested that high cognitive load shifts processing towards the global level. To briefly recapitulate, participants performed a selective-attention hierarchical-patterns task and had to respond to either the local or global level of briefly presented hierarchical patterns, under low or high cognitive load. They showed that high cognitive load impaired local selection (by making it more difficult to ignore global information on a local-selection task) and improved global selection (by making it easier to ignore local detail on a global-selection task) and concluded that high cognitive load should always facilitate global processing.

To explain their data, Ahmed and de Fockert (2012) invoked evidence to suggest that the window of attention defocuses under high cognitive load (Caparos & Linnell, 2010) and thereby increases the salience of global information. If cognitive load does always defocus the window of attention then it should also enhance global salience, making it more likely that hierarchical information will be interpreted according to its global structure than local detail. However, in the General Introduction we suggested that Ahmed and de Fockert (2012) saw a “shift towards global processing” because they used hierarchical patterns with strong stimulus-driven global salience; cognitive load then made it more difficult to ignore global structure on a local-selection task and easier to ignore local detail on a global-selection task. We suggested that a ‘shift towards *local* processing’ would be observed if local salience was strong. If cognitive load does not *always* cause a shift in the global direction then cognitive load may not *always* enhance global salience.

Indeed, there is evidence to suggest that cognitive load may in fact reduce the perceptual bias towards global structure, reducing the weight assigned to global structure over local detail and thus enhancing the salience of local over global information. In other words, rather than increasing the global bias, cognitive load may decrease it and make people *less* likely to see a set of eyes instead of two fireflies, or the wood for the trees.

We invoke a hemispheric activation account to support this possibility. As was outlined in the General Introduction, several researchers have proposed the existence of separate mechanisms for processing the different levels of hierarchical information, with local and global processing being lateralised to the left and right cerebral hemispheres respectively (Ivry & Robertson, 1998; Lamb, London, Pond & Whitt, 1998; Lamb & Yund, 1996). This is said to be due to how the brain processes spatial frequency information; generally speaking, the left hemisphere is dominant for processing of the high spatial frequencies that underpin local detail whereas the right hemisphere processes the low spatial frequency information that defines global structure (e.g., LaGasse, 1993; Shulman, Sullivan, Gish & Sakoda, 1986). Ivry and Robertson's (1998) Double Filtering by Frequency theory suggests that both hemispheres receive the same spatial frequency information, but that the left and right hemispheres amplify high and low spatial frequency information (which denote local detail and global structure) respectively. It is possible that perceptual bias could be determined by the resting activation of the lateralised hierarchical processing mechanisms. If the relative activation of the cerebral hemispheres determines the extent to which high and low spatial frequency information (and consequently local and global information) is prioritised then relative hemispheric activation could plausibly determine the relative weight that local detail and global structure receive in hierarchical processing.

There is evidence to support this assertion. Yovel et al. (2001) have suggested that each hemisphere prepares to respond to its preferred level of representation in anticipation of the onset of hierarchical information, and that the relative extent of this preparation determines the extent to which local or global information is prioritised. In a divided-attention hierarchical patterns task – arguably a measure of perceptual bias (Roalf, Lowery & Turetsky, 2006) in which participants have to indicate whether a target is present or absent in a hierarchical pattern regardless of whether or not it appears at the local or global level – Yovel et al. demonstrated that participants responded to local targets more quickly if patterns were presented to the left hemisphere but responded to global targets more quickly if patterns were presented to the right hemisphere. This suggests that each hemisphere prioritises information at its preferred level of representation (i.e., the left prepares to respond to local information while the right prepares to respond to global information). Relative hemispheric activation, therefore, will determine the extent to which local or global information is prioritised.

The suggestion that relative hemispheric activation determines the extent to which local and global information is prioritised also suggests that that relative hemispheric activation could determine perceptual bias. Evidence has suggested that the right hemisphere is relatively more activated than the left when the brain is preparing to respond to upcoming visual information (Duschek & Schandry, 2003; Helton et al., 2007; Hitchcock et al., 2003; Stronbant & Vingerhoets, 2000). This asymmetric hemispheric activation could explain why, all else being equal, global structure receives priority of processing over local detail (Kimchi, 1992) and thus makes people more likely to see the wood for the trees. This also suggests that anything that alters hemispheric activation could also have an effect on perceptual bias.

Recent evidence has suggested that elevated right hemisphere activation when preparing to respond to visual stimuli is only apparent when the task is easy (Helton et al., 2010). When the task is difficult – and comes with a higher cognitive load – right hemisphere activation drops and hemispheric activation becomes bilateral. Thus, this suggests that a right hemispheric (global) advantage may only be apparent when in the absence of cognitive load. Helton et al. ran a detection task where participants had to respond to a target that appeared at irregular intervals in a stream of centrally-presented letter stimuli. In the easy condition, the contrast between stimuli and the background was high and targets were easy to detect. In the difficult task, the contrast between the background and the experimental stimuli was low and it was much more difficult to detect the target. While participants were performing the detection task, functional near infrared spectroscopy (fNIRS) was used to measure cerebral tissue oxygen saturation, a measure of brain activation. It was found that right hemisphere activation was only higher than left hemisphere activation when the task was easy; when the task was difficult, and participants were under a higher cognitive load, cerebral activation was bilateral and there was no longer a right hemisphere advantage. Thus, when the task is easy (in the absence of cognitive load) activation of the right hemisphere is higher than the left, but when the task is difficult (and imposes a high cognitive load), hemispheric activation becomes bilateral. In terms of perceptual bias, this suggests that a global bias should be observed under low cognitive load because activation of the global-dominant right hemisphere is higher than the local-dominant left. Under high cognitive load, however, global structure should no longer receive priority over local detail and global salience should be reduced (and local salience increased).

There is further evidence to suggest that the change in hemispheric activation by Helton et al. (2010) is due to an imposition of cognitive load. Research has suggested that the act of monitoring the environment for an extended period of time, as was required in the target detection task employed by Helton et al., is cognitively demanding in itself. This is known as *vigilance*, and has been shown to incur a high cognitive load (Helton & Russell, 2011) and to increase stress and mental fatigue (Warm & Parasuraman, 2008). Interestingly, Helton, Hayrynen and Schaeffer (2009) demonstrated that remaining vigilant when performing a global speeded-response hierarchical patterns task both impaired responses to the global level of hierarchical-patterns and resulted in elevated right tympanic membrane temperature (TMT), a physiological marker which increases as cortical activation decreases and is indicative of cognitive fatigue. Sustained attention to the local level during a local speeded-response task, however, had neither a behavioural nor physiological effect. This provides direct evidence to suggest that the cognitive load incurred through vigilant behaviour specifically affects processing of global information, and it is possible that this is because the right-hemispheric fatigue caused by cognitively-demanding vigilant behaviour reduces global salience.

Taken together, the work of Helton and colleagues (Helton et al., 2010; Helton & Russell, 2011) suggests that high cognitive load is associated with reduced right hemisphere activation. Extrapolating from this, it is possible that high cognitive load will alter relative hemispheric activation and thus affect the extent to which global structure is prioritised over local detail. Under low cognitive load, activation of the right hemisphere should be higher than the left so that global structure is prioritised over local detail. Under high cognitive load, however, hemispheric activation should become bilateral and the right-lateralised global and left-lateralised local mechanisms equally activated; as a result, the global bias should be reduced and global salience relatively weakened under high than low cognitive load.

In this chapter, we present three experiments to investigate the effect of cognitive load on hierarchical perceptual bias and local-global salience. Although local-global processing is most commonly addressed with selective-attention paradigms (e.g., Navon, 1977), Navon (2003) has suggested that similarity-matching paradigms (e.g., Kimchi & Palmer, 1982; see Figure 6) – where participants instead choose to match hierarchical-patterns according to perceived similarity at either the local or global level – are better suited to addressing which level of a hierarchical-pattern is "given more weight in high-order processes" (p. 275) and allow insight into whether local elements or global structure is most salient. In this task, participants are presented with a test pattern, which they must match to one of two comparison patterns on the basis of which two look most similar. Importantly, the test pattern matches one of the comparison patterns at the local level while the other matches it at the global level. The proportion of occasions on which patterns are matched according to the global or local level of representation can be taken as an indication of the salience of global information.

We explored how cognitive load might affect perceptual bias by observing how performing a secondary task designed to engage cognitive resources – an operationalisation of cognitive load – affected global salience in a similarity-matching version of the hierarchical patterns task (Kimchi & Palmer, 1982). There were two contrasting possibilities. If high cognitive load always causes the attentional window to defocus (Ahmed & de Fockert, 2012), then we might expect to see a higher proportion of global matches under high than under low cognitive load. However, if high cognitive load reduces global salience by affecting relative hemispheric activation and reducing the global perceptual bias then we would expect *fewer* global matches under high than low cognitive load.

In the present chapter we broaden Ahmed and de Fockert's (2012) conclusions regarding the effect of cognitive load on selection of hierarchical information and explore how cognitive load affects the likelihood that global structure is prioritised over local detail. However, whether global information is ultimately most "salient in the final percept" (p 26; Kimchi, 1992) will also depend on stimulus-driven factors which affect global salience. In their similarity-matching hierarchical-patterns task, Kimchi and Palmer (1982) used four different pattern densities to demonstrate that the likelihood that patterns would be matched at the global level increased with pattern density; whereas low-density stimuli were most likely to be matched at the local level, high-density stimuli were most likely to be matched at the global level. We used a manipulation of pattern density in the present experiments as we wanted to demonstrate that the effect of cognitive load was independent of pattern density.

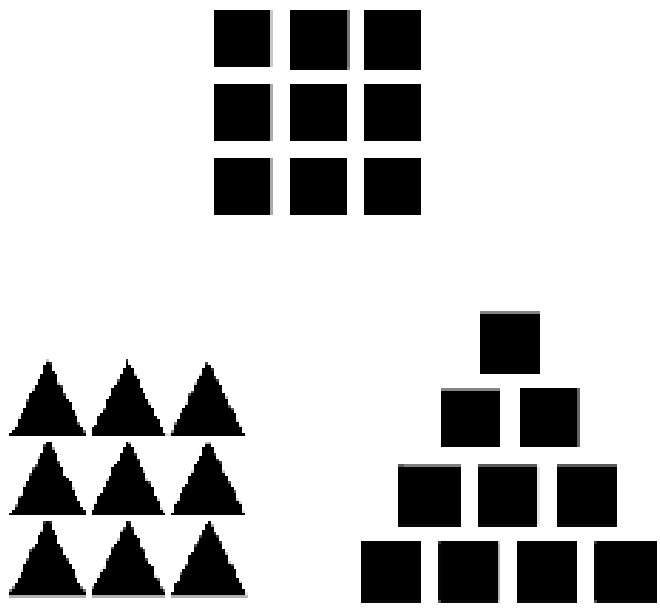


**Figure 6**. *An example of a single trial in the similarity-matching version of the hierarchical patterns task. Matching the pattern at the top with the pattern on the bottom left is a global match, whereas a match with the pattern on the bottom right is a local match.*

In the General Introduction we discussed the extent to which global salience was affected by the exposure duration of hierarchical-patterns. Global information is most salient when hierarchical patterns are presented very briefly (e.g. Paquet & Merikle, 1984; Sripati & Olson, 2009). Even if cognitive load does affect relative hemispheric activation and increases the salience of local information, the sudden onset of hierarchical patterns at short exposures could mean that global coherence is increased so that global structure is still more salient than local detail. However, at longer exposures – when the effects of common onset have worn off – the effect of cognitive load on perceptual bias may become apparent. Therefore, we ran two versions of the task: one where exposure durations were limited (Experiment 1) and another where exposure durations were unlimited (Experiments 2 and 3). We argue that unlimited exposure durations – which allow observers to look at stimuli for as long as they like – are more suitable for investigating the effect of cognitive load on the representation of hierarchical information in real-world scenarios as real-world vision is not driven by a series of brief exposures.

## 2.2 Experiment 1

In this first experiment we investigated the effect of cognitive load on local-global salience when exposure durations were limited. To test this, we added a cognitive load manipulation to Kimchi and Palmer's (1982) similarity-matching task and limited the exposure duration of the patterns to either 30 ms or 150 ms. We have suggested that cognitive load may either enhance or reduce global salience; we propose that evidence favouring the latter possibility is more convincing than that supporting the former. Nevertheless, even if cognitive load reduces global salience (and enhance local salience), global structure is usually dominant in the early stages of processing (e.g., Shulman et al., 1986; Sripati & Olson, 2009) and we predict that the sudden onset of hierarchical patterns should mask any effect of cognitive load to reduce global salience. Thus, we did not predict that cognitive load would have any effect on local-global salience when exposure durations were limited.

The proportion of global matches was taken to reflect the salience of local and global information; more than 50% global matches indicates that global structure is more salient than local detail whereas fewer than 50% global matches indicates that local detail is more salient than global structure. Kimchi and Palmer (1982) demonstrated that the proportion of global matches increases as the relative density of the individual elements increases; by including a *pattern-density* manipulation in the present study, we could observe whether cognitive load affected all densities equally.

## 2.2.1 Method

### 2.2.1.1 Design

A mixed design was used, with *pattern density* (*low, medium* and *high*) and *display time* (*30 ms* and *150 ms*) as the within-subjects variables and *cognitive load* (*low* or *high*) as the between-subjects variable. *Proportion of global matches* was the dependent variable.

### 2.2.1.2 Participants

Forty individuals (mean age 24.98 years; 28 females, 12 males) participated in the study and were reimbursed £5 for their time. All participants reported to have normal or corrected-to-normal vision. All participants were first year undergraduate students at

Goldsmiths, University of London, UK. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

#### 2.2.1.3 Apparatus and stimuli

The experimental stimuli were presented on a Sony Trinitron CRT (F520) monitor using E-Prime version 1.2 (Psychology Software Tools Inc., Sharpsburg, PA). Patterns were presented on a white background and were small black triangles or squares configured to form large triangles or squares; the large shape could be either compatible (e.g., a large square formed of small squares) or incompatible (e.g., a large square formed of small triangles; see Figure 7) with the small shapes. Each pattern subtended approximately 2.4° of visual angle. The small squares subtended 1.2°, 0.8°, and 0.6°, and the small triangles 1.0°, 0.7°, and 0.5° for the low, medium, and high densities, respectively. Each pattern was presented once at the top of a stimulus triad (see Figure 7), with two comparison patterns below it, one of which it matched at the local level only, and the other of which it matched at the global level only. Previous work with similarity-matching tasks in our laboratory has shown that performance does not change with multiple presentations of matching stimuli. Kimchi and Palmer (1982) used only one version of each stimulus triad; however, to avoid the possibility that matching was based on the positioning of the comparison patterns rather than local-global salience, each triad existed in two forms with the locations of the comparison patterns switched. A total of 24 unique stimulus triads were used. Each stimulus triad was presented once for 30 ms and once for 150 ms; the whole experiment consisted of 48 trials presented in a randomized order.

For the between-subjects cognitive-load manipulation, either one digit (low cognitive load) or six digits (high cognitive load) between '1' and '9' were pseudorandomly selected; for the high-cognitive-load condition, the digits were drawn without replacement.

2.2.1.4 Procedure

Participants were seated 60 cm from a computer screen (maintained using a chinrest) and were informed that the task was to indicate, with a keypress, whether the pattern on the bottom left or right of the triad 'looked most like' the pattern at the top, whilst remembering either one (low cognitive load) or six (high cognitive load) digits. The digit(s) were presented (simultaneously) for 3,000 ms, followed by a blank screen for 1,000 ms, at the beginning of blocks of 24 trials; each trial began with a 1,000-ms fixation cross before the stimulus triad was presented, centred on fixation, for either 30 or 150 ms. After each block of 24 trials, participants were asked to type in the digit(s) that they had been remembering; for the high-cognitive-load manipulation, the digits were to be recalled in serial order, and participants were considered to have adequately recalled the digit string if at least five digits were recalled in the correct order. The procedure was then repeated for the remaining 24 trials.

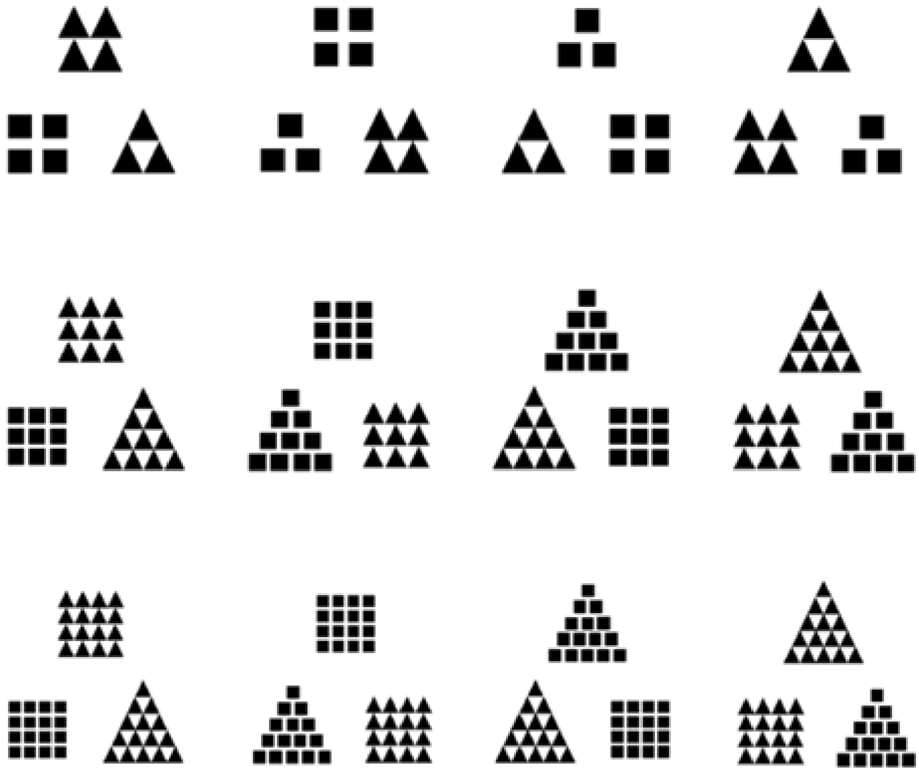


**Figure 7.** *An illustration of the stimulus triads used. The top row depicts the low-density patterns, the middle row the medium-density patterns and the bottom row the high-density patterns. For the purpose of brevity we omitted Kimchi & Palmer's (1982) highest-density patterns from our stimulus set.*

### 2.2.2 Results

The cognitive-load task was performed adequately by all participants. A preliminary analysis of the matching data indicated that *display time* (30 vs. 150ms) had no effect on the responses [$p > .1$]; hence, this variable was excluded from further analysis. *The proportion of global matches* on the matching task were analysed in a two-way mixed analysis of variance (ANOVA) with *pattern density* and *cognitive load* as the independent variables. A Bonferroni adjustment for multiple comparisons was applied to all post-hoc tests. We found no main effect of high (M= .64, SE = .05) versus low (M= .63, SE= .05) cognitive load on the proportions of global matches [$p > .1$].

A significant main effect of *pattern density* [$F(2, 76) = 4.11$, $p < .01$, $\eta^2 = .7$] demonstrated that more global matches were made to high-density (M = .76, SE = .04) than to medium-density (M = .69, SE = .04) patterns [$t(39) = –3.46$, $p < .01$] and that medium-density patterns in turn were matched more often on the global level than were low-density patterns (M = .45, SE = .04) [$t(39) = –9.20$, $p < .01$]. This replicates the pattern observed by Kimchi and Palmer (1982) in their original task. *Pattern density* did not interact with *cognitive load* [$p > .1$; see Figure 8]; importantly, this illustrates that cognitive load did not affect the relationship between the density of the local elements and the likelihood that they would be matched according to their global structure.

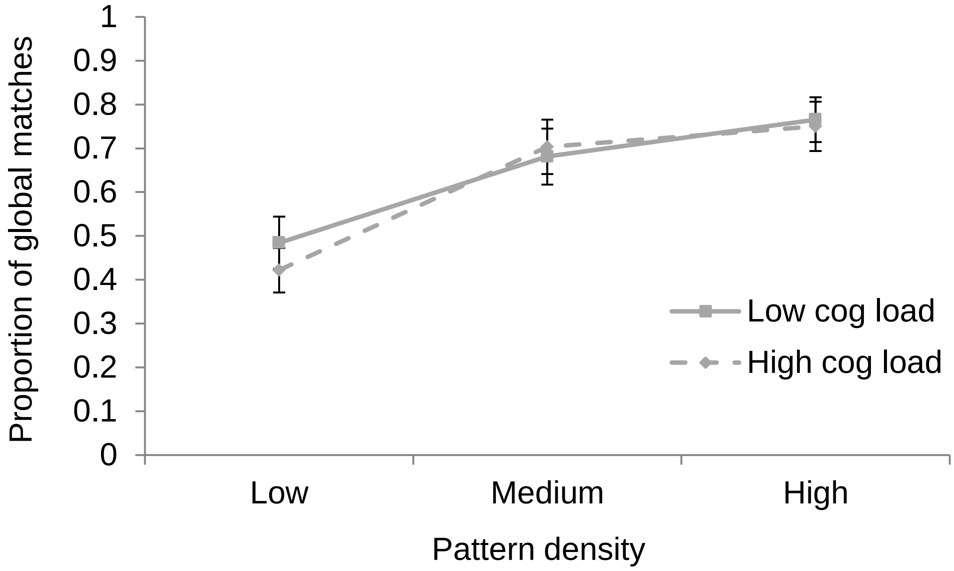



**Figure 8.** *Limited exposure-duration (Experiment 1). The proportion-of-global-matches made to hierarchical-patterns as a function of pattern-density under both low- and high-cognitive-load. Error bars represent one standard error of the mean.*

### 2.2.3 Discussion

Our data show that, when exposure durations were limited, local-global salience was the same for participants under low and high cognitive load. We concluded that cognitive load does not affect the initial representation of global structure. In Experiment 2, we investigated the effect that high cognitive load may have on local-global salience once the initial global salience has decayed.

## 2.3 Experiment 2

In this experiment, we investigated the effect of cognitive load on local-global salience when exposure durations are unlimited. We allowed participants to view stimuli for as long as they liked, by using unlimited exposure durations. If cognitive load always makes processing more global (Ahmed and de Fockert, 2012) then the global bias should increase and participants under high cognitive load should be more likely to match patterns according to their global structure than those under low cognitive load. However, if cognitive load affects relative hemispheric activation and weakens global salience (and enhances local salience), then we expect participants under high cognitive load to make *fewer* global matches than those under high cognitive load.

### 2.3.1 Method

2.3.1.1 Design

All variables remained the same as in Experiment 1 with the exception of *display time* which was removed as exposure durations were now unlimited. Additionally, we recorded reaction times (RTs) to address whether any observed effects were due to the length of the viewing time.

#### 2.3.1.2 Participants

A group of 40 new individuals (mean age 25.05 years; 31 female, 9 male) participated in the experiment and were reimbursed with £5. All of the participants reported having normal or corrected-to-normal vision. All participants were first year undergraduate students at Goldsmiths, University of London, UK. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

#### 2.3.1.3 Apparatus and stimuli

The stimuli and apparatus were identical to those in Experiment 1.

#### 2.3.1.4 Procedure

The procedure was identical to that of Experiment 1, with the exception that each stimulus triad was presented only once for an unlimited duration and only one block of 24 trials was presented. As with Experiment 1, participants in the high-cognitive-load condition were considered to have adequately recalled a digit string if at least five of the digits were recalled in the correct order.

### 2.3.2 Results

The cognitive-load task was adequately performed by all participants. The *proportion of global matches* on the matching task were analysed with a two-way mixed ANOVA with *pattern density* and *cognitive load* as the independent variables. A Bonferroni adjustment for multiple comparisons was applied to all post-hoc tests. A main effect of *cognitive load* [F(1, 38) = 5.49, $p < .05$, $\eta^2 = .13$] indicated that participants under high cognitive load made significantly fewer global matches (M = .41, SE = .07) than did those under low cognitive load (M = .62, SE = .06). *Cognitive load* did not interact with *pattern density* (see Figure 9).

A significant main effect of *pattern density* [F(2, 76) = 8.85, $p < .01$, $\eta^2 = .19$] demonstrated that significantly more global matches were made to the high (M = .58, SE = .05) [t(39) = –3.46, $p < .05$] and medium (M = .55, SE = .05) [$t$(39) = –3.49, $p < .05$] densities than to the low (M = .46, SE = .04) density. As with Experiment 1, the absence of an interaction between *pattern density* and *cognitive load* suggests that cognitive load did not affect the relationship between the density of a pattern and the likelihood that it would be represented according to its global structure.

It was important to establish that the effect of load on matching was not driven by differences in inspection times. We repeated the two-way mixed ANOVA using RTs as the dependent variable and found that RTs under low cognitive load (M = 1,352 ms, SE= 158.6) were statistically identical to those under high cognitive load (M = 1,366 ms, SE = 192.14); additionally, RTs did not interact with pattern density [$p > .1$].

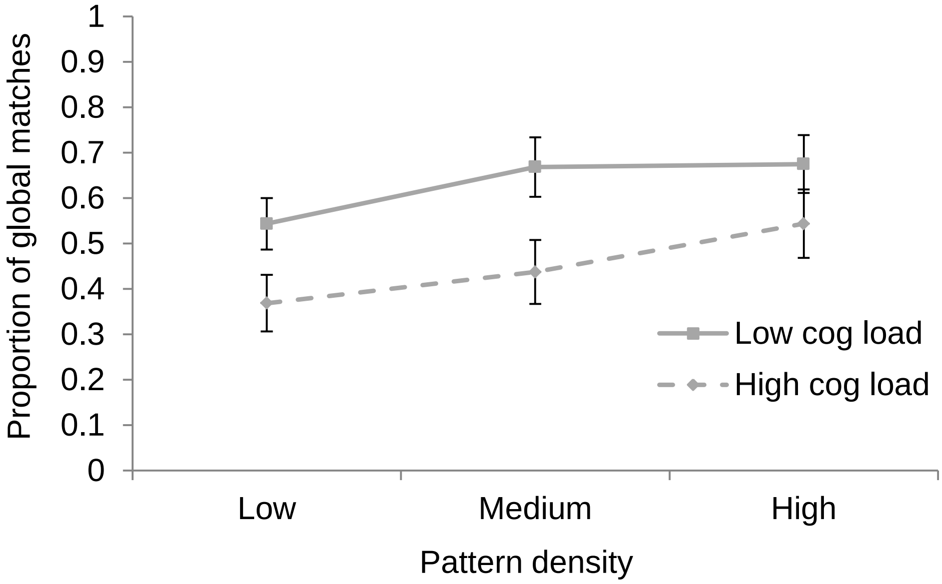



**Figure 9.** *Unlimited exposure-duration (Experiment 2). The proportion-of-global-matches made to hierarchical-patterns as a function of pattern-density under both low and high cognitive load. Error bars represent one standard error of the mean.*

### 2.3.3 Discussion

Experiment 2 illustrated that the extent of global salience demonstrated in Experiment 1 remained for participants under low cognitive load when exposure duration was unlimited. However, global salience was reduced, and local salience enhanced, when the task was performed under high cognitive load and exposures were unlimited. This does not support Ahmed and de Fockert's (2012) assumption that cognitive load should *always* make processing more global. Rather, it supports an account which suggests that cognitive load reduces global salience. We suggest that this could be due to an effect of cognitive load on relative hemispheric activation and the likelihood that information will be represented in terms of its global structure rather than local detail. In Experiment 3 we try to replicate this finding using a slightly different version of the hierarchical-patterns similarity-matching task.

## 2.4 Experiment 3

We wanted to replicate the observed effect of cognitive load in Experiment 2. Furthermore, the measure used in Experiment 2 required that participants compared a test pattern to two comparison patterns and it is possible that this was cognitively demanding and could have induced a cognitive load in itself. In Experiment 2 we showed that cognitive load enhances local salience and it is possible that the higher cognitive load of the task may have meant that patterns were matched at the global level less often than would be expected if the measure were less demanding. Therefore, in Experiment 3 we simplified the measure of hierarchical perceptual bias. We expected cognitive load to reduce global salience (and enhance local salience) but predicted that a higher proportion of global matches would be made overall in comparison to Experiment 3.

## 2.4.1 Method

### 2.4.1.1 Participants

36 participants (mean age 24.9 years; 27 females, 9 males) took part in the study. They were first-year undergraduate psychology students at Goldsmiths, University of London, UK, and participated in exchange for course credit. All of the participants reported having normal or corrected-to-normal vision. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

### 2.4.1.2 Design

The design was identical to that in Experiment 2.

### 2.4.1.3 Apparatus and stimuli

The apparatus and stimuli were the same as those used in Experiments 1 and 2. However, stimuli were now presented on their own instead of as part of a stimulus triad. Furthermore, we presented only incompatible stimuli (see Figure 10).

#### 2.4.1.4 Procedure

The procedure was similar to that in Experiments 1 and 2. Participants were seated 60 cm from a computer screen (maintained using a chinrest) and had to indicate their response with a key-press. However, this time the task was to indicate whether 'square' or 'triangle' best described their first impression of the pattern. As the local and global level of the patterns was always incompatible, responses were taken as an indication of which level was most salient. As with Experiments 1 and 2, participants performed the task whilst remembering either one (low cognitive load) or six (high cognitive load) digits. The digit(s) were presented (simultaneously) for 3,000 ms, followed by a blank screen for 1,000 ms, at the beginning of the block; each trial began with a 1,000-ms fixation cross before the stimulus was presented, centred on fixation, for an unlimited duration. The stimulus disappeared from the screen when the participant made their response and was replaced with a fixation cross beginning the next trial. At the end of the block, participants were asked to type in the digit(s) that they had been remembering; for the high-cognitive-load manipulation, the digits were to be recalled in serial order, and participants were considered to have adequately recalled the digit string if at least five digits were recalled in the correct order. As participants were to judge either 'square' or 'triangle', only incompatible patterns (where it was possible for this choice to be made) were included in the task, meaning that the procedure contained only 6 unique trials. These were presented twice, totalling 12 trials.

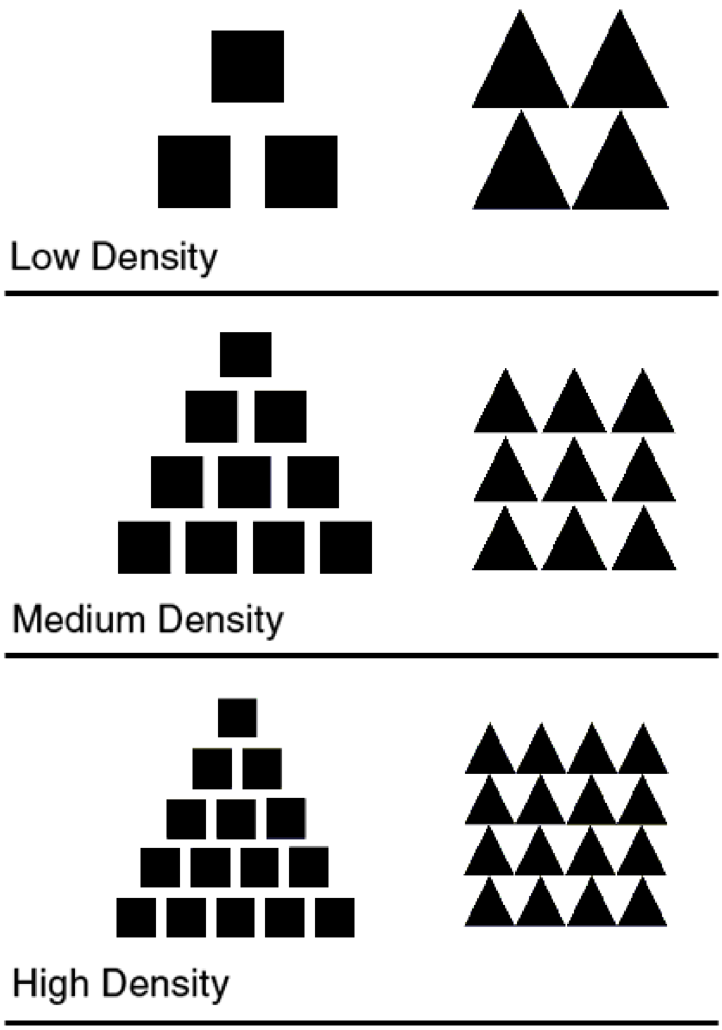



**Figure 10.** *An illustration of the hierarchical patterns used in Experiment 3 (replicated from Kimchi and Palmer, 1982).*

### 2.4.2 Results

All participants adequately performed the cognitive load task, and so data from all participants were entered into the analysis. Data were analysed with a mixed ANOVA, with *pattern density* (*low*, *medium* and *high*) as the within-subjects variable and *cognitive load* (*low* vs. *high*) as the between subjects variable. The dependent variable was *proportion of global matches*, and reflected the proportion of times that participants responded to the patterns in accordance with its global structure. As in Experiments 1 and 2, there was a main effect of *pattern density* [$F(2, 68) = 7.28$, $p < .01$, $\eta^2 = .18$]. Medium-density patterns ($M = .74$, $SE = .07$) were matched significantly more globally than low-density patterns ($M = .59$, $SE = .07$) [$t(35) = -3.22$, $p < .05$]; however the global matches made to high-density patterns ($M = .77$, $SE = .06$) were not significantly greater than those made to medium-density patterns [$p > .1$]. Again, *pattern density* did not interact with *cognitive load* [$p > .1$; see Figure 11].

There was a main effect of *cognitive load* [$F(1, 34) = 4.69$, $p < .05$, $\eta^2 = .12$], indicating that significantly fewer global matches were made under high cognitive load than under low cognitive load (see Figure 12).

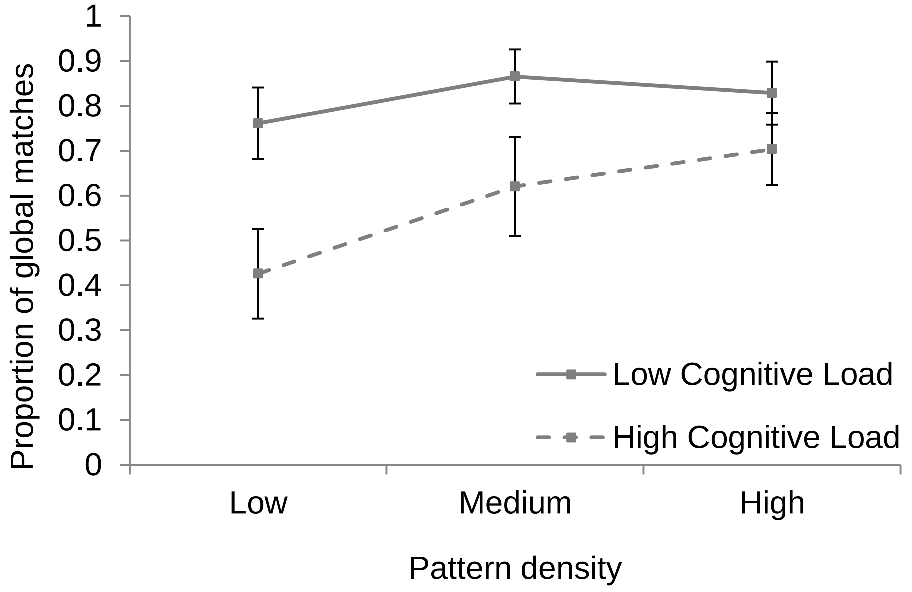



**Figure 11.** *Unlimited exposure-duration with single patterns (Experiment 3). The proportion of global matches made to hierarchical-patterns as a function of pattern-density under both low and high cognitive load. Error bars represent one standard error of the mean.*

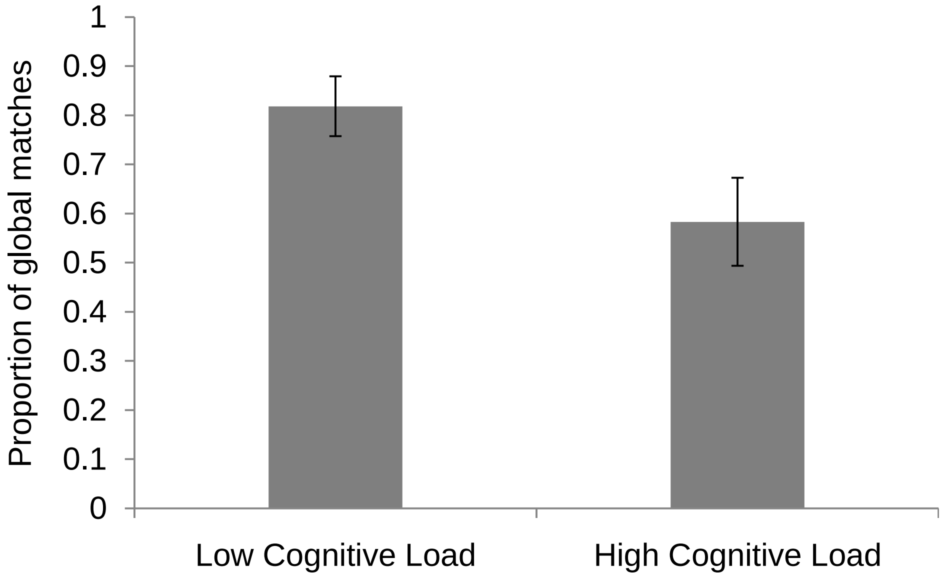



**Figure 12.** *Unlimited exposure-duration with single patterns (Experiment 3). The proportion of global matches made to hierarchical-patterns under both low and high cognitive load. Error bars represent one standard error of the mean.*

### 2.4.3 Discussion

In the present experiment, we again demonstrated that cognitive load enhances the salience of local elements and decreases the salience of global structure, meaning that the proportion of global matches decreases under high cognitive load. Interestingly, overall global matches are higher than those in Experiments 1 and 2 for both low and high cognitive load. This could be because the demands associated with this measure were less than those associated with the standard similarity-matching measure utilised in Experiments 1 and 2. Interestingly, the drop in the proportion of global matches under high compared to low cognitive load in the present experiment was roughly the same as in Experiments 1 and 2 (about 20 percentage points). We suggest that high cognitive load weakens global salience (at unlimited exposure durations) but that global salience may ultimately be stronger than local salience if global salience is very strong to begin with.

## 2.5 Discussion of Chapter 2

The present chapter explored the effect of cognitive load on perceptual bias and considered the mechanisms that could underlie its effects. We used a matching task that directly probed whether observers were more likely to represent hierarchical patterns in terms of their local elements or global structure. We report that global salience was equally strong for participants under both low and high cognitive load at limited exposure durations (Experiment 1). When exposure durations were unlimited, however, high cognitive load reduced the global bias and was associated with a decrease in global salience and an increase in local salience (Experiments 2 and 3). Our data do not support the idea that cognitive load causes a “shift towards global processing” (Ahmed & de Fockert, 2012) that is associated with enhanced global salience. Instead, our findings suggest that cognitive load reduces the likelihood that hierarchical information will be interpreted in terms of its global structure over its local detail. As real-world perception does not result from a series of limited exposure durations, we argue that our findings from Experiments 2 and 3 could be more representative of how cognitive load affects local-global salience in real-world vision; we suggest that high cognitive load could fundamentally affect how hierarchical information is prioritised by making it more likely that we will see ‘eyes’ instead of a ‘two fireflies’ or the ‘trees’ instead of the ‘forest’.

We have outlined two possible effects that cognitive load might exert on local-global salience via effects on perceptual bias. Firstly, Ahmed and de Fockert’s (2012) conclusion that high cognitive load causes the attentional window to defocus might suggest that high cognitive load should increase the weight given to global structure over local detail; this would enhance global salience and significantly increase the proportion of global matches made in the similarity-matching paradigm. We did not find any evidence in favour of this account and therefore cannot support the assertion that high cognitive load *always* enhances processing of global information. The second possibility follows on from the work of Helton et al. (2010). Cognitive load (as a task-difficulty effect) could affect relative hemispheric activation and thus affect the relative priority given to local and global information. Importantly, according to this account cognitive load should reduce the perceptual bias towards global structure and enhance local salience. This is indeed what we found in Experiments 2 and 3, where significantly fewer global matches were made under high cognitive load than low cognitive load.

A schematic representation of our hemispheric-activation account can be seen in Figure 13. When the task is easy – such as under low cognitive load – the global-dominant right hemisphere should be relatively more active than the local-dominant left and thus a perceptual bias towards global structure should be observed. Under high cognitive load, however, activation should become bilateral as a result of performing a secondary (cognitive-load) task (Helton et al., 2010). Thus, under high cognitive load, both hemispheres should be equally active and local detail should be more salient than under low cognitive load.

Increasing local salience with cognitive load was exactly what we found when we presented hierarchical patterns for an unlimited duration; however, we did not see any effect of cognitive load when we presented patterns for a limited duration. Global salience is strongest when patterns are presented very briefly (e.g., Paquet & Merikle, 1984). We suggest that the sudden onset of a hierarchical pattern meant that global salience was strong enough to compensate for the effect of cognitive load on relative hemispheric activation. Thus, the effect of cognitive load on relative hemispheric activation was not observable at limited exposure durations. Once however the initial global salience due to common onset had decayed, the effect of cognitive load on perceptual bias became apparent. Because real-world vision does not usually result from a series of briefly-presented stimuli, we suggest that unlimited-exposure measures are better than limited-exposure ones for addressing the extent of perceptual bias. From this point on, our discussion focuses on our data from Experiments 2 and 3 with unlimited exposure durations.

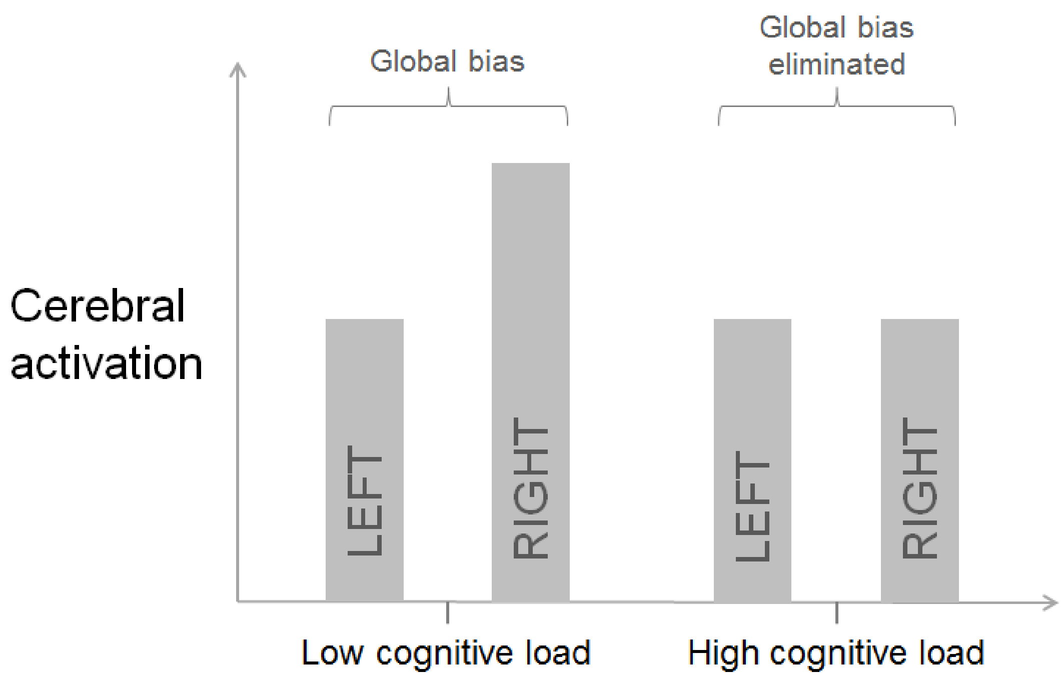



**Figure 13.** *Schematic representation of hemispheric activation under low and high cognitive load. Right hemispheric activation is higher than left hemispheric activation under low cognitive load but under high cognitive load right hemispheric activation is reduced and left-right cerebral activation is equal. When exposure durations are unlimited, under low cognitive load we should see a global bias, whereas under high cognitive load we should see a reduction in global bias.*

Our explanation of the data suggests that cognitive load should always enhance the salience of local information. However, whether global structure or local detail is ultimately most salient is still dependent on stimulus-driven factors such as goodness of form; a particularly good Gestalt will have stronger global salience than a grouping with a bad Gestalt, regardless of perceptual bias (that is, the tendency to prioritise global structure over local detail; Figure 14 depicts this schematically with respect to our unlimited-exposure data from Experiment 2). This has important implications for the use of the phrase ‘perceptual bias’ when describing the extent to which global structure is prioritised over local detail. Findings from similarity-matching paradigms are often interpreted as reflecting absolute perceptual bias: over 50% global matches are often assumed to reflect a global bias whereas fewer than 50% global matches are said to reflect a local bias. However, matching patterns with poor global form less than 50% of the time at the global level does not necessarily indicate an absolute local bias; rather, it may simply reflect the fact that stimuli with poor form have weak global salience. We move on now to illustrate this issue with respect to our findings from Experiments 2 and 3.

In Experiment 2, when our data were collapsed across pattern density, global salience was stronger than local salience under low cognitive load (~60% global matches) but local salience was stronger than global salience under high cognitive load (~40%). If we had (misguidedly) assumed that absolute perceptual bias is reflected in fewer or greater than 50% global matches then we might have concluded that participants showed a global bias under low cognitive load but a local bias under high cognitive load. In Experiment 3, however, patterns were matched at the global level approximately 80% of the time under low cognitive load and approximately 60% of the time under high cognitive load. Now, if we (misguidedly) assumed that perceptual bias is reflected in fewer or greater than 50% global matches, we might have concluded that participants showed a global bias under both low and high cognitive load.

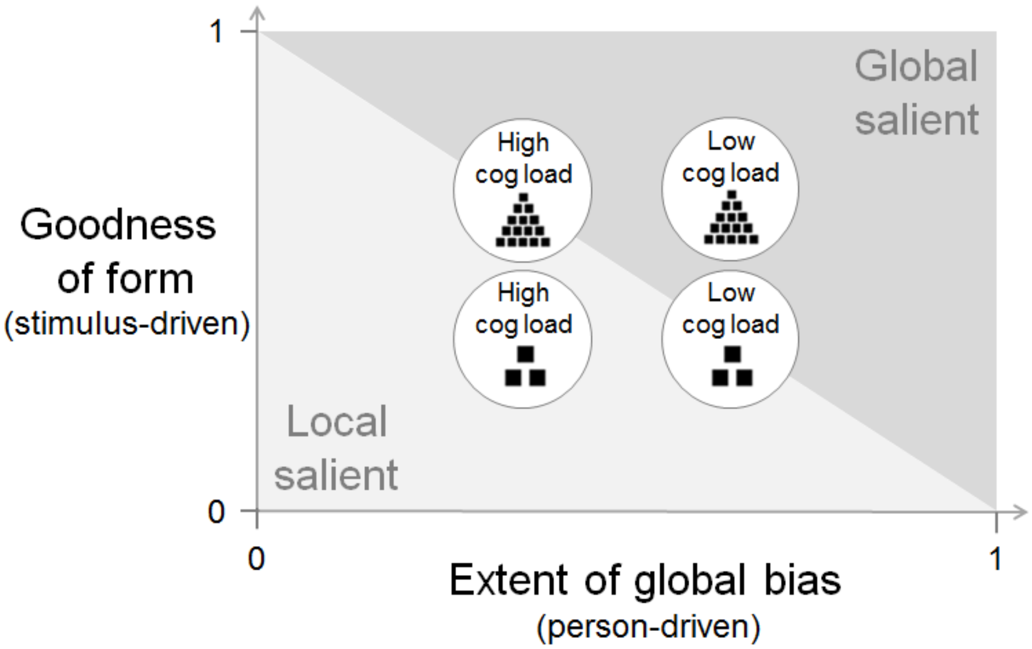



**Figure 14**. *An illustration of how local-global salience is influenced by both person-driven perceptual bias and stimulus-driven determinants of local-global salience. Here, high cognitive load reduces global salience, but local-global salience is still influenced by pattern-density.*

Therefore, it is important to avoid the temptation of referring to 'local bias' or 'global bias' in absolute terms. Rather, it is necessary to speak in relative terms; for example, when describing the effect of cognitive load on perceptual bias we could say that cognitive load reduces the number of global matches, and by implication the extent to which global structure is prioritised over local detail. Alternatively it is possible to speak in terms of local-global salience. For example, for both Experiments 2 and 3 we can say that cognitive load reduced global salience and enhanced local salience. The emphasis on salience also allows us to make cross-experimental comparisons when using the same stimuli. For example, we can say that cognitive load reduced global salience and enhanced local salience in both Experiments 2 and 3 but that global salience was stronger overall in Experiment 3 than in Experiment 2.

The difference in local-global salience seen between Experiments 2 and 3 shows that even slight variations in measures of hierarchical processing can affect local-global salience. There are several reasons why this could have been the case. It is possible that participants in Experiment 3 were simply more likely to represent patterns in terms of their global structure than local detail than participants in Experiment 2. Indeed, participants in Experiment 2 were first year undergraduate students from a mixture of study programmes at an arts university, whereas participants in Experiment 3 were first-year psychology undergraduates. It is possible that the different content of these study courses could encourage different processing styles (or, conversely, could attract individuals with different processing styles). Research has suggested that artists process visual information more holistically than scientists (Blazhenkova & Kozhevnikov, 2010) and thus we might expect students of psychology, which has a large scientific component, to match patterns at the global level *less* than students from arts programmes; however, we demonstrated that our psychology undergraduate participants in Experiment 3 matched patterns at the global level *more* than the mixed-programme participants in Experiment 2. This suggests that differences in matching between participants in Experiments 2 and 3 were unlikely to be due to differences in scientific/artistic processing style. However, it is possible that the two groups of participants could have by chance differed on traits known to influence local-global matching, such as culture (Davidoff et al., 2008).

There could also have been paradigmatic reasons for their differences in matching behaviour. For example, matching a test stimulus with one of two comparison stimuli in Experiment 2 may have been more cognitively demanding than responding to a single pattern presented in isolation in Experiment 3. Thus, asymmetric hemispheric activation in Experiment 2 may not have been as pronounced under low cognitive load as it was in Experiment 3 with the result that local salience was stronger in the former experiment than it was in the latter. Encouragingly, regardless of the salience of local-global information in Experiments 2 and 3, cognitive load caused the likelihood that patterns would be matched at the global level to reduce by the same magnitude of twenty percentage points. Thus, although it is possible that individual differences could affect baseline local-global salience, the effect of cognitive load on local-global salience is constant.

The present discussion has highlighted the problems with using the term 'perceptual bias' when trying to describe an absolute tendency for individuals to prioritise global structure or local detail. It is intuitive by appealing to suggest that a default state exists that dictates whether individuals prioritise local or global information. However, local-global salience is dependent on stimulus-driven and paradigm-driven factors as well as person-driven ones. Thus, in this thesis we use the term perceptual bias only in relative terms (for instance, increasing cognitive load reduces the likelihood that hierarchical information will be interpreted in terms of its global structure) and refer to local-global salience when speaking in absolute terms.

In the General Introduction, we suggested that local-global salience should also determine how well local and global level information can be selected in a selective-attention task. This is an intuitively appealing suggestion as stronger global than local salience, for example, should make the global structure more accessible than the local detail. Conversely, stronger local than global salience should make local detail more accessible than global structure. We have suggested that cognitive load should make it more difficult to ignore irrelevant yet salient hierarchical information. Crucially, we suggest that the effect of high cognitive load on selection of hierarchical information should depend on whether local detail or global structure is most salient: high cognitive load will make it difficult to ignore global information if global salience is strong and difficult to ignore local detail if local salience is strong. In the following chapters we address the issue of selection, and explore the extent to which cognitive load affects the ability to select behaviourally-relevant hierarchical information.

The experiments presented in this chapter have shown that high cognitive load can enhance local salience (and reduce global salience) when exposure durations are unlimited. Thus in Experiments 4 and 5 (presented in Chapter 3) we run a selective-attention version of the hierarchical-patterns task (Navon, 1977) to test this assumption and use exposure-duration as a manipulation of local-global salience. In Experiment 1, we showed that global salience was stronger than local salience under both low and high cognitive load when exposure durations were limited. However, in Experiments 2 and 3, we showed that cognitive load reduced global salience and enhanced local salience when exposures were unlimited. We would then expect cognitive load to make it more difficult to ignore salient global information at limited exposure durations but harder to ignore salient *local* information at unlimited exposure durations.

In conclusion, the experiments reported in the present chapter have shown that high cognitive load can enhance the salience of local detail. We appeal to a hemispheric-activation account and suggest that hemispheric activation is asymmetric under low cognitive load – and favours global structure – but is bilateral under high cognitive load. This means that local detail is more salient under high than low cognitive load. We saw this effect only when exposure durations were unlimited; when exposure durations were limited, cognitive load had no effect on global salience. This illustrates the importance of accounting for exposure duration when drawing conclusions about the effect of cognitive load on perceptual bias. In the following chapters, we investigate the extent to which cognitive load affects attentional selection. We also explore the extent to which the effect of cognitive load on selection is influenced by stimulus-driven salience, and discuss whether the effect of cognitive load on perceptual bias can influence attentional selection.

# CHAPTER 3 - SELECTIVE ATTENTION TO HIERARCHICAL PATTERNS

## 3.1 Introduction

It has been suggested that cognitive load will always benefit global processing (Ahmed & de Fockert, 2012). The present thesis explores this assertion in more depth and distinguishes between the effect that cognitive load has on perceptual bias and its effect on attentional selection. We explored the effect of cognitive load on perceptual bias in a series of experiments reported in Chapter 2 and showed that participants under high cognitive load were *less* likely to match patterns according to global structure than were participants under low cognitive load (but only when exposure durations were unlimited). This suggests that cognitive load enhances local salience (and reduces global salience) and does not support the assumption that cognitive load should *always* enhance global processing. In the present chapter we explore the effect of cognitive load on selection. Ahmed and de Fockert (2012) showed that cognitive load increased interference from global structure on a local-selection task and reduced interference from local detail on a global-selection task. They took this to mean that cognitive load enhanced global processing. However, we suggest that this effect was due to the strong global salience of their experimental stimuli. This being the case, when local salience is strong, high cognitive load should *impair* global selection; indeed, in line with our findings presented in Chapter 2, cognitive load may even increase local salience and make it more difficult to ignore salient local detail in a global-selection task. In the present chapter, we explore the effect that cognitive load might have on the selection of hierarchical information and set out to demonstrate that high cognitive load can increase interference from *local* information when local salience is strong.

To explore the effect of cognitive load on selection of hierarchical information we used the original – and probably most widely used – measurement of the ability to select hierarchical information, the selective-attention hierarchical-patterns task (Navon, 1977). Attention can be flexibly deployed to local detail or global structure depending on task demands (Treisman, 2006); sometimes it may be important to process the scene as a whole while at other times analysis of local detail may be more appropriate. The selective-attention hierarchical-patterns task provides an indication of how well local and global information can be selected in the face of competing hierarchical information.

Navon (1977) was interested in whether, despite a preference for global form, participants would be able to voluntarily direct their attention toward either the local or global level of a hierarchical pattern and ignore competing information from the unattended level. To test this, he developed the selective-attention hierarchical-patterns task which measures responses to either the local or global level of hierarchical patterns (Experiment 3 in Navon, 1977, is the best example of the sort of task that is popular now). As previously described in the General Introduction, the logic of the selective-attention hierarchical-patterns task was that if participants are distracted by information at the unattended level, then responses to the target level will be interfered with. Specifically, responses will be slower when information at the unattended level is response-incompatible compared to response-compatible. Two key findings emerged from Navon’s study. Firstly, overall latencies to global targets were faster than to local targets. Secondly, responses to local elements were significantly slowed when incompatible information was present at the global level, while responses to global targets were unaffected by the identity of local elements. These two findings were taken to support the idea that global-level information has a processing advantage over local detail. These observations have been referred to collectively as a ‘global advantage’ (Kimchi, 1992).

The selective-attention version of the hierarchical-patterns task was recently used to show that high cognitive load increases interference from irrelevant global information and decreases interference from irrelevant local information (Ahmed & de Fockert, 2012); this was interpreted as cognitive load always enhancing the global advantage in a hierarchical-patterns task. We have discussed this finding in the General Introduction but will briefly review Ahmed and de Fockert’s task here. Participants performed a selective-attention version of the hierarchical-patterns task (Navon, 1977) and, in separate blocks, had to indicate the identity of the local elements in the local task or the global structure in the global task. The task was performed under either low cognitive load (remember one digit while performing the selection task) or high cognitive load (remember six digits) and stimuli were presented for a limited duration (250 ms). Ahmed and de Fockert found that, under high cognitive load, participants experienced increased interference from global information on a local-selection task and decreased interference from local information on a global-selection task. Ahmed and de Fockert invoked the finding that cognitive load causes the perceptual resources involved in spatial attention to spread or defocus (Caparos & Linnell, 2010; Linnell & Caparos, 2011) and concluded that cognitive load invariably spreads attention and thus makes people more global.

However, it is unsurprising that Ahmed and de Fockert (2012) observed a “shift towards global processing under [high cognitive] load” as they used stimuli in which global salience was stronger than local salience, evidenced by the fact that participants responded to global structure more quickly than they responded to local detail. In general, high cognitive load makes it more difficult to maintain behavioural goals and increases the processing of irrelevant information (e.g., Lavie et al., 2004) and thus it is likely that cognitive load made it more difficult to ignore the salient global level of representation in Ahmed and de Fockert’s study. However, if stimuli have strong *local* salience, we predict that the opposite pattern of performance should be observed and cognitive load should make it more difficult to ignore salient local information when performing a global-selection task.

Indeed, there is evidence to suggest that it may be cognitively demanding to attend to the global level of a hierarchical pattern when global salience is weaker than local salience. Helton, Hayryen and Schaeffer (2009) ran a divided-attention hierarchical-patterns task (Navon, 1977) in which participants had to monitor a stream of briefly presented hierarchical patterns and indicate, with a button press, when a target appeared at either the global level or the local level. They also recorded tympanic membrane temperature (TMT), a physiological measure of cognitive fatigue which increases as cortical activation decreases. In the behavioural task, participants were faster to respond to local than global targets, which suggests that local detail was more salient than global structure. The physiological measure also showed elevated right hemisphere TMT, indicative of cognitive fatigue, but only when responding to global-level information. Responding to a local-level target, however, had no physiological effect. This was taken to reflect an increase in cognitive fatigue as a result of sustained attention *only* to the global level. We suggest that right hemisphere cognitive fatigue may be the result of attending to the less salient global structure whilst ignoring the more salient local detail. If this is the case, then this evidence suggests that it may be cognitively-demanding to ignore local detail when it is more salient than global structure.

In the General Introduction, we discussed a host of stimulus-driven factors that have been shown to affect global salience (as summarised by Kimchi, 1992) and in Chapter 2 we presented a series of experiments to demonstrate the extent to which one of these factors – exposure duration – could influence the effect that cognitive load has on the salience of local and global information. In the present chapter, we present two experiments in which we explore whether the effect of cognitive load on local-global salience will 'feed into' the effect of cognitive load on attentional selection with the aim of demonstrating that cognitive load can cause a shift towards local processing when local salience is strong. In Experiments 1-3 (presented in Chapter 2) we provided evidence to suggest that exposure duration impacts the effect of cognitive load on local-global salience and we considered the possibility that we could use exposure duration and cognitive load to manipulate local-global salience on a selective-attention hierarchical-patterns task[1].

In Experiment 1 – the limited-exposure hierarchical patterns task – it was shown that global information was more salient than local information in medium-density patterns (~60% global matches overall) when stimuli were presented for a limited duration, under both high and low cognitive load. In Experiment 2 we then demonstrated that high cognitive load reduced global salience (and increased local salience) when stimuli were presented for an unlimited duration; now, local detail was more salient than global structure under high cognitive load (~40% global matches) whereas global information remained more salient than local information under low cognitive load (~60% global matches).Thus, our data from Experiments 1 and 2 (described in Chapter 2) suggest that global salience is strong under both low and high cognitive load at limited exposure durations but that *local* salience is strong under high cognitive load at unlimited exposure durations (while global information remains salient under low cognitive load;

[1] The reader is reminded that we ran an unlimited-exposure similarity-matching paradigm in both Experiments 2 and 3 and found that global salience was weaker overall in Experiment 2 than in Experiment 3. In the discussion to Chapter 2 we suggested that this was because task demands were higher in Experiment 2 than Experiment 3 and thus local salience was stronger in the former than in the latter. Task demands in a selective-attention hierarchical-patterns task should be higher than in Experiment 3 and therefore we predict that local-global salience in a selective-attention hierarchical-patterns task will be more comparable to local-global salience in Experiment 2 than in Experiment 3. Thus, from here on we discuss local-global salience of hierarchical patterns with respect to the findings from Experiment 2.

Figure 15 illustrates the hypothesised global salience under low and high cognitive load at limited and unlimited exposure durations). Thus, we reasoned that we could use exposure duration to manipulate global salience in medium-density patterns under high cognitive load in a selective-attention hierarchical-patterns task; at limited exposures we should see a global advantage under high cognitive load but at unlimited exposures we should see a *local* advantage under high cognitive load. High cognitive load should then make it more difficult to ignore global information on a local-selection task at limited exposure durations but more difficult to ignore *local* information on a global-selection task at unlimited exposure durations. This would demonstrate that the effect of cognitive load on local-global salience (reported in the experiments presented in Chapter 2) would then influence the effect of cognitive load on selection of hierarchical information.

We ran a selective-attention version of the hierarchical-patterns task (Navon, 1977) with an added cognitive load manipulation and presented stimuli for either a limited (Experiment 4) or unlimited (Experiment 5) duration. We chose to use the medium-density patterns from Chapter 2 as our experimental stimuli, for the reasons just discussed. We also chose this density of pattern so that we could make cross-experimental comparisons between the experiments detailed in Chapter 2 (Experiments 1 and 2) and the experiments detailed in the present chapter.

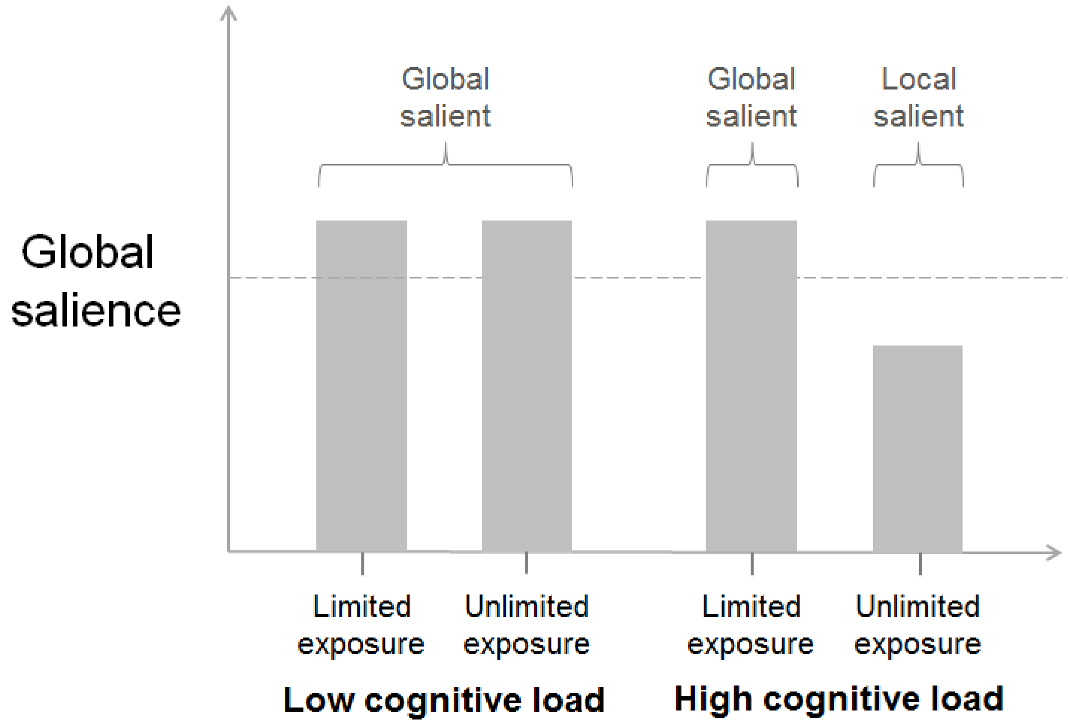



**Figure 15.** *Schematic representation of global and local salience under low and high cognitive load at limited and unlimited exposure durations for medium-density patterns reported in Experiments 1 and 2. The dotted line marks the point at which local and global information is equally salient.*

In the present experiments, we aim to show that high cognitive load does not always make processing more global but can in fact impair global selection if local detail is sufficiently salient. We predicted that a slight global advantage should be observed under low and high cognitive load at limited exposure durations as global information should be more salient than local information (Experiment 4). Given a global advantage, high cognitive load should make global information more difficult to ignore and interference from irrelevant global structure on a local-selection task should increase (as was observed by Ahmed and de Fockert, 2012, when using stimuli with strong global salience). At unlimited exposures, however, a local advantage should be seen under high cognitive load (Experiment 5). Under these circumstances, high cognitive load should make it more difficult to ignore the salient local detail and interference from local information on a global-selection task should increase.

## 3.2 Experiment 4

In the present experiment we used a variant of the original – and most widely-used – version of the hierarchical patterns task (Navon, 1977). This task was designed to measure the ability to selectively attend to either local elements or global structure. We presented the patterns for a limited exposure duration with a cognitive load manipulation.

### 3.2.1 Method

#### 3.2.1.1 Participants

66 participants (mean age 19 years; 50 females, 16 males) were all first-year-undergraduate psychology students and participated in exchange for course credit. Testing took place in a series of undergraduate lab classes and thus participant numbers were dictated by class attendance. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

3.2.1.2 Design

The within-subjects variables were *task* (*local* vs. *global* selection) and *compatibility* (*compatible* vs. *incompatible*). The between-subjects variable was *cognitive load* (*low vs. high*; remember one digit vs. six digits). The order in which the tasks were performed was counterbalanced across participants; half performed the local selection task before the global task and the other half performed the global selection task before the local task. Participants had to response as quickly but as accurately as possible to a series of hirarchical patterns: the dependent variables were *reaction time* (RT) and *accuracy*.

3.2.1.3 Apparatus and stimuli

The experiment was developed using E Prime version 1.2 and was presented on a Sharp LL-172A-B LCD monitor in a dimly-lit room. Stimuli were identical to the medium-density patterns that we used in Experiments 1-3 (see Figure 16). We replicated the hierarchical patterns developed by Kimchi and Palmer (1982) using Adobe Photoshop CS2. Patterns were small black triangles or squares configured to form large triangles or squares; the large shape could be either compatible (e.g., a large square formed of small squares) or incompatible (e.g., a large square formed of small triangles) with the small shapes (see Figure 16). There were 4 unique hierarchical patterns and each subtended approximately 2.4° of visual angle. Small squares subtended 0.8° and small triangles 0.7°. Stimuli were presented on a white background and were viewed from a distance of 60 cm.

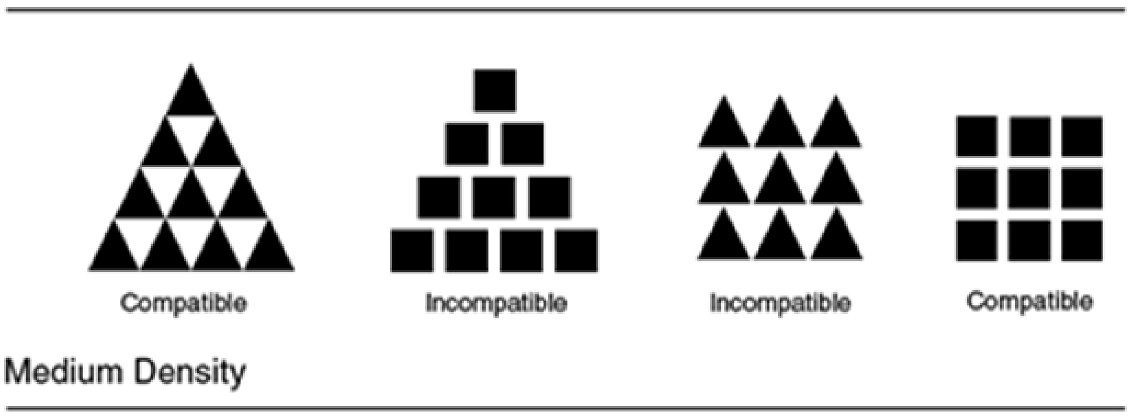



**Figure 16**. *An illustration of the medium-density hierarchical patterns used in the present experiment (recreated from Kimchi & Palmer, 1982).*

3.2.1.4 Procedure

Participants were seated so that their eyes were 60 cm from the screen and they placed the index finger of each hand on the ‘c’ and ‘m’ keys of a QWERTY keyboard. They were then presented with on-screen instructions about the task that they were about to perform. For the local task, they were informed that they were to indicate whether the *small* shapes were squares or triangles, whereas, for the global task, they were to indicate whether the *large* shape was a square or a triangle. Participants were asked to respond quickly but to keep their responses as accurate as possible. They were then presented with 8 practice trials in which each of the four hierarchical patterns was presented three times. Stimuli were presented in a random order. After the practice block had finished participants were given the opportunity to tell the experimenter if anything was unclear.

This experiment required the task to be performed whilst remembering either one (*low cognitive load*) or six (*high cognitive load*) digits. On completion of the practice trials, participants were informed that they would be shown either one (for those in the *low cognitive load* condition) or six (*high cognitive load* condition) digits at the beginning of the main task. They were told that they would have to remember this/these whilst performing the trials, before typing them in when prompted to do so. The order in which the local and global tasks were performed was counterbalanced, so that half of the participants performed the local task first and the other half performed the global task first.

The structure of the limited-exposure task can be seen in Figure 17. Each block of trials began with the presentation of either one digit (*low cognitive load* task) or six digits (*high cognitive load* task) for 2500 ms. A block of trials then began. Each trial ran as follows. A fixation cross was presented for 1000 ms before presentation of a hierarchical pattern for 250 ms. This was then replaced with a blank screen which remained until participants made their response. The fixation cross appeared once again and the trial procedure was repeated. To increase location uncertainty, each of the 4 unique patterns were presented in three different locations: once in the centre of the screen, once 1.7° above centre along the vertical midline and once 1.7° below centre along the vertical midline. Each of the four unique patterns in each of the three locations was presented three times per block. Four blocks of trials were presented per task, meaning that each of the four unique patterns in each of the three locations was presented twelve times per task. This is comparable with trial numbers in other speeded-response experiments in our laboratory, to allow for cross-experimental and cross-paradigmatic comparisons. After all 36 trials in the block had been completed participants were asked to type in the digit(s) that they had been rehearsing since the beginning of the block. After four blocks had been completed, participants were then presented with instructions for the second task (global if the first task was local, or local if the first task was global) and given an opportunity to practice before the experimental trials proper were presented. Participants then completed four blocks of the second task.

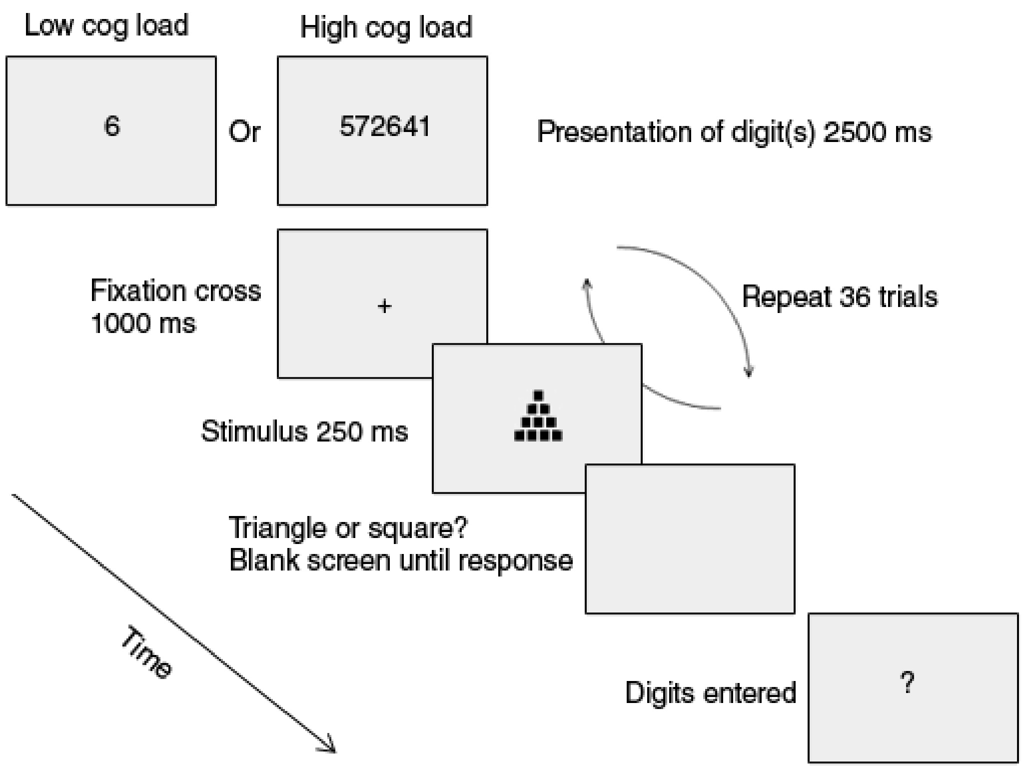



**Figure 17.** *Schematic representation of a single block of trials in the limited-exposure hierarchical-patterns task (Experiment 4). There were four blocks of 36 trials for the local task and four for the global task, making eight blocks in total.*

### 3.2.2 Results

Participants were included in the analysis if they accurately recalled the single digit in the low cognitive load condition or five out of six digits, in the correct order, in the high cognitive load condition. Blocks of trials were excluded from the final analysis if the participant failed to adequately recall the cognitive load associated with that block. If participants correctly recalled digits in less than 50% of the blocks, their data were excluded from the final analysis. Data were also excluded from the analysis if participants achieved below 75% accuracy on either the local or the global task overall. In total, the data from nine participants were excluded in accordance with these criteria: four from the low cognitive load condition and five from the high cognitive load condition. In total the data of 57 participants were entered into the final analysis.

We excluded the first trial for each participant from the final analysis as we have previously seen that participants are much slower to respond to this trial than the following trials. Furthermore, instead of using raw RT or accuracy as dependent variables we used *inverse efficiency* as our dependent variable. Inverse efficiency scores are calculated by dividing mean reaction time by the mean accuracy for that condition (Townsend & Ashby, 1983; mean RTs and accuracy can still be seen in Table 2) and are a way of combining RT and accuracy into a single DV. This can help control for the possibility of a speed-accuracy trade off. This is especially important when considering the effect of cognitive load on performance of a task, as cognitive load has been shown to both increase RTs and reduce accuracy in response (ref) and inverse efficiency allows us to account for both of these possible effects in a single DV. We calculated efficiency scores for each level of factor that was entered into the analysis.

**Table 2**. *Mean reaction times and accuracy for responses in Experiment 4.*

| | | | Local task | | Global task | |
|---|---|---|---|---|---|---|
| | Reaction time | | Comp | Inc | Comp | Inc |
| Limited Exposure | Low cognitive load | *M* | 485.64 | 514.83 | 500.02 | 551.25 |
| | | *SE* | *17.07* | *18.72* | *16.94* | *17.53* |
| | High cognitive load | *M* | 485.93 | 513.2 | 477.76 | 522.7 |
| | | *SE* | *13.09* | *14.97* | *11.95* | *12.17* |
| | Accuracy | | | | | |
| Limited Exposure | Low cognitive load | *M* | .96 | .93 | .97 | .91 |
| | | *SE* | *0.01* | *0.01* | *0.01* | *0.01* |
| | High cognitive load | *M* | .97 | .93 | .97 | .91 |
| | | *SE* | *0.0* | *0.01* | *0.01* | *0.01* |

Data were entered into a three-way mixed-subjects ANOVA with *task* (*local* vs. *global*) and *compatibility* (*compatible* vs. *incompatible*) as the within-subjects factors and *cognitive load* (*low* vs. *high*) as the between-subjects factor. Inverse efficiency was the dependent variable. Descriptive statistics can be seen in Figure 18a.

There was a significant main effect of *task* [$F(1, 55) = 8.08$, $p < .01$, $\eta^2 = .04$], surprisingly in the direction that participants were significantly quicker to respond to the local elements [$M = 528.4$ ms, $SE = 10.81$] than global structure [$M = 548.4$ ms, $SE = 10.48$] of the hierarchical patterns used in this task. The main effect of *compatibility* [$F(1, 55) = 178.26$, $p < .001$, $\eta^2 = .76$] replicates the standard finding that responses to incompatible stimuli [$M = 572.63$ ms, $SE = 10.81$] are slower than those to compatible stimuli [$M = 504.18$ ms, $SE = 10.48$]. Furthermore, the interaction between *task* and *compatibility* was highly significant [$F(1, 55) = 22.11$, $p < .001$, $\eta^2 = .29$]. Follow-up *t*-tests revealed that inverse efficiency scores to compatible patterns were statistically identical [$p > .1$] in the local [$M = 502.64$ ms, $SE = 10.85$] and global tasks [$M = 504.27$ ms, $SE = 10.9$] but inverse efficiency scores to incompatible patterns were significantly larger [$t(56) = 3.86$, $p < .01$] in the global task [$M = 589.94$ ms, $SE = 10.66$] than in the local task [$M = 553.58$ ms, $SE = 12.72$]. This is compatible with the suggestion that, regardless of cognitive load, interference from local detail on the global-selection task is greater than interference from global structure on the local-selection task.

The interaction of interest was between *task, compatibility* and *cognitive load* which would have allowed us to suggest that interference on the local- and global-selection tasks was different under low and high cognitive load (see Figure 18b for interference, calculated by subtracting inverse efficiency scores to compatible trials from inverse efficiency scores to incompatible trials, as a function of task and cognitive load). However, this was non-significant [$p > .1$].

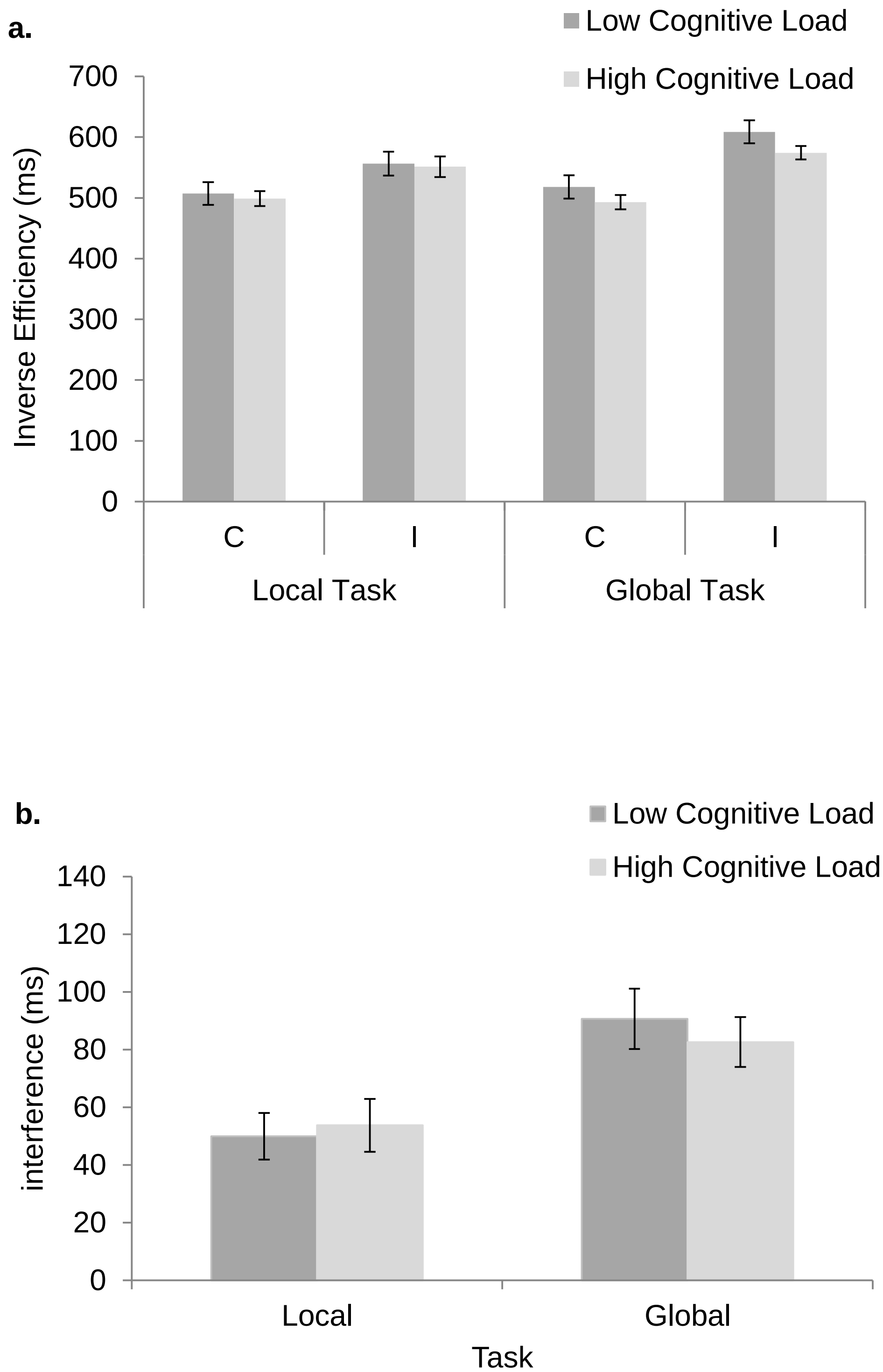



**Figure 18**. **a**. *Inverse efficiency scores for participants under high and low cognitive load in the local and global limited-exposure selection tasks for both compatible and incompatible trials.* **b.** *Interference scores (incompatible inverse efficiency minus compatible inverse efficiency scores) for responses in the local and global tasks under low and high cognitive load. Error bars represent one standard error of the mean.*

### 3.2.3 Discussion

We had predicted that we would see a global advantage for our medium-density patterns in the present experiment, as they were matched more frequently at the global level than at the local level at limited exposure durations in Experiment 2. We then predicted that cognitive load would increase interference from salient global information on a local-selection task (as was observed by Ahmed and de Fockert, 2012, when using stimuli with strong global salience). However, participants responded to our medium-density patterns with a *local advantage* and we did not observe a significant asymmetric effect of cognitive load on interference in the local and global selection tasks (although there was a very slight trend in the direction compatible with Ahmed & de Fockert, 2012, see Figure 18b). As participants responded to our medium-density stimuli with a global bias but a local advantage it is possible that neither local nor global information was sufficiently salient to provoke an asymmetric effect of cognitive load. In Experiment 5, we aim to show that cognitive load can further enhance local salience and increase interference from local information on a global selection task.

## 3.3 Experiment 5

In Experiment 4 we ran a limited-exposure version of the selective-attention hierarchical-patterns task. Experiment 2 (presented in Chapter 2) illustrated that cognitive load enhances local salience of hierarchical patterns presented for an unlimited duration. Thus, in the present experiment we repeated the task in Experiment 4 but presented patterns for an unlimited duration in order to enhance local salience. We predicted that local salience would be stronger than global salience under high cognitive load and expected cognitive load to increase interference from local detail on a global selection task.

## 3.3.1 Method

### 3.3.1.1 Participants

79 participants (mean age 19.04 years; 58 females, 21 males) were all first-year-undergraduate psychology students at Goldsmiths, University of London, UK and participated in exchange for course credit. Testing took place in a series of undergraduate lab classes and thus participant numbers were dictated by class attendance. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

### 3.2.1.2 Design

The design was identical to that in Experiment 4.

### 3.3.1.3 Apparatus and stimuli

The apparatus and stimuli were identical to those used in Experiment 4.

3.3.1.4 Procedure

The procedure for the unlimited exposure-duration task can be seen in Figure 19. The procedure was identical to that used in the limited-exposure-duration task in Experiment 4 with the exception of exposure duration and response: patterns were now presented for an unlimited duration and only disappeared when the participant made their response. Thus, participants had the opportunity to view the patterns until they had decided on, and started to execute, their response.

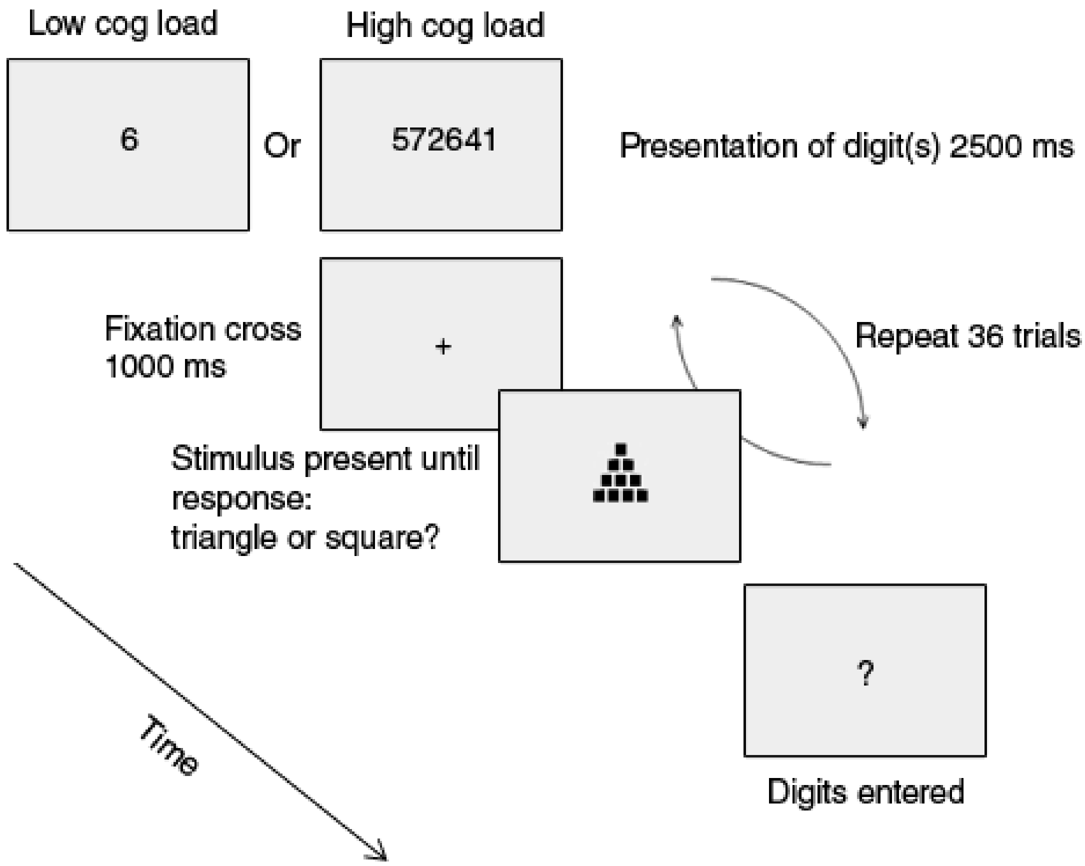



**Figure 19.** *Schematic representation of a single block of the unlimited-exposure version of the hierarchical patterns task (Experiment 5). As in the limited-exposure condition (Experiment 4), there were four blocks of 36 trials for the local task and four for the global task, making eight blocks in total.*

### 3.3.2 Results

Participants were included in the analysis if they accurately recalled the single digit in the low cognitive load condition or five out of six digits, in the correct order, in the high cognitive load condition. Blocks of trials were excluded from the final analysis if the participant failed to adequately recall the cognitive load associated with that block. If participants correctly recalled digits in less than 50% of the blocks, their data were excluded from the final analysis. Data were also excluded from the analysis if participants achieved below 75% accuracy on either the local or the global task overall. In total, the data from five participants were excluded in accordance with these criteria; one from the low cognitive load condition and four from the high cognitive load condition. As in Experiment 4 we calculated inverse efficiency scores for each variable (mean RTs and accuracy can still be seen in Table 3).

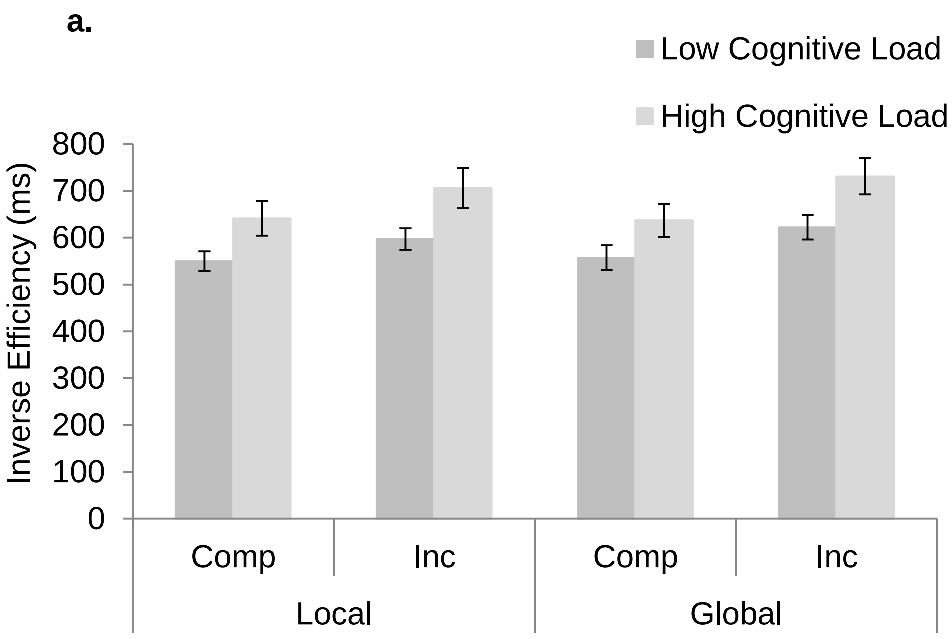
As in Experiment 4, data were entered into a three-way mixed-subjects ANOVA with *task* (*local* vs. *global*) and *compatibility* (*compatible* vs. *incompatible*) as the within-subjects factors and *cognitive load* (*low* vs. *high*) as the between-subjects factor. Inverse efficiency was the dependent variable (descriptives can be seen in Figure 20a).

**Table 3.** *Mean reaction times and accuracy for responses in Experiment 5.*

| | | | Local task | | Global task | |
|---|---|---|---|---|---|---|
| | Reaction time | | Comp | Inc | Comp | Inc |
| Unlimited Exposure | Low cognitive load | *M* | 538.93 | 569.86 | 546.88 | 592.36 |
| | | *SE* | *20.84* | *21.2* | *26.52* | *25.7* |
| | High cognitive load | *M* | 623.23 | 662.3 | 609.32 | 675.11 |
| | | *SE* | *35.1* | *38.41* | *32.73* | *32.95* |
| | Accuracy | | | | | |
| Unlimited Exposure | Low cognitive load | *M* | .99 | .97 | .99 | .96 |
| | | *SE* | *.0* | *.01* | *.0* | *.01* |
| | High cognitive load | *M* | .98 | .96 | .97 | .94 |
| | | *SE* | *.0* | *.01* | *.01* | *.01* |

The main effect of *task* was non-significant [$p > .1$]; unlike Experiment 4, participants were not significantly quicker to respond to local detail than global structure (although there was a trend in this direction). There was a main effect of *compatibility* [$F(1, 72) = 2.42$, $p < .01$, $\eta^2 = .59$] which again replicates the often-observed finding that incompatible stimuli ($M = 655.76$, $SE = 21.5$) are responded to slower than compatible stimuli ($M = 591.37$, $SE = 21.01$). As in Experiment 4, the interaction between task and compatibility was significant [$F(1, 72) = 4.63$, $p < .01$, $\eta^2 = .06$]. Incompatible patterns in the global task were responded to slower than incompatible patterns in the local task; however, the Bonferroni-corrected post-hoc *t*-test failed to reach significance [$p > .05$]. The main effect of *cognitive load* was significant [$F(1, 72) = 4.95$, $p < .05$, $\eta^2 = .06$] which illustrates that participants under high cognitive load ($M = 670.33$, $SE = 29.72$) were slower to respond than participants under low cognitive load ($M = 576.8$, $SE = 29.7$).

As in Experiment 4, the interaction of interest was between *task, compatibility* and *cognitive load.* A significant interaction would allow us to suggest that cognitive load had an asymmetric effect on interference in the local- and global-selection tasks. The descriptive statistics presented in Figure 20b show that there was a trend in the expected direction; however, this was not significant [p > .1].



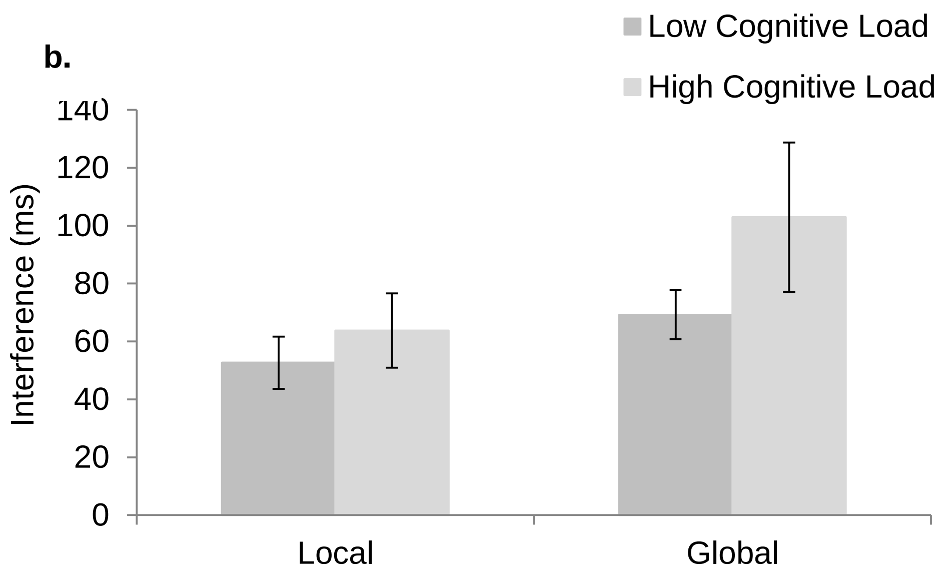




**Figure 20**. **a.** *Inverse efficiency scores for participants under high and low cognitive load in the local and global selection tasks for both compatible and incompatible trials.* **b.** *Interference scores (incompatible inverse efficiency minus compatible inverse efficiency scores) for responses in the local and global tasks under low and high cognitive load. Both figures are for Experiment 5. Error bars represent one standard error of the mean.*

### 3.3.3 Discussion

We had predicted that cognitive load would enhance the salience of local detail at unlimited exposure durations and would make it more difficult to ignore local information in a global-selection task. This would provide evidence to suggest that the effect of cognitive load on local-global salience (discussed in Chapter 2) would feed into the effect of cognitive load on attentional selection. We saw a trend in the expected direction, where interference from local elements on a global-selection task was greater under high than low cognitive load, but this was not significant.

## 3.4 Discussion of Chapter 3

The present experiment explored the effect of cognitive load on the selection of hierarchical information. Previous research using hierarchical patterns with strong global salience has shown that cognitive load enhances processing of irrelevant global information, described as a "shift towards global processing" (Ahmed & de Fockert, 2012). However, we suggested that this effect was driven by the strong global salience of the stimuli and that high cognitive load should make it more difficult to ignore the most salient level of representation, irrespective of whether this is global structure or local detail. We thus aimed to show that cognitive load would cause a 'shift towards local processing' when local salience was strong.

In Experiments 1-3, we demonstrated that high cognitive load enhanced the salience of local elements when exposure durations were unlimited; at limited exposure durations, however, global structure was most salient under both low and high cognitive load. In the experiments reported in the present chapter we predicted that cognitive load would affect local-global salience in a selective-attention hierarchical patterns task. We used exposure duration and cognitive load as a manipulation of global salience and predicted that global salience would be stronger than local salience under both low and high cognitive load at limited exposure durations. However, at unlimited exposures cognitive load would make local detail more salient than global structure and thus high cognitive load would increase interference from irrelevant but salient *local* information on a global-selection task. We observed a slight trend in the predicted direction, but this was not statistically significant.

The present thesis argues that the effect of cognitive load on selection of hierarchical information will depend on the relative salience of the attended and unattended levels of the hierarchical stimulus. We argue that Ahmed and de Fockert (2012) saw increased global interference under high cognitive load because they used hierarchical patterns with strong global salience, which was likely determined by the high density and limited exposure of the patterns. Had they used stimuli with strong local salience, then we predicted that they would have seen the opposite effect: cognitive load would have increased interference from irrelevant local detail. In the present chapter we attempted to manipulate local-global salience by using identical stimuli to that used in our previous experiments (Experiments 1-3, presented in Chapter 2) and varying their exposure duration. We predicted that local or global salience – as indexed by matching performance in Experiments 1 and 2 – would translate into a local or global advantage respectively on a selection task.

Interestingly, we saw a local advantage for participants under both low and high cognitive load for stimuli presented at unlimited and as well as limited exposure durations. Thus, global salience as indexed in a matching task does not necessarily translate into global salience in a selection task. Failure to show a global advantage at limited exposure-durations is not necessarily surprising in itself, as global advantage depends on a number of stimulus-driven factors (see Kimchi, 1992 for a review). However, what is more surprising is that we saw a local advantage on a selection task in the present experiments for the same hierarchical patterns where global matches were preferred on a matching task (in Experiments 1 and 2), which illustrates that local-global salience on a matching paradigm does not necessarily indicate local-global salience (as indexed by local or global advantage) on a selective-attention task even when using identical hierarchical patterns. The fact that we did not see a global advantage at limited exposure durations may also be why we did not replicate Ahmed and de Fockert's (2012) finding that cognitive load enhances global processing at limited exposure durations, as global salience was weaker than local salience. It is important to acknowledge that the argument presented in this thesis would suggest that we should have seen a 'shift towards local processing' at limited exposures in Experiment 4 because we (unexpectedly) observed a local advantage at limited durations. However, the fact that the global level of our medium-density patterns was more salient than local detail in a limited-exposure matching task (Experiment 1) but less salient than local detail in a limited-exposure selection task suggests that local salience at limited exposure durations may not have been strong enough to observe a 'shift towards local processing' under high cognitive load.

There are several reasons that may explain why local-global salience on our measures of perceptual bias and attention selection did not converge. Firstly, it is possible that the selective-attention task used in the present experiment was more cognitively-demanding than the similarity-matching paradigm used in Chapter 2; this could have imposed an extra cognitive load which in turn could have enhanced the relative salience of local information over global structure. Secondly, it is possible that a preference to weight global information more highly than local detail does not necessarily mean that the global level is easier to select. While perceptual bias could be determined by person-driven factors such as hemispheric activation it could also be driven by higher cognitive decision-making processes; indeed, Navon (2003) has suggested that similarity-matching paradigms could be "suspected…of being too-much influenced by post-perceptual biases" (p. 278). Thus, a preference to favour global over local information could be influenced to an extent by post-perceptual biases which may not determine efficiency of selection. Hence, global salience was stronger than local salience in a measure of perceptual bias but a local advantage was observed in a task of attentional-selection. It is also important to acknowledge that we presented the medium-density hierarchical patterns in isolation in the present experiment, whereas the medium-density patterns were presented intermixed with low- and high-density patterns in Experiments

1-3. It is entirely possible that global salience is dependent on whether pattern-density is blocked or intermixed; against this, however, we have run single-pattern-density similarity-matching experiments as part of other studies and found that global salience of medium-density stimuli is comparable when they are presented alone and when they are presented intermixed with other densities (~60% global matches).

It may also be the case that differences in local-global salience induced by cognitive load were insufficiently strong to influence the selection of global and local information. Indeed, in our unlimited-exposure version of the task in Experiment 5, exposure durations were participant-determined and it was likely that durations were too brief to see an enhancement of local salience to the extent that it was observed in Experiment 2. For example, in Experiment 2 the average response latency when exposures were unlimited was approximately 1,350 ms, almost twice as long as the approximately 650 ms reported in Experiment 4. Thus, failure to show that cognitive load can increase interference from local detail on a global-selection task may be due to the use of exposure duration as a means of increasing local salience, rather than the absence of an effect of cognitive load on selection of hierarchical information. Indeed, the issue of using variable exposure durations is a problem in itself, beyond the issue just highlighted. The selective-attention hierarchical-patterns task (Navon, 1977) was developed to test an assumption about the *initial* dominance of global-level information and was not designed to explore the development of the percept. Arguably, there can never be any true unlimited-exposure version of the selective-attention hierarchical-patterns task, as by its very nature the task depends on quick responses.

Although we did not see an effect of cognitive load on local-global salience expressed in an effect of cognitive load on attentional selection, our data more generally show the importance of controlling for exposure duration when using the hierarchical-patterns task to make inferences about local and global processing, especially when person-driven influences on selection are the subject of investigation. We did see that, for both the local and global tasks, responses were significantly slower when stimuli were presented for an unlimited, as opposed to a limited, duration. This in itself is to be expected as participants would have felt under less time pressure. However, responses under high cognitive load were significantly slower than those under low cognitive load (for both the local and global tasks) when exposures were unlimited but not when exposures were limited. If we had run only a limited-exposure version of the task, we would have concluded that cognitive load had no effect on responses. If we had looked solely at data from an unlimited-exposure version of the task, however, we would have concluded that cognitive load did exert an effect. This observation is important as exposure duration is not a variable that is rigorously controlled when using selective-attention hierarchical-patterns tasks. Studies present stimuli for varying durations, and this is not taken into account in cross-experiment, or cross-paradigm, comparisons. Our data suggest that top-down differences in control may exert their effects when stimulus presentation is unlimited in a different way to when it is limited.

In conclusion, the experiment presented in this chapter attempted to address the extent to which the effect of cognitive load on selection is modulated by local-global salience. To manipulate global salience we varied exposure duration, predicting that global salience would be strongest at limited exposures and that local salience would be strongest at unlimited exposure durations under high cognitive load. However, we found that local salience was stronger than global salience at both limited and unlimited exposure durations, and did not see high cognitive load increase interference from irrelevant local information on a global selection task. We reasoned that exposure duration was an inappropriate manipulation of local-global salience with medium-density hierarchical patterns.

We suggest that there are more appropriate ways of increasing local salience. Indeed, in Chapter 2 we used hierarchical patterns in which the number of elements and their density varied; higher-density patterns were more likely to be represented in terms of their global structure than lower density patterns (Kimchi & Palmer, 1982). Furthermore, Kimchi (1998, 2000) has suggested that high-density stimuli are initially represented in terms of their global structure but that low-density stimuli are initially represented in terms of their local elements. It is likely that a density manipulation is a more appropriate manipulation of local-global salience. Specifically, by using hierarchical patterns that are very low in density we may see strong local salience even at limited exposure durations. In Chapter 4, we present two experiments (Experiments 6 and 7) in which we continue our investigation with hierarchical patterns but manipulate local-global salience by varying pattern density. By using low-density stimuli we set out to demonstrate that cognitive load can increase interference from local information when local salience is strong in a limited-exposure paradigm. In Experiments 6 and 7 we also utilise a different cognitive load manipulation to that used in the experiments presented thus far; whereas in Experiments 1-5 participants had to perform a secondary cognitive load task while performing the attentional-selection task, in Experiments 6 and 7 participants had to perform a task-switching task. The ability to switch between tasks efficiently is essential for controlled cognitive functioning in everyday life. However, it is cognitively demanding and arguably provides a more ‘real-world’ manipulation of cognitive load.

# CHAPTER 4 - TASK SWITCHING

## 4.1 Introduction

In the experiments reported in Chapter 3, we explored how cognitive load affects the selection of hierarchical information. It has been argued that cognitive load always benefits global selection while impairing local selection (Ahmed & de Fockert, 2012). However, we suggest that the effect of cognitive load on local and global selection is influenced by stimulus-driven factors which affect local-global salience. When global salience is strong – as it was in Ahmed and de Fockert's study – high cognitive load makes it more difficult to ignore salient global information when performing a local-selection task. When *local s*alience is strong, however, high cognitive load should make it harder to ignore irrelevant local information when performing a global-selection task. In two experiments in Chapter 3, we used a selective-attention version of the hierarchical-patterns task (Navon, 1977) to explore whether high cognitive load can improve local selection when local salience is strong. We did not find convincing evidence to suggest that high cognitive load can make processing more local. We suggest that our manipulation of stimulus-driven salience – involving varying the exposure duration of the stimulus – did not enhance local salience to a sufficiently great extent. In the present chapter, we continue our investigation with hierarchical patterns and present two experiments in which we vary stimulus density in order to manipulate local and global salience. We demonstrate that high cognitive load can impair global selection when patterns have strong local salience and conclude that high cognitive load does not always cause a “shift towards global processing” (Ahmed & de Fockert, 2012).

In addition to changing our manipulation of global salience from exposure-duration to pattern-density, in the experiments reported in this chapter we also changed the way in which we manipulated cognitive load. Instead of having participants rehearse digit strings whilst performing the selection task, we introduced a task-switching variable. Task switching involves managing the balance between competing goals – the hallmark of efficient goal-directed behaviour (Monsell, 2003) – and is in itself cognitively demanding and imposes a cognitive load (Yeung & Monsell, 2003). Indeed, it comes with a behavioural cost and is associated with increased response latencies and higher error rates (e.g., Allport, Styles & Shulan, 1994; Jersild, 1927; Rogers & Monsell, 1995) which are both markers of cognitive load (e.g., Baddeley, 1986; Lavie et al., 2004). The ability to efficiently switch between different tasks is crucial for efficient cognitive functioning in everyday life. Task-switching may be necessary for complex operations, such as driving a vehicle, but can also occur as a result of entertaining repeated distractions such as text messages, telephone calls or e-mails. Thus, task-switching may not only be an effective manipulation of cognitive load but also allows us to consider how task-switching – an ubiquitous everyday task – could affect hierarchical processing.

Each time a task is changed or distraction is indulged, the brain must *reconfigure* the cognitive *task set* essential for performance of a particular task (Allport et al., 1994;

Rogers and Monsell, 1996). In terms of the selection of hierarchical information, the task set specifies which level of the hierarchy is to be responded to, that is, whether participants are preparing to select either local or global information. In experimental scenarios, task-switching is explored by measuring performance on consecutive trials in which the task to-be-performed is the same, in comparison to trials on which the task-to-be-performed changes. For example, switching from performing a local task on one trial to performing a global task on the next constitutes a task-switch; performing a local task on two consecutive trials, however, does not. If task set can be perfectly reconfigured then task-switching should not affect how efficiently local and global information is selected. However, the high cognitive load associated with task switching should increase interference from irrelevant-yet-salient hierarchical information on switch trials.

In Chapter 3, we considered the possibility that the salience of the to-be-selected hierarchical information in a selective-attention hierarchical-patterns task would be influenced by the effect of cognitive load on perceptual bias. To briefly review our previous findings, in Chapter 2 we presented a series of experiments which demonstrated that high cognitive load reduced the salience of global structure and enhanced the salience of local elements but only when stimuli were presented for unlimited exposure-durations. The experiments reported in Chapter 3, however, showed us that exposure duration was an inappropriate manipulation of global salience in a selective-attention hierarchical-patterns task. We suggest this is because selective-attention paradigms are not capable of delivering sufficiently long exposure-durations. Therefore, in the present study we chose stimuli for which local salience was likely to be stronger than global salience even at limited exposure durations. In other words, we used a limited-exposure paradigm but manipulated global salience through pattern-density. Global salience is dependent on the number and relative density of local elements in a hierarchical pattern (Kimchi, 1998, 2000; Kimchi & Palmer, 1982; our data from Experiment 1-3 also replicate this) and very-low-density patterns should have strong local salience even at limited exposure-durations.

Kimchi (1998, 2000) used a primed-matching paradigm to study the microgenesis of global and local salience in hierarchical patterns and demonstrated that the temporal trajectory of local and global salience varied with the number and relative size of the elements comprising the global whole. She presented participants with a hierarchical pattern as a prime for a duration varying between 40 ms and 690 ms (Kimchi, 1998) or 390 ms (Kimchi, 2000). The prime then disappeared and was replaced by a pair of hierarchical patterns which could be the same or different; the task was to indicate whether the two patterns were the same or different. In such primed-matching tasks, 'same' responses are faster if the test patterns are similar to the prime than if they are different from it; the logic of the hierarchical-patterns version of this paradigm is that 'same' responses will be faster if the target patterns are matched at a hierarchical level which matches the participant's internal representation of the prime. For example, if participants are biased towards representing the prime at the local level, then responses should be faster to test patterns which are matched at the local than at the global level. Conversely, positive responses to target similarity should be faster to stimulus pairs matched on global structure if the prime is represented in terms of its global structure more than its local detail.

By presenting primes for differing exposure-durations, Kimchi (1998, 2000) was able to demonstrate how the relative salience of local and global information changes with time and showed that the temporal trajectory of local and global salience varies with the density of hierarchical patterns. She suggested that the local elements of low-density patterns form the entry-level perceptual units of these patterns, and that time and attentional resources are necessary to consolidate these elements into a global whole. For high-density patterns, however, she suggested that global structure is the entry-level unit and that attentional resources were necessary to dis-embed local elements from their strong global context. This being the case, very-low-density hierarchical patterns should have strong local salience, *especially* at limited exposure durations, whereas high-density patterns should have strong global salience at limited exposures. In the present experiments we predicted that high cognitive load – induced by task-switching – should make it more difficult to ignore salient local information when selecting the global level of low-density hierarchical patterns.

In sum, we endeavoured to show that high cognitive load (induced by task-switching) does not always benefit global processing but that it can make processing more local when stimuli have strong local salience. We continued our investigation with the selective-attention version of the hierarchical-patterns task (Navon, 1977) – used in

Experiments 4 and 5 (presented in Chapter 3) – but manipulated global salience by changing pattern density and made exposure duration always limited. In Experiment 4, we saw that our medium-density patterns (Kimchi & Palmers, 1982) were responded to with a local advantage (namely that local detail was responded to more quickly than global structure) whereas in Experiments 1-3 (presented in Chapter 2) we saw that these same stimuli were matched more at the global level, suggesting that global salience was stronger than local salience. We suggested that participants may have preferred to represent these stimuli in terms of their global structure even though their local detail was easier to select. In other words, a change of paradigm was sufficient to induce a switch in the level of hierarchical information that was most salient. We conclude that medium-density patterns possessed neither strong local salience nor strong global salience. Thus, in the experiments reported in the present chapter we used our lowest-density stimuli from Experiments 1-3 (Kimchi & Palmer, 1982) in order to ensure that stimuli had strong local salience. These patterns were a similar density to Kimchi's (1998) few-element patterns which the evidence suggests are represented initially in terms of their local elements. We reasoned that increasing cognitive load should make it more difficult to select the global structure of these low-density patterns and that an increase in interference from salient-but-irrelevant local detail should be observed. We also ran our task-switching experiment with the medium-density patterns used in Experiments 4 and 5; this time, we predicted that cognitive load would have no effect on selection as we had observed no effect of cognitive load on selection of these patterns in Experiments 4 and 5.

The task-switching version of the selective-attention hierarchical-patterns task, which we use in the present experiments, differs from the usual version of the selective-attention hierarchical-patterns task in the way that the local- and global-selection tasks are blocked. In the selective-attention version of the hierarchical-patterns task (as used in Experiments 4 and 5, Chapter 3), the local- and global-selection tasks are completed in separate blocks. In the switching version of the task presented here, however, participants are only informed of the task they are to perform at the start of each *trial*, and thus have to quickly reconfigure their task set to either 'go local' or 'go global' on each trial. This should reduce the influence of block-wise strategic effects and allows for the effect of cognitive load on selection of hierarchical information to be explored within-participants in the same block of trials. It should also make it harder to ignore salient information given that it is relevant on half of all trials.

Research has shown a robust 'switch cost' for switch trials in comparison to no-switch trials (e.g., Allport et al., 1994), with reaction times and error rates being greater in the former than in the latter. We equate 'switch' trials with high cognitive load and 'no-switch' trials with low cognitive load. If cognitive load makes it more difficult to ignore salient (yet irrelevant) information then we would expect switch costs to depend on both the task to be performed (local or global) and on pattern density. When using low-density patterns with strong local salience, we would expect to see worse performance on a global-selection trial which immediately follows a local-selection trial, as the task switch should incur a high cognitive load and make it more difficult to ignore salient irrelevant local detail. When switching from a global to a local task using the same low-density stimuli, however, we would not expect high cognitive load to increase interference from irrelevant global structure given its low salience. When using medium-density patterns we would not expect to see asymmetric effects of cognitive load on local and global selection given that local and global salience are reasonably equated.

We ran two experiments, one with medium-density patterns (Experiment 6), and the other with low-density patterns (Experiment 7), with the patterns corresponding to the ‘medium-’ and ‘low-density’ patterns used in Experiments 1-3. In Experiment 6 we did not expect to see any effect of cognitive load on local and global selection as we had seen no effect of cognitive load on selection of these patterns at limited exposure-durations in Experiment 4. In Experiment 7, however, we predicted that we would see an asymmetric effect of cognitive load on local and global selection; cognitive load, as induced by switching, should increase interference from salient local information on a global-selection task but should not increase interference from global information on a local-selection task.

## 4.2 Experiment 6

Task switching is known to be cognitively demanding (Yeung & Monsell, 2003) and in the present experiment we used a task-switching paradigm as a manipulation of cognitive load, equating no-switch trials with low cognitive load and switch trials with high cognitive load. In the present experiment, we altered the selective-attention version of the hierarchical-patterns task used in Chapter 3 so that the local and global tasks were no longer performed in separate blocks; now, participants were told at the beginning of each trial which task they were to perform. In the present experiment, we used medium-denisty patterns so that the task was identical to the task in Experiment 4 except for the manner in which the trials are performed (blocked in Experiment 4 vs. switching in Experiment 6). As we saw no effect of cognitive load on selection of hierarchical information in Experiment 4, we did not expect to see an effect of task switching in the present experiment.

### 4.2.1 Method

#### 4.2.1.1 Participants

Forty-three undergraduate students (mean age 21.2 years; 38 females, 5 males) at Goldsmiths, University of London, participated in the present experiment. Participation was in exchange for course credit. Testing took place in a series of undergraduate lab classes and thus participant numbers were dictated by class attendance. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

4.2.1.2 Design

We used a 2x2x2 within-participants design. The independent variables were *switch* (switch trials vs. no-switch trials), *task* (local vs. global) and *compatibility* (compatible vs. incompatible). The dependent variable was *inverse efficiency,* which we computed from dividing reaction time (ms) by accuracy for each factor. (We also used an inverse efficiency measure of performance in Chapter 3; more detail on this calculation is provided in the results section.)

4.2.1.3 Apparatus and stimuli.

The task was developed and executed with E-Prime version 1.2 (Psychology Software Tools Inc., Sharpsburg, PA). Stimuli were presented on a Sony Trinitron GDM-F520 CRT monitor with a 21-in flat screen. Stimuli were identical to the medium-density hierarchical patterns used in Experiments 1, 2, 3, 4, and 5 (originally developed by Kimchi & Palmer, 1982) and were created using Adobe Photoshop CS2. Patterns were small black triangles or squares configured to form large triangles or squares. The local and global levels of hierarchical patterns could be either compatible (e.g., small squares arranged to form a large square) or incompatible (e.g., small squares arranged to form a large triangle). Figure 21 depicts our stimulus set. There were four unique hierarchical patterns and each subtended approximately 2.4° of visual angle. Small squares subtended 0.8° and small triangles 0.7°. Whether participants were to perform the global or local task was indicated with a vocal instruction, which was ‘big’ for the global task or ‘small’ for the local task. The voice was female and was recorded and edited using GoldWave® software.

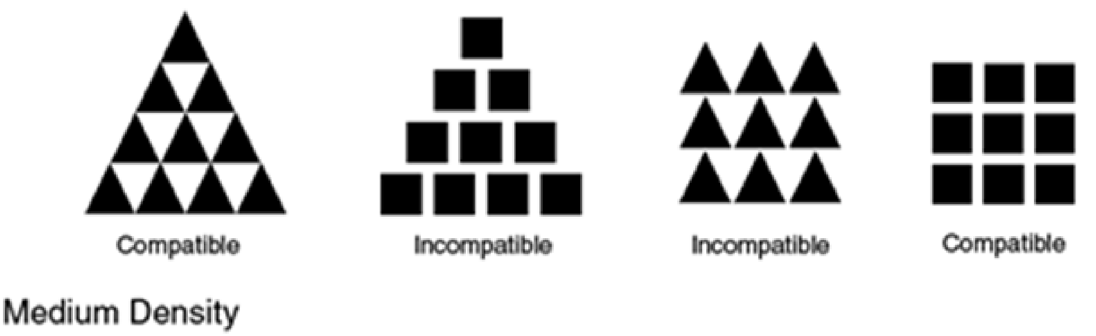



**Figure 21.** *The complete stimulus set used in the present experiment (replicated from Kimchi & Palmer, 1982, and identical to our medium-density patterns used in Experiments 1-5).*

There were 96 trials in total. Each of the four original hierarchical patterns was presented once in the global task and once in the local task. Each of these eight possible trials was presented once in the centre of the screen, once 1.7° above centre along the vertical midline, and once 1.7° below centre along the vertical midline. The resulting 24 possible trials were presented four times, totalling 96 trials, with each stimulus in each location being presented 12 times per task.

4.2.1.4 Procedure.

Figure 22 illustrates the procedure for Experiment 6. Participants were seated 60 cm from the screen and were asked to place the index finger of each hand on the ‘c’ and ‘m’ keys of a QWERTY keyboard. They were then asked to read through a series of on-screen instructions describing the task that they were about to perform. Participants were informed that they would hear a voice at the start of each trial, which would say either ‘big’ or ‘small’. If the voice said ‘big’ then participants were to indicate whether the large shape was a square or a triangle. If the voice said ‘small’ then they were to say whether the small shapes were squares or triangles. Each trial ran as follows: a fixation cross was presented in the centre of a white screen for 1,000 ms. As soon as this disappeared, it was replaced with a blank screen for 1,500 ms and participants immediately heard either ‘big’ or ‘small’. The blank screen was then replaced with a hierarchical pattern which was presented for 250 ms. The pattern then disappeared and was replaced with a blank screen; participants had 3,000 ms to make their response. The response screen timed-out after 3,000 ms. If a response was made within this time, the blank screen remained for a further 1,000 ms following the response before the next trial began. Participants were asked to respond as quickly but as accurately as possible. They then performed a practice block that consisted of sixteen trials; each of the four unique stimuli were presented twice in the local task and twice in the global task. After the practice block, participants were told that the main task was to begin and performed 96 experimental trials.

‘Switch’ and ‘no-switch’ trials were computed after the data had been collected. A trial was designated a switch trial if the task to be performed was different to the one in the trial that preceded it (e.g., if the global task was to be performed on a trial following a trial where the local task was performed). A trial was a no-switch trial if the task was the same as on the previous trial (e.g., if a global-task-trial followed another global-task-trial). 'Switch'/'no-switch' was treated as an additional independent variable. Whether the local or global task was to be performed on each trial was determined at random. Thus, whether a trial was designated 'switch' or 'no-switch' depended on the random order in which the local or global task was selected and therefore there were potentially slightly uneven numbers of switch and no-switch trials in each dataset.

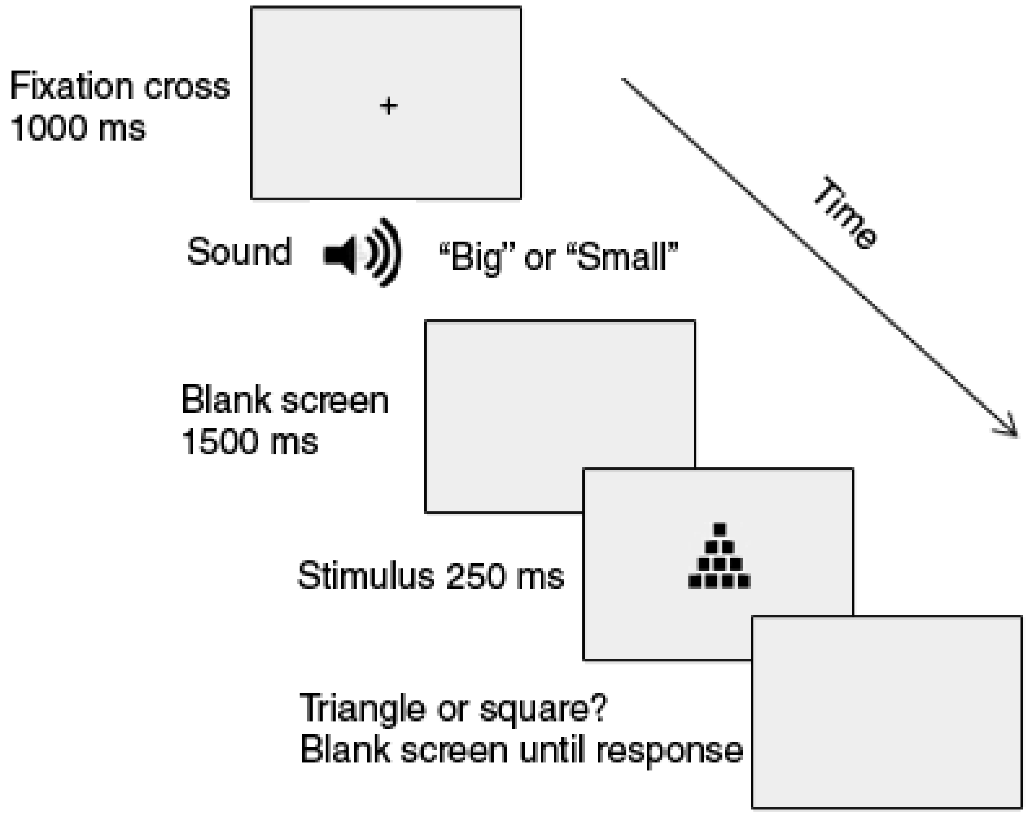



**Figure 22.** *A schematic representation of a single trial of the task-switching hierarchical-patterns task used in Experiment 6 (medium-density patterns).*

### 4.2.2 Results

We excluded the first trial for each participant from the final analysis. We then calculated inverse efficiency scores, by dividing reaction times for each condition by the accuracy for that condition. This was to limit the influence of potential speed-accuracy trade-offs. The mean RTs and errors before calculation of inverse efficiency can be seen in Table 4. We then calculated interference scores by subtracting inverse efficiency scores on compatible trials from those on incompatible trials.

**Table 4**. *Mean reaction times and accuracy for Experiment 6.*

| | | | Local task | | Global task | |
|---|---|---|---|---|---|---|
| | | | Comp | Inc | Comp | Inc |
| Reaction time | No-switch | *M* | 720.99 | 797.94 | 706.56 | 825.52 |
| | | *SE* | *25.96* | *30.88* | *23.36* | *30.49* |
| | Switch | *M* | 846.06 | 913.86 | 832.68 | 932.69 |
| | | *SE* | *28.02* | *32.19* | *31.09* | *32.23* |
| Accuracy | No-switch | *M* | .99 | .96 | .99 | .96 |
| | | *SE* | *.01* | *.01* | *.0* | *.02* |
| | Switch | *M* | .96 | .94 | .97 | .91 |
| | | *SE* | *.01* | *.01* | *.0* | *.02* |

Participants were excluded from the final analysis if they achieved below 75% accuracy on either the local or global task in switch or no-switch trials. Accuracy was high overall (see Table 4), and no participants fell below our exclusion threshold. The data from all participants were entered into a 2x2x2 within-subjects ANOVA, with *switch* (*switch* vs. *no-switch*), *task* (*local* vs. *global*) and *compatibility* (*compatible* vs. *incompatible*) as the factors. The dependent variable was the inverse efficiency score (see Figure 23).

There were main effects of *switch* [$F(1, 42) = 73.9$, $p < .001$, $\eta^2 = 64$] and *compatibility* [$F(1, 42) = 6.12$, $p < .05$, $\eta^2 = 13$]. Responses were more efficient on no-switch trials [$M = 811.19$, $SE = 53.48$] in comparison to switch trials [$M = 986.18$, $SE = 74.63$] and more efficient on compatible trials [$M = 796.92$, $SE = 28.94$] as opposed to incompatible trials [$M = 1{,}000.45$, $SE = 99.16$]. The main effect of task was non-significant [$p > .1$] indicating that, overall, participants were equally efficient at responding to local elements and global structure.

There were no significant interactions [$p > .1$]. The interaction between *switch*, *task* and *compatibility* would have shown that switching affects interference on the local and global tasks differently; however, this interaction was non-significant [$p = .2$] (see Figure 24).

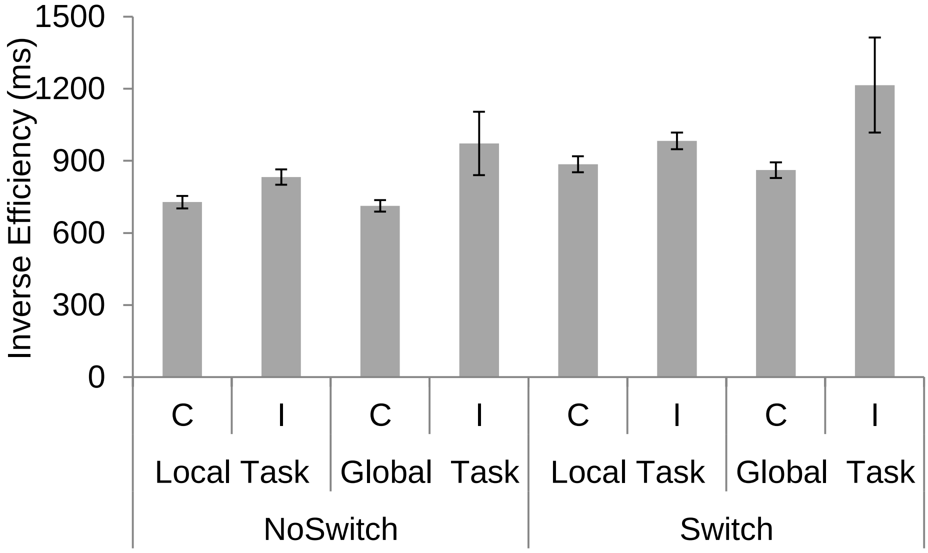



**Figure 23.** *Inverse efficiency scores for compatible and incompatible patterns in the local and global tasks, for both no-switch and switch trials (Experiment 6). Error bars show one standard error of the mean.*

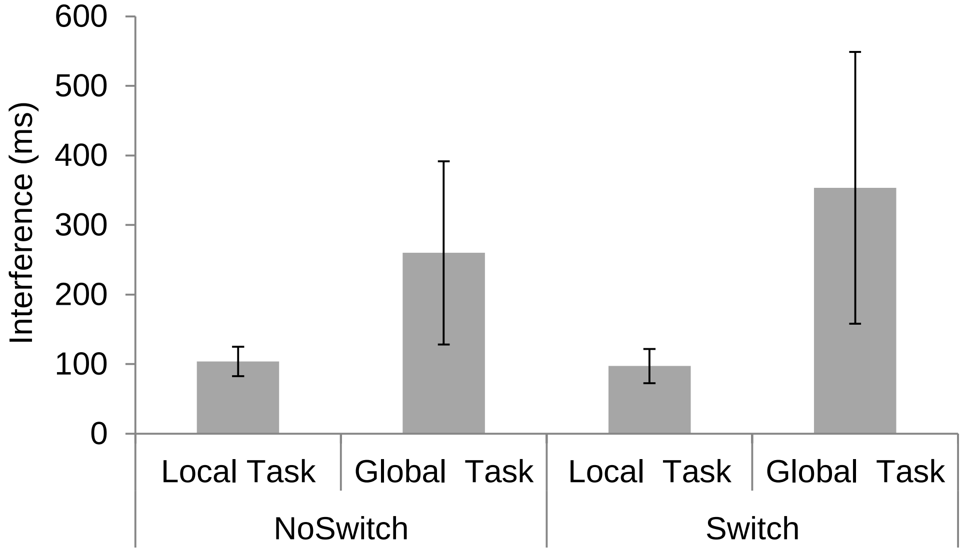



**Figure 24.** *Interference in no-switch and switch trials for both the local and global tasks. We calculated interference by subtracting inverse efficiency scores for compatible stimuli from those for incompatible stimuli (Experiment 6). Error bars show one standard error of the mean.*

### 4.2.3 Discussion

The present experiment has demonstrated that a switch cost is apparent on a task-switching version of the hierarchical-patterns task – evidenced by less efficient responses and more interference in switch trials compared to no-switch trials – but this pattern was present in the local task and the global task to the same extent. This is not surprising as we had shown no task-specific effect of cognitive load in a selective-attention version of the hierarchical-patterns task in Experiment 4 using these same stimuli. In Experiment 7 we aimed to show that switch costs for local and global tasks are asymmetric when local salience is strong.

## 4.3 Experiment 7

In the previous experiment, we demonstrated that switch-costs on a task-switching selective-attention hierarchical-patterns task were comparable to the effects of high cognitive load on selection; efficiency in responses was impaired and more interference was experienced from irrelevant information. However, interference was symmetrical across the local and global tasks. We now repeat the experiment using low-density hierarchical patterns which should have strong local salience. We suggest that switching will now be associated with increased interference from irrelevant – and salient – local information on a global-selection task, but that switching should have no effect on interference from irrelevant global information on a local-selection task.

## 4.3.1 Method

### 4.3.1.1 Participants

38 participants (mean age 23.6 years; 32 females, 6 males) were recruited from Goldsmiths, University of London. Participants were all undergraduate students and participation was reimbursed with course credit. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

### 4.3.1.2 Design

The design was identical to that in Experiment 6.

### 4.3.1.3 Apparatus and stimuli.

The apparatus was identical to that used in Experiment 6. However, in the present experiment we used low-density stimuli (equivalent to our lowest-density stimuli used in Chapter 2, replicated from Kimchi & Palmer, 1982; see Figure 25). Each pattern subtended approximately 2.4° of visual angle. The small squares subtended 1.2° and the small triangles 1.0° of visual angle. There were 96 trials in total. Each of the four original hierarchical patterns was presented once in the global task and once in the local task. Each of these eight possible trials was presented once in the centre of the screen, once 1.7° above centre along the vertical midline, and once 1.7° below centre along the vertical midline. These resulting 24 possible trials were presented four times, totalling 96 trials.

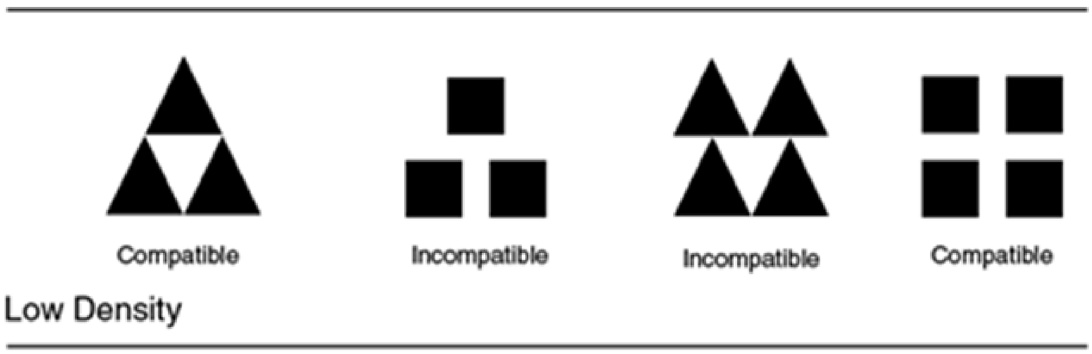



**Figure 25.** *The complete stimulus set used in the present experiment (replicated from Kimchi & Palmer, 1982).*

4.3.1.4 Procedure.

The procedure was identical to that in Experiment 6.

### 4.3.2 Results

As in Experiment 6, we excluded the first trial for each participant from the final analysis. We again calculated inverse efficiency scores, by dividing reaction times for each condition by the accuracy for that condition. Mean RTs and errors before inverse efficiency calculations can be found in Table 5.

Data were entered into a 2x2x2 within-subjects ANOVA, with *switch* (*switch* vs. *no-switch*), *task* (*local* vs. *global*) and *compatibility* (*compatible* vs. *incompatible*) as the factors. The dependent variable was *inverse efficiency*. Participants were excluded from the final analysis if they achieved less that 75% accuracy in either the global or local task for either switch or no-switch trials. All participants met this threshold, so the data from all participants were entered into the analysis. See Figure 26 for inverse efficiency scores.

There were significant main effects of *switch* [$F(1, 36) = 112.46$, $p < .001$, $\eta^2 = .76$], *compatibility* [$F(1, 36) = 98.23$, $p < .001$, $\eta^2 = .73$] and *task* [$F(1, 36) = 4.86$, $p < .05$, $\eta^2 = .12$]: responses on switch trials [$M = 942.88$, $SE = 40.45$] were less efficient than those on no-switch trials [$M = 760.94$, $SE = 30.23$]; responses to incompatible patterns [$M = 925.99$, $SE = 38.55$] were less efficient than to compatible patterns [$M = 777.83$, $SE = 32.13$]; participants were more efficient in responding to the identity of local elements [$M = 831.46$, $SE = 35.68$] than global structure [$M = 872.35$, $SE = 34.99$]. The fact that responses to local patterns were more efficient than to global patterns is consistent with a local advantage.

**Table 5**. *Mean reaction times and accuracy for Experiment 7.*

| | | | Local task | | Global task | |
|---|---|---|---|---|---|---|
| | | | Comp | Inc | Comp | Inc |
| Reaction time | No-switch | *M* | 692.91 | 753.21 | 685.29 | 797.62 |
| | | *SE* | *26.19* | *32.42* | *26.46* | *28.6* |
| | Switch | *M* | 826.18 | 863.44 | 791.38 | 934.83 |
| | | *SE* | *33.9* | *34.82* | *29.75* | *31.23* |
| Accuracy | No-switch | *M* | .99 | .97 | .98 | .94 |
| | | *SE* | *.01* | *.01* | *.01* | *.02* |
| | Switch | *M* | .97 | .90 | .96 | .86 |
| | | *SE* | *.01* | *.02* | *.01* | *.02* |

There was also a significant interaction between *task* and *compatibility* [$F(1, 36) = 10.12$, $p < .01$, $\eta^2 = .22$]. To explore this interaction, we subtracted inverse efficiency scores for compatible patterns from inverse efficiency scores for incompatible patterns, for both the local and global tasks, to obtain a measure of interference. Overall, interference was greater in the global task [*M* = 200.52, *SE* = 23.57] than in the local task [*M* = 95.8, *SE* = 20.82], indicating that participants found it more difficult to ignore irrelevant local information than irrelevant global information. This again suggests that local salience was strong in this task. *Compatibility* also interacted significantly with *switch* [$F(1, 36) = 5.98$, $p < .05$, $\eta^2 = .14$]. We calculated interference scores for both switch and no-switch trials and found that, overall, there was more interference from incompatible information in switch trials [*M* = 185.34, *SE* = 25.24] than in no-switch trials [*M* = 110.98, *SE* = 16.5]. The interaction between *switch* and *task* was non-significant [$p > .1$].

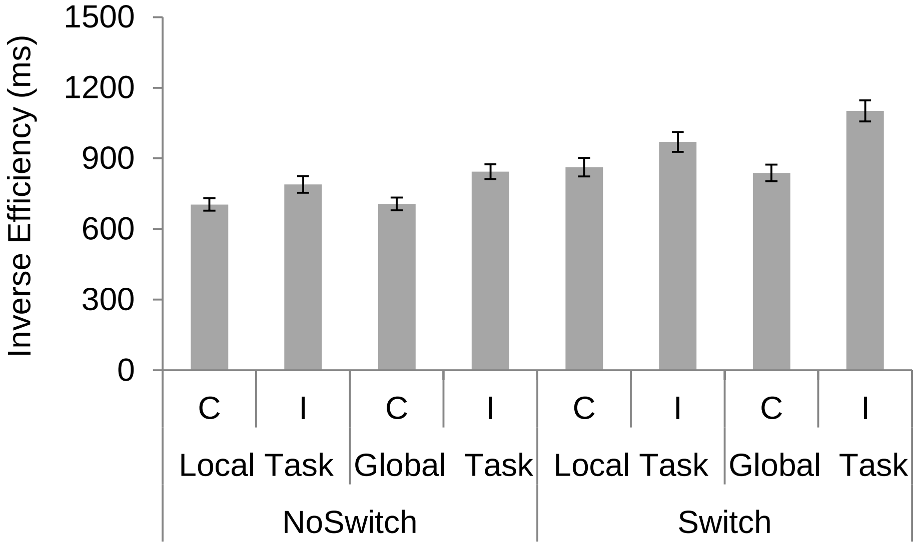



**Figure 26.** *Inverse efficiency scores for compatible and incompatible patterns in the local and global tasks, for both no-switch and switch trials (Experiment 7). Error bars represent one standard error of the mean.*

The main interaction of interest was between *switch*, *task*, and *compatibility*. This was also significant [$F(1, 36) = 4.28$, $p < .05$, $\eta^2 = .11$]. We again calculated an interference measure by subtracting compatible inverse efficiency scores from incompatible inverse efficiency scores. We did this for the local and global task, for both no-switch and switch conditions, giving us four interference scores in total (see Figure 27). Bonferroni-corrected post-hoc *t*-tests revealed that there was significantly more interference in the global task for switch trials in comparison to no-switch trials [$t(36) = -3.35$, $p < .01$]. Switching, however, had no significant effect on interference in the local task [$p > .1$]. This suggests that switching makes it harder to ignore irrelevant-but-salient local information, but has no effect on the suppression of irrelevant low-salient global information.

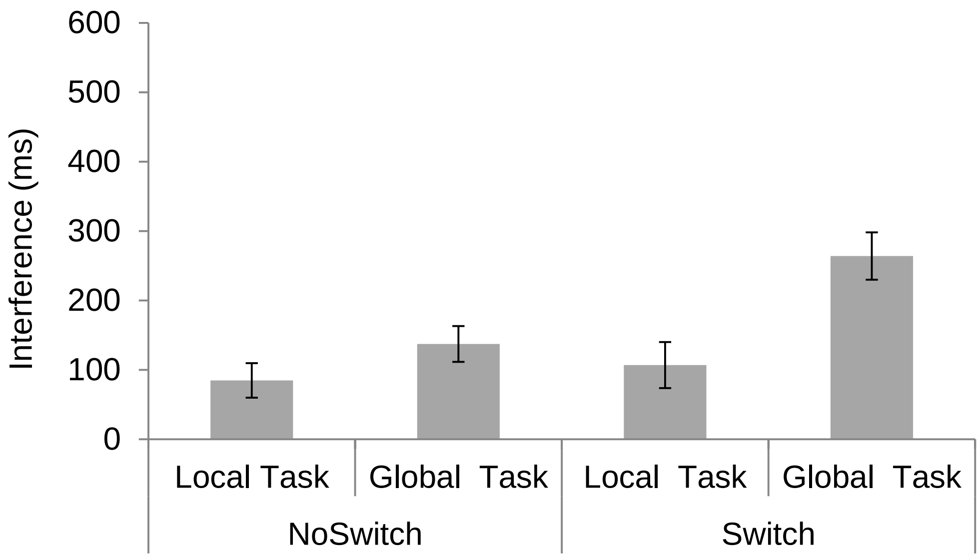



**Figure 27.** *Interference derived from inverse efficiency scores in no-switch and switch trials for both the local and global tasks (Experiment 7). Error bars represent one standard error of the mean.*

### 4.3.3 Discussion

The results indicate that cognitive load (induced by task-switching) can impair global selection when local salience is strong. This does not support the assertion that cognitive load always facilitates global processing (Ahmed & de Fockert, 2012); rather, it supports the idea that the effect of cognitive load on selection of hierarchical information depends on the relative salience of the different levels of hierarchical information.

## 4.4 Discussion of Chapter 4

Cognitive load has been shown to enhance selection of global information (Ahmed & de Fockert, 2012) and this finding has been interpreted as cognitive load inducing a "shift towards global processing". However, we have suggested that the effect of cognitive load should depend on the salience of the stimulus, such that cognitive load should make the most salient level of a hierarchical stimulus more difficult to ignore. Whereas increased interference from global information has been found in a local-selection task performed on hierarchical patterns with strong global salience (Ahmed & de Fockert, 2012), in the present study we showed that cognitive load increases interference from *local* information in a global-selection task performed on hierarchical patterns with strong local salience (Experiment 7). When, however, we used stimuli in which local and global salience were reasonably well matched, task switching increased local and global interference to the same extent (Experiment 6). This suggests that cognitive load does not always facilitate selection of global information. Rather, the effect of cognitive load on selection of hierarchical information depends on stimulus salience: cognitive load impairs local selection when global salience is strong but impairs global selection when local salience is strong. In the present experiments we also confirmed that task-switching is an effective manipulation of cognitive load in a hierarchical-patterns task and our results suggest that task-switching, common in everyday life, affects how well we can selectively process hierarchical information.

In Experiments 4 and 5 (reported in Chapter 3), we attempted to manipulate local-global salience by varying the exposure-duration of the experimental stimuli. However, we found that participants in the unlimited-exposure condition were still quite quick to respond to patterns and we questioned the efficacy of manipulating local-global salience through exposure duration in a speeded-response paradigm. Thus, in the present experiments we manipulated local-global salience using pattern density. Our data from the present experiments suggest that our manipulation of pattern density did indeed affect local-global salience. In Experiment 6, where we used medium-density stimuli, local and global responses were equally fast; with the low-density patterns used in Experiment 7, however, we observed a local advantage. These data suggest that local salience was strong for low-density patterns, but that global and local salience was reasonably matched for medium-density patterns.

We have shown that high cognitive load can increase interference from irrelevant local information when local salience is strong. It is perhaps unsurprising that this pattern of data has not been reported before – and that Ahmed and de Fockert (2012) concluded that high cognitive load always facilitates global processing – as research with hierarchical patterns tends to use very dense stimuli. Navon's (1977) original stimuli were very dense, with 19 or 22 local elements comprising each global structure. This is in stark contrast to Kimchi and Palmer’s (1982) low-density stimuli used in Experiment 7, which have only three or four individual elements in each pattern. By only using hierarchical patterns with strong global salience to make conclusions about hierarchical processing in real-world vision, we are missing an important interaction between local-global salience and top-down effects on hierarchical processing. This is especially important when investigating individual differences in hierarchical processing; where individual differences are associated with top-down differences in cognitive control, using only hierarchical patterns with strong global salience will only tell us half the story.

Comparing performance on a selection task with both low- and high-density patterns allows us to distinguish between different accounts of the underlying mechanisms responsible for individual differences in performance. If individual differences are due to differences in cognitive control, then interference from irrelevant local information should increase for stimuli with strong local salience (Experiment 7) while interference from irrelevant global information should increase for stimuli with strong global salience (as in the findings of Ahmed & de Fockert, 2012). However, if individual differences in local-global selection *always* result in impaired local selection or *always* result in impaired global selection, regardless of local-global salience, then we could conclude that the underlying mechanism is unlikely to be associated with cognitive control.

In addition to the effect that cognitive load has on cognitive control (induced by task-switching), it is worth considering the possibility that task-switching might also affect the relative activation of the global-dominant right- and local-dominant left-hemisphere mechanisms and with it the salience of global and local information. Increasing task difficulty has been shown to reduce right hemisphere activation so that brain activation becomes bilateral (Helton et al., 2010) and we have previously show that cognitive load reduces the salience of global information and enhances the salience of local information (Experiments 2 and 3). It is possible that task-switching might make it more difficult to activate the right-lateralised global-level mechanism which means that global salience should be reduced and interference from irrelevant local information should be increased (on a global-selection task). The effect of this would be apparent on trials where a global trial follows a local trial, as the global-level mechanism may not be fully activated and interference from local-level information should be increased. On trials where a local trial follows a global trial, however, responses should not be affected by irrelevant global structure.

Our findings followed this pattern, but only when we used low-density hierarchical patterns (Experiment 7); when we used medium-density patterns, we did not see an asymmetric effect of task-switching on performance of the local- and global-selection tasks (Experiment 6). This is comparable to our findings reported in Experiment 4 (presented in Chapter 3) where we argued that local salience in our medium-density patterns was not strong enough for an effect of cognitive load on selection to be apparent. This suggests that, although task-switching may be affecting the activation of the global-level mechanisms, it may only be possible to observe the effect of cognitive load on perceptual bias feed into a selection task when local information is sufficiently salient.

In conclusion, we have demonstrated that high cognitive load does not always promote a "shift towards global processing". Rather, we have shown that high cognitive load (as induced by task-switching in Experiments 6 and 7) can make irrelevant local detail more difficult to ignore, but only when it is salient. This is important for two reasons. Firstly, it shows that cognitive load does not necessarily make people more global but can make processing more local when local salience is strong. Secondly, our data suggest that task-switching in the real-world may affect the selective processing of hierarchical information. The modern world is full of distractions that compete for our attention and indulging each e-mail, text message and phone call may have an impact on how we process the visual world. The effect that it will have on our ability to select information, however, will depend on the salience of information in the environment.

We now move our investigation beyond hierarchical patterns. Although research into local-global processing is most frequently conducted with hierarchical patterns, these patterns have received criticism for lacking certain grouping principles – such as closure and connectedness – which define global structure in real-world objects (Navon, 2003). This may mean that the global salience of 'real-world' objects in which local detail is connected to global structure may not decay with time. As real-world vision does not consist of a series of limited-exposure presentations, the selective-attention version of the hierarchical-patterns task may not indicate the efficiency of selection in real-world scenarios, in which stimuli can often be inspected for longer periods of time. Thus, in Chapter 5 we continue our investigation of hierarchical processing by using the Framed Line Test (Kitayama et al., 2003), an unlimited-exposure paradigm designed to address selection of local and global hierarchical information.

# CHAPTER 5 - THE FRAMED LINE TEST

## 5.1 Introduction

Over the last three chapters, we have explored the effect exerted by cognitive load on perceptual bias and attentional selection. It has been suggested that high cognitive load always causes the attentional window to spread and will thus always benefit global processing (Ahmed & de Fockert, 2012). However, we have found that cognitive load can increase interference from irrelevant local detail when local salience is strong (Experiment 7, presented in Chapter 4). This suggests that the effect of cognitive load on the selection of hierarchical information is influenced by stimulus-driven factors which determine local-global salience. The present chapter continues this line of investigation but moves away from hierarchical patterns as a means of investigating hierarchical processing. Although hierarchical patterns provide a compelling index of local-global processing, it has been noted that they lack certain grouping properties, such as closure and connectedness, that are present in real-world objects (Navon, 2003). In this chapter, we investigate the effect of cognitive load on performance of the Framed Line Test (Kitayama et al., 2003), a task which measures local and global selection using a stimulus where the local element is usually physically connected to the global structure. We show that simply disconnecting the local line from its global context alters the relative salience of local and global information and can dramatically alter the effect of cognitive load on selective attention to hierarchical information.

To reiterate, the experiments presented in this thesis so far have explored the effect of cognitive load on hierarchical processing exclusively through the use of hierarchical patterns. Hierarchical patterns allow exploration of the ability to select either local or global information without interference from the other hierarchical level (e.g., Navon, 1977; Kimchi, 1992). However, the ecological validity of hierarchical patterns has been questioned as they lack grouping principles such as connectedness and closure which define many real-world objects (Navon, 2003). Previously, we discussed a host of stimulus-driven factors which could affect local-global salience in hierarchical patterns. In the present chapter we move beyond hierarchical patterns in our investigation of cognitive load and hierarchical processing and present a series of experiments which explore the extent to which our observations with hierarchical patterns are applicable to objects defined by other grouping principles. We suggest that cognitive load should still make it more difficult to ignore salient information, but the properties that define local-global salience in hierarchical patterns (e.g., pattern density and exposure duration) may not be important in defining local-global salience in objects with stronger groupings.

An important grouping factor that is absent in hierarchical patterns is *uniform connectedness* (Palmer & Rock, 1994) which describes how elements that are physically connected to each other, and uniform in terms of their visual properties (e.g., colour, luminance), form a single entry-level perceptual unit upon which grouping principles later act. Connectedness is a strong determinant of how the visual field is initially segregated into likely candidates for object groupings and has been shown to be dominant over proximity, similarity, and both similarity and proximity in conjunction

(Palmer & Rock, 1994; although see Han, Humphreys & Chen, 1999). Indeed, local elements in hierarchical patterns are distinct connected objects in their own right which are then grouped by proximity, similarity and common onset (e.g., Han et al., 1999; Kimchi, 2009; Wertheimer, 1923/1950) before the process of *shape formation* determines how these clusters appear as a global whole (Koffka, 1935; Trick & Enns, 1997). Palmer and Rock went so far as to suggest that connectedness was the "foundation of perceptual organisation" and "what really 'goes together' in the strongest physical sense is a single connected piece of matter, not separate ones that happen to be near each other in space" (p. 32). Thus, objects defined by connectedness should have stronger global salience than hierarchical patterns.

Furthermore, the global salience of objects in which global structure is defined by connectedness should not decay over time and we should be able to see the effect of cognitive load on selection of hierarchical information in an unlimited exposure-duration task, unlike hierarchical patterns in which global salience decays with exposure duration (e.g., Paquet & Merikle, 1984). In the present research we used stimuli in which global and local salience was manipulated by connecting or disconnecting the local element from the global structure. We predicted that global salience would be strong when the local element was attached to the global structure. In this circumstance, we would predict that cognitive load should have the same impact on selection as was observed by Ahmed and de Fockert (2012) in their selection task; we would expect cognitive load to make it harder to ignore salient global structure when selecting local detail. When, however, the local element is disconnected from the global structure, local salience should be stronger and we should find that cognitive load makes it more difficult to ignore salient local information when performing a global-selection task. In the present chapter, we used the Framed Line Test (FLT; Kitayama et al., 2003) – a selection task that uses stimuli in which local detail is connected to the global structure – to investigate the impact of cognitive load on selection of hierarchical information in an unlimited-exposure task. We first describe extant work with the original version of the task – in which the local element is connected to the global structure – before we describe a disconnected version of the task.

The Framed Line Test (FLT), as originally conceived by Kitayama et al. (2003; developed as an extension of the Rod and Frame Test; Witkin, 1950), is a pen-and-paper task designed as a measure both of the ability to integrate local information into its context and the ability to isolate it from its context (see Figure 28 for a schematic depiction of the task). In the FLT, participants are shown a square frame with a line descending from the top and, after it is removed from view, are required to redraw the line from memory in a test frame either i) in accordance with the line's absolute length, for the *absolute* task, or ii) its length relative to the first frame, for the *relative* task. Crucially, the first and second frame may be different sizes; thus, success in reproducing the line in the absolute task depends on the ability to isolate local detail and ignore surrounding context, whereas success on the relative task depends on the ability to integrate the line into the global structure. All participants perform both tasks; better performance on the absolute task is said to reflect a more local style of processing, whereas better performance on the relative task is said to indicate a more contextual/holistic style of processing.

As the FLT explores the ability to select global structure or local detail whilst ignoring distracting hierarchical information we discuss it here as a measure of selective attention to hierarchically structured information: successful performance on the absolute task requires that the participant ignores the distracting global context, whereas successful performance on the relative task requires that local detail is ignored. Thus, the absolute and relative tasks can be aligned respectively with the local and global tasks in the selective-attention hierarchical-patterns paradigm. Therefore, we expect cognitive load to affect performance on the FLT in the same way that cognitive load affects performance on the selective-attention hierarchical-patterns task: the effect of cognitive load should depend on stimulus-driven salience.

Research with the FLT has suggested that performance on the relative task should always be better than on the absolute task, given that a visible frame of reference (as in the relative task in the FLT) will always enable more accurate performance than when there is no visible frame of reference (as in the absolute task; Zhou et al.)[2]. This mirrors findings which suggest that phenomenal size is determined relationally (Rock & Ebenholtz, 1959) and that selection of line elements is more difficult when part of a configuration (known as the *configurational superiority* effect; Pomerantz & Garner, 1973). These observations combine to suggest that the global structure in the FLT – that is, the relationship between the line and the frame – is more salient than the line in isolation. Thus, the relative task should always be easier to perform than the absolute task and high cognitive load should disproportionately impair performance on the absolute task (the local-selection task) as it should make it more difficult to ignore the salient global context.

Evidence to support the idea that cognitive load may selectively impair performance on the relative task comes from a study which measured performance on the FLT while experimentally manipulating social power (Guinote, 2007). Social power, that is the extent to which an individual holds power over a situation, has been shown to alter cognition; powerless individuals are hyper-vigilant in the face of uncertainty (Keltner, Gruenfeld & Anderson, 2003), are at the mercy of others (Galinsky, Gruenfeld, &

[2] In the original task, Kitayama et al. (2003) found that American participants were better at the absolute task than at the relative task, whereas Japanese performance were better at the relative task than the absolute task. However, Zhou et al. (2008) conducted several replications of the original study with both American and Chinese participants and failed to find any circumstances where performance on the absolute task was better than performance on the relative task.

Magee, 2003) and exhibit less cognitive flexibility than powerful individuals (Guinote, 2007). Especially pertinent to the present research is that powerlessness has also been associated with impaired executive functioning (Smith, Jostmann, Galinsky & van Dijk, 2008). This means that powerless individuals could potentially be under higher cognitive load than powerful individuals. In a study into the effect of social power on basic cognition, participants were experimentally manipulated to feel either powerful or powerless, and then performed a number of tasks including the FLT (Guinote, 2007). Guinote found that powerful participants could perform the absolute and relative tasks equally well. Powerless participants, on the other hand, were significantly worse at the absolute task than the relative task (performance on the relative task did not differ from that of the powerful participants). Guinote suggested that powerless individuals found it harder to ignore irrelevant contextual information and therefore were less able to ignore the surrounding frame when performing the absolute task. We suggest that their impaired executive functioning – which could be analogous to operating under high cognitive load – made them less able to perform the more cognitively-demanding task of isolating the (connected) line from its salient global context.

Interestingly, Guinote (2007) also had participants perform a selective-attention hierarchical-patterns task, in which exposure durations were unlimited. In this task, powerless participants were relatively faster to respond to local elements than global structure, whereas no difference between responses to local detail or global structure were found with powerful individuals. It is possible that Guinote showed what we failed to demonstrate in Experiment 5 (reported in Chapter 3), namely that high cognitive load (driven by powerlessness) enhances the salience of local elements in an unlimited-exposure hierarchical-patterns paradigm and thus impairs selection of global structure. This may be because powerlessness is a stronger manipulation of cognitive load than our digit-span task.

In this chapter we present a series of experiments designed to explore the effect of cognitive load on performance of the FLT. We firstly report the results of an experiment on the connected FLT without a cognitive load manipulation so that we can confirm that global structure is indeed more salient than local detail (Experiment 8) and show that performance on the relative task is better than on the absolute task. We then run the connected FLT with an added cognitive load manipulation (Experiments 9 and 10); as global structure is more salient than local detail, we would expect high cognitive load to make it harder to isolate the local line element and to ignore its salient task-irrelevant context when performing the absolute task. Thus, performance on the absolute task should become worse under high cognitive load in comparison to low cognitive load. In the relative task, cognitive load should only increase interference from irrelevant *salient* information; as local information is less salient than global information in the FLT, we would not expect cognitive load to impair performance on the relative task.

Throughout the present thesis we have suggested that the effect of cognitive load on attentional selection should depend on stimulus-driven factors which determine local-global salience. Thus, high cognitive load should impair performance on the *relative* task if we can make the global structure less salient than the local line element. This is what we aimed to do in Experiment 11. Zhou et al. (2008) have previously demonstrated that superior performance on the relative task can be eliminated by degrading the context surrounding the line element. To achieve this they used paper cut-outs as frames rather than black squares printed onto paper. Furthermore, evidence has shown that irrelevant contextual elements are easily ignored when local elements are separable (Pomerantz & Garner, 1973). Thus, we reasoned that we could degrade global salience even further than Zhou et al. managed if we disconnected the line element from its global context. As the disconnected line and frame no longer form a single entry-level unit, local information should be more salient than global structure and cognitive load should increase distraction from the line when performing the relative task. Thus, in Experiment 11 we expected high cognitive load to impair performance on the *relative* task.

The four experiments presented in this chapter explore the effect of cognitive load on selection of hierarchical information and demonstrate that the effect of cognitive load is dependent on stimulus-driven local-global salience. If global context is more salient than local detail we expect cognitive load to increase processing of irrelevant global information. On the other hand, cognitive load will increase processing of irrelevant local information if local salience is strong. Although this is an idea we have explored in the last two chapters, the present experiments test the extent to which the effect of cognitive load on selection of hierarchical information is applicable beyond hierarchical patterns.

## 5.2 Experiment 8

In the present experiment, we ran the FLT in its original form to see whether participants would perform better on the relative task than the absolute task in the absence of cognitive load. Recent research has suggested that performance on the relative task should always be better than the absolute task as there is a visible frame of reference to assist with reproduction of the line element (Zhou et al., 2008). If we observe this pattern of performance in our sample it would suggest that global salience is stronger than local salience.

However, the FLT (Kitayama et al., 2003) was originally developed to demonstrate cross-cultural differences between ‘Westerners’ (thought to have a more analytic processing style) and ‘East Asians’ (thought to have a more contextual processing style). It was found that Westerners were better at the absolute task than the relative task, whereas East Asians were better at the relative task than the absolute task. This would suggest that our participants – who were a sample of university students studying at Goldsmiths, University of London, UK – might find local detail more salient than global structure. Faced with this discrepancy in the literature, we ran the FLT with no cognitive load first to establish whether our sample were better at the relative task (as in Zhou et al., 2008) or the absolute task (as in Kitayama et al., 2003).

### 5.2.1 Method

#### 5.2.1.1 Participants

Participants (*N* = 33; 28 females, 5 males; mean age 19.4 years) were first-year psychology undergraduates at Goldsmiths, University of London, and participated in exchange for course credit. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

#### 5.2.1.2 Design

The study used a mixed design, with *task* (*absolute* vs. *relative*) and *trial-type* (corresponding to five different stimulus trial-types; see Table 6 for dimensions and Appendix A for the complete stimulus set) as the within-subjects variable, and *order* (absolute task or relative task first) as the between-subjects variable. *Magnitude of error* from correct response, measured either as absolute error, in mm, or percentage error, in %, were the dependent variables.

#### 5.2.1.3 Apparatus and stimuli

Stimuli were similar to those used in Kitayama et al. (2003). Five differently-sized square frames with vertical lines descending from the top were used for five different *trial-types* and each was paired with a corresponding empty response-frame. As can be seen in Table 6, the proportional size relationship between pairs of frames, as well as the length of the line in the first frame, varied with the trial. In the version of the FLT developed by Kitayama et al. (2003), and used here, there are five different frame sizes; each frame is paired with another frame, forming five different frame-combinations, or trial-types, and the length of the original line is different for each trial (see Table 6 for details of the stimulus dimensions).

**Table 6.** *Sizes of frames in each trial and the length of their corresponding lines (mm)*

| | | | | **Correct line length** | |
|---|---|---|---|---|---|
| Trial type | Height of first frame | Length of line | Height of second frame | Absolute task | Relative task |
| 1 | 89 | 62 | 179 | 62 | 125 |
| 2 | 102 | 29 | 153 | 29 | 43 |
| 3 | 127 | 53 | 127 | 53 | 53 |
| 4 | 153 | 87 | 102 | 87 | 58 |
| 5 | 179 | 31 | 89 | 31 | 15 |

The task was performed using a pen and paper. Stimuli were printed on A4-size (297 x 210 mm) 210 gsm white card in black ink (1.5 point). Empty response frames were printed on A4-size 80 gsm white paper in black ink. Participants were provided with a medium-point (1.0 mm) black Bic ‘Cristal’ ballpoint pen with which to draw their responses.

Participants' responses were measured by the experimenter with a transparent ruler. The same ruler was used to measure responses from all participants to reduce any variation due to measurement error. An effort was made to either round up or round down to the nearest millimetre if the line length fell between two millimetre measurements.

#### 5.2.1.5 Procedure

Participants were seated at a table in a well-lit but quiet room. The task was verbally explained to participants with the aid of a schematic diagram (identical to Figure 28) to ensure that they were aware of the differences between the two tasks. The diagram was for illustrative purposes only and did not correspond to a specific trial type. Participants were told that in the absolute task they must copy the absolute length of the line and ignore its size in relation to the frame, whereas in the relative task they must take the size of the frame into account and redraw the line in the same proportion to the test frame as the first line was to the first frame. The experimenter ensured that both the absolute and relative tasks were completely understood before the trials began.

The FLT consists of ten trials, five absolute trials and five relative trials. Trials are blocked by task and participants are always aware in advance of each trial as to which task they are to perform. Participants were presented with each trial-type twice, once when performing the absolute task and once when performing the relative task. Half of the participants performed the absolute task first and the other half performed the relative task first; participants were alternately assigned to either the ‘absolute first’ or ‘relative first’ conditions.

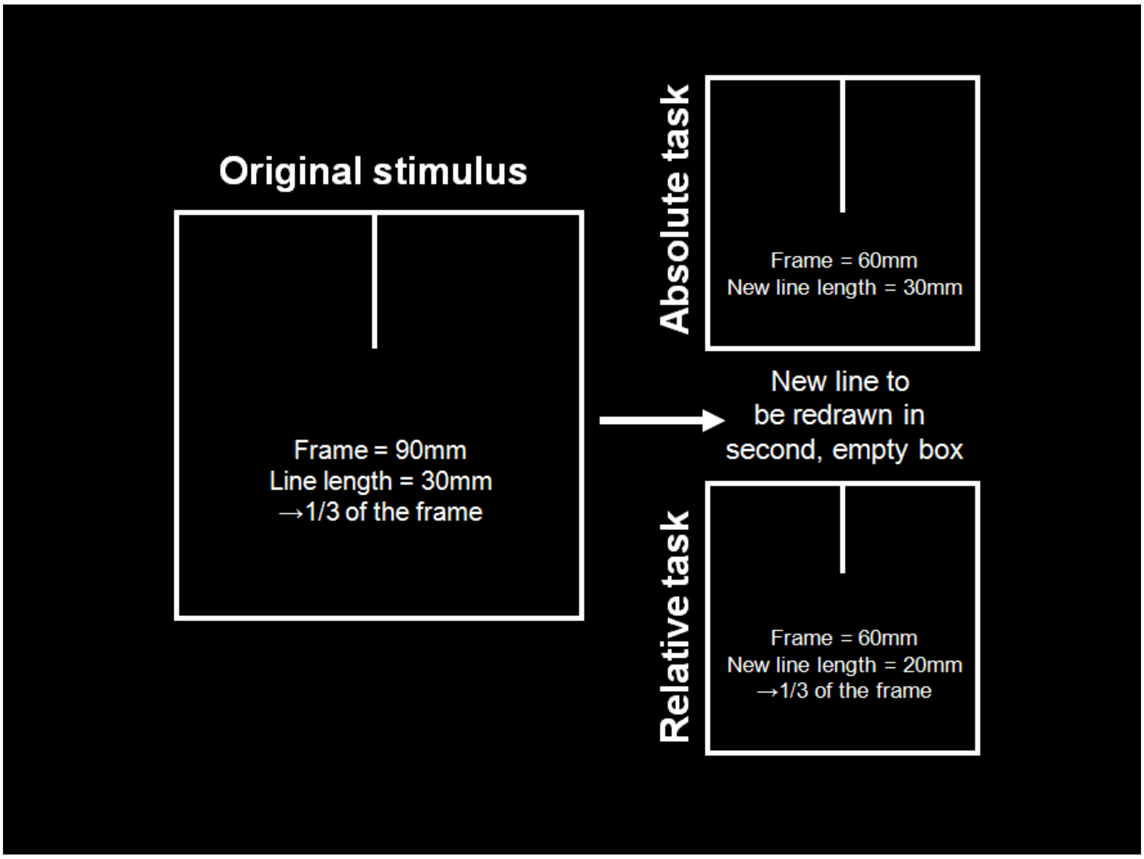



**Figure 28.** Schematic illustration of the Framed Line Test (FLT; Kitayama et al., 2003). Ideal performance on the absolute (top right) and relative (bottom right) tasks is illustrated and frame dimensions are for illustrative purposes only. Participants are first shown a frame with a line descending from the top (left image). In the absolute task (top right), the new line has been redrawn in the test frame exactly the same length as the line in the first frame (original stimulus on left), which in this instance is 30 mm. In the relative task (bottom right), the new line has been redrawn in the same proportion to the test frame as the first line was to the first frame, namely one third of the height of the frame.

At the beginning of each trial, participants were verbally reminded of the task that they were to perform. Each trial ran as follows. The experimenter drew a frame-and-line stimulus at random and placed it in front of the participant, and the participant was given five seconds to study it. The stimulus was then removed and the participant was asked to move to another table where the experimenter had placed the corresponding empty test frame. The change in location was to minimize the role that iconic memory could play in the reproduction of the line, as in Kitayama et al. (2003). The participant then redrew the line in the empty frame as best as possible, in accordance with task demands. In the absolute task, they attempted to draw the line the same absolute length as it was in the first frame. In the relative task, they redrew the line in the same proportion to the test frame as the first line was to the first frame. The participant then moved back to the first table to wait for the next trial to begin.

### 5.2.2 Results

Participant responses were measured with a ruler and calculated in terms of both the absolute error (mm) and percentage error (%) from the correct line length. The direction of error was not taken into account so that overestimations and underestimations of line length were treated equally. Although participants were reminded of the demands of both the absolute and relative tasks before each trial, there were some trials for which errors were extreme; in these instances, it was judged that the wrong task had been performed by the participant. Therefore, participants whose error on any trial of the absolute or the relative task exceeded three standard deviations from the group mean were excluded from further analysis. The data from only two participants were excluded from the final analysis in accordance with this criterion. In Experiments 4-7 we calculated inverse efficiency scores on the data; however, an inverse efficiency calculation is inappropriate for performance on the FLT because although there is an accuracy measure there is no measure of reaction time. Instead, we performed separate analyses on the data for absolute error (mm) and percentage error (%). These analyses are detailed below.

#### 5.2.2.1 Absolute error (mm)

Our first analysis was performed on the *mean magnitude of error* (mm). This was calculated by measuring the deviation from correct line length, in mm, ignoring the sign. The data were entered into a 2x5x2 mixed analysis of variance (ANOVA) with *task* (absolute vs. relative) and *trial type* (89-179, mm 102-153 mm, 127-127 mm, 153-102 mm, and 179-89 mm) as the within-subjects factors and *task order* (absolute task first or relative task first) as the between-subjects factor. There was a highly significant main effect of both *task* [$F(1, 29) = 15.04$, $p < .01$, $\eta = .34$] and of *trial-type* [$F(4, 116) = 8.4$, $p < .001$, $\eta = .23$], and furthermore the interaction between these two factors was highly significant [$F(4, 116) = 10.75$, $p < .001$, $\eta = .27$]. *Order* was non-significant as a main effect and did not contribute to any significant interactions [$p > .1$].

The main effect of *task* reflected the fact that errors were larger in the absolute task [$M$ = 8.95 mm, $SE$ = .59] compared to the relative task [$M$ = 6.04 mm, $SE$ = .5]. This suggested that our participants found the relative task easier than the absolute task. The interaction with *trial-type* suggested that this effect was not uniform across all trial types (see Table 7 for descriptives). Post-hoc *t*-tests revealed that errors in the absolute task were greater than errors in the relative task in all except the 102-153 mm trial-type (although this effect was statistically reliable in only the 153-102 trial-type [$t(30) = 5.9$, $p < .01$] after Bonferonni correction [all other tests $p > .5$]).

**Table 7**. *Mean magnitude of error (mm) for each trial type in both the absolute and relative tasks (Experiment 8).*

| Size of first and second frames | | 89 – 179 mm | 102 – 153 mm | 127 – 127 mm | 153 – 102 mm | 179 – 89 mm |
|---|---|---|---|---|---|---|
| Absolute Task | *M* | 10.06 | 5.97 | 7.84 | 15.03 | 5.87 |
| | *SE* | *1.19* | *0.87* | *1.05* | *1.7* | *0.81* |
| Relative Task | *M* | 9.32 | 7.23 | 5.32 | 4.26 | 4.06 |
| | *SE* | *1.19* | *1.03* | *0.87* | *.61* | *0.85* |

5.2.2.2 Percentage error (%)

We repeated the analysis on the *mean percentage error* (%). This was because a 1 mm error on a line of 15 mm is a much greater percentage of error than a 1 mm deviation from a line of 125 mm. We calculated this by dividing the absolute error (mm) by the correct line length, to see the percentage error from correct line length (see Table 8).

**Table 8**. *Mean percentage error (%) for each trial-type in both the absolute and relative tasks (Experiment 8).*

| Size of first and second frames | | 89 – 179 mm | 102 – 153 mm | 127 – 127 mm | 153 – 102 mm | 179 – 89 mm |
|---|---|---|---|---|---|---|
| Absolute Task | *M* | 16.23 | 20.58 | 14.79 | 17.28 | 18.94 |
| | *SE* | *1.93* | *3.0* | *1.98* | *1.95* | *2.61* |
| Relative Task | *M* | 7.46 | 16.8 | 10.04 | 7.34 | 27.1 |
| | *SE* | *.95* | *2.4* | *1.64* | *1.05* | *5.66* |

As in the previous analysis, *task* and *trial-type* were the within-subjects variables and *order* was the between-subjects variable. The main effect of *task* was marginally significant [$F(1, 29) = 3.83$, $p = .06$, $\eta = .12$]; percentage error was greater in the absolute task [$M = 17.56$ %, $SE = .1.18$] than in the relative task [$M = 13.75$ %, $SE = .1.61$]. There was a main effect of *trial-type* [$F(4, 116) = 7.61$, $p < .01$, $\eta = .21$], which interacted with *task* [$F(4, 116) = 4.26$, $p < .05$, $\eta = .13$]. Error in the absolute task was significantly higher than that in the relative task for the 89-179 mm [$t(30) = 4.34$, $p <$

.001] and 153-102 mm [$t(30) = 4.41$, $p < .001$] trial-types but all other comparisons were non-significant [$p > .1$]. *Order* was not significant as a main effect and did not contribute to any significant interactions [$p > .1$].

### 5.2.3 Discussion

The data from the present experiment show that our participant sample found the relative task easier than the absolute task, as evidence by a greater magnitude of error in the absolute task than in the relative task. This is in agreement with research that suggests that performance should be better in a task with a visible frame of reference (e.g., Zhou et al., 2008), such as in the relative task, and suggests that global salience is stronger than local salience with these stimuli. This is analogous to most instances of the selective-attention hierarchical-patterns task in which a global advantage is usually observed (as most studies use hierarchical patterns with strong global salience). This is at odds with Kitayama et al (2003), whose data suggest that our 'Western' participants should show an advantage for the absolute task over the relative, and adds to evidence which has failed to replicate their findings (e.g. Zhou et al, 2008). The present experiment gave us confidence in the FLT as a task that could be used to measure the effect of cognitive load in a task where global salience is strong at unlimited exposure durations. In Experiment 9, we explored the effect of cognitive load on performance of the FLT.

## 5.3 Experiment 9

In Experiment 8, we demonstrated that global salience was stronger than local salience in the connected FLT. Ahmed and de Fockert (2012) have shown that cognitive load makes it harder to isolate local information from its global context when global salience is very strong. They showed this pattern in performance using hierarchical patterns; in the present experiment, we wanted to show that the same effect could be observed for stimuli other than hierarchical patterns. Thus, in the present experiment we ran the connected FLT with an added cognitive-load manipulation. We predicted that cognitive load should make it more difficult to ignore salient global information and thus that cognitive load should impair performance of the absolute task. However, cognitive load is unlikely to have any effect on performance of the relative task as the irrelevant local detail is less salient than the global structure and consequently should not be distracting. In the present experiment, participants performed the FLT twice, once under low cognitive load and once under high cognitive load.

### 5.3.1 Method

#### 5.3.1.1 Participants

We endeavoured to test the same number of participants as Kitayama et al. (2003) in their original experiment (twenty) in each of our four conditions (see the variable *order* in section *5.3.1.2 Design* below for further explanation). Thus, eighty-four participants (63 females, 21 males; mean age 24.1 years) were recruited from either Goldsmiths, University of London, UK, or the Science Museum, London, UK. Goldsmiths students were reimbursed with course credit and Science Museum staff received snacks in exchange for participation. The study was approved by the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

#### 5.3.1.2 Design

The design was mixed, with *task* (absolute vs. relative), *trial-type* (89-179, 102-153, 127-127, 153-102, 179-89 mm) and *cognitive load* (low vs. high) as the within-subjects variables, and *order* as the between-subjects variable. Participants performed the FLT twice, once under low cognitive load and once under high cognitive load. The order in which cognitive load was performed (low first or high first) was counterbalanced across participants. The manipulation of task was nested within the manipulation of cognitive load and counterbalanced (absolute task followed by relative task, or relative task followed by absolute task). This meant that there were four possible levels of order. The four possible orders were: (1) absolute task low cognitive load (AL), relative task low cognitive load (RL), absolute task high cognitive load (AH), relative task high cognitive load (RH); (2) RL, AL, RH, AH; (3) AH, RH, AL, RL; (4) RH, AH, RL, AL. *Mean magnitude of error* from correct response, measured either as absolute error, in mm, or percentage error, in %, were the dependent variables.

#### 5.3.1.3 Apparatus and stimuli

The apparatus and stimuli were identical to those used in Experiment 8 with the exception that there was now a cognitive load manipulation. For the low-cognitive-load condition the numbers 1-9 were printed on separate pieces of card (one card for each number). The numbers were shuffled for each trial and one was drawn at random on each trial. To prepare the high cognitive load manipulation six numbers from 1-9 were drawn, without replacement, using a program developed for a previous experiment. 40 of these combinations of six numbers were printed on white card. One six-digit number was selected at random for each trial.

#### 5.3.1.4 Procedure

The procedure was identical to that in Experiment 8, with the exception that the FLT was now performed twice by each participant, once under low cognitive load (remember one digit) and once under high cognitive load (remember six digits). In the low-cognitive-load condition, participants were shown a digit on a piece of card and were told to memorise it for the duration of the trial. They were then shown the first frame and line, which was replaced with the test frame into which they were to draw the line, as in Experiment 8. When they had drawn the line they wrote down the digit that they had been remembering, at the bottom of the page. The next trial then began. The procedure for the high-cognitive-load condition was the same as for the low load condition, with the exception that participants were shown six digits at the beginning of each trial. Participants were required to write down the six digits at the end of the trial in the same order that they had been presented at the beginning of the trial.

## 5.3.2 Results

### 5.3.2.1 Absolute error (mm)

As with Experiment 8, there were some trials for which errors were extreme and it was judged that the wrong task had been performed by the participant. Therefore, participants whose error on any trial of the absolute or the relative task exceeded three standard deviations from the group mean were excluded from further analysis. The data of seven participants were excluded in accordance with this threshold. Thus, the data of 77 participants were entered into the analysis. A 2x2x5x4 mixed ANOVA was performed on the data with *task* (absolute vs. relative), *cognitive load* (low vs. high) and *trial-type* (89-179 mm, 102-153 mm, 127-127 mm, 153-102 mm, and 179-89 mm) as the within-subjects variables and *order* as the between-subjects variable. *Order* was non-significant as a main effect and did not contribute to any significant interactions, and it was therefore removed from the analysis. Table 9 shows the mean error for all conditions.

**Table 9**. *Mean magnitude of error (mm) in line reproduction made for each trial-type for each task under both low and high cognitive load (Experiment 9).*

| | Size of first and second frames | | 89 – 179 mm | 102 – 153 mm | 127 – 127 mm | 153 – 102 mm | 179 – 89 mm |
|---|---|---|---|---|---|---|---|
| Absolute Task | Low Cognitive Load | *M* | 7.62 | 4.0 | 5.19 | 12.42 | 5.49 |
| | | *SE* | *0.8* | *0.4* | *0.4* | *1.01* | *0.49* |
| | High Cognitive Load | *M* | 11.48 | 4.21 | 5.19 | 12.88 | 6.04 |
| | | *SE* | *1.55* | *0.66* | *0.5* | *1.01* | *0.45* |
| Relative Task | Low Cognitive Load | *M* | 11.23 | 5.34 | 4.48 | 5.91 | 3.9 |
| | | *SE* | *0.87* | *0.58* | *0.2* | *0.68* | *0.38* |
| | High Cognitive Load | *M* | 9.97 | 7.01 | 4.84 | 6.29 | 2.62 |
| | | *SE* | *0.82* | *0.64* | *0.51* | *0.69* | *0.27* |

There was a significant main effect of *task* [$F(1, 76) = 10.62$, $p < .01$, $\eta = .12$] indicating that participants overall were more accurate on the relative task than the absolute task, replicating our finding from Experiment 8. The main effect of *cognitive load* was marginally significant [$F(1, 76) = 3.09$, $p = .08$, $\eta = .04$], indicating a trend for performance to be worse overall under high than low cognitive load.

The interaction of interest here was between *task* and *cognitive load*. The prediction was that cognitive load would impair performance on the absolute task more than on the relative task. Although Figure 29 shows a trend in that direction, the interaction between *task* and *cognitive load* was only marginally significant [$F(1, 76) = 2.89$, $p = .09$, $\eta$ = .04].

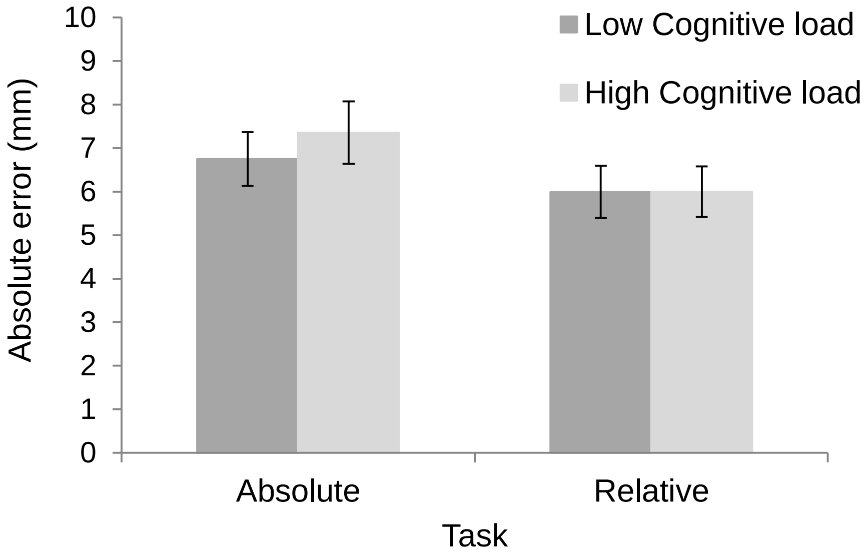



**Figure 29.** *Mean magnitude of error (mm) for all trial-types combined for the absolute and relative tasks under low and high cognitive load (Experiment 9). Error bars represent one standard error of the mean.*

The main effect of *trial-type* was significant [$F(4, 304) = 50.11$, $p < .01$, $\eta$ = .4] and interestingly contributed to a significant interaction between *task, cognitive load,* and *trial-type* [$F(4, 304) = 4.58$, $p < .01$, $\eta$ = .06], suggesting that cognitive load affected task performance differently for different trial-types. We reasoned that we might only see an effect of cognitive load on task performance in the trial-types where the first frame and test frame varied the most in size (89-179 mm and 179-89 mm) and there was most room for error. In contrast, we might not expect an effect of cognitive load in the trial-types where the first frame and test frame varied less in size (102-153 mm and 153-102 mm) or indeed where the first frame and test frame were the same size (127-127 mm).

To explore this prediction we combined the data from the 89-179 mm and 179-89 mm trial-types to generate a new *most extreme* condition; we then combined the data from the 102-153 mm and 153-102 mm trial-types to generate a new *least extreme* condition (see Figure 30). The resulting data were entered into a 2x2x2 ANOVA with *task* (absolute vs. relative), *cognitive load* (low vs. high), and *trial-type* (most extreme vs. least extreme) as the factors.

Our interaction of interest was *task* x *cognitive load* x *trial-type*, which was significant [$F(1, 76) = 12.32$, $p < .01$, $\eta = .14$]. This suggests that cognitive load did indeed affect performance differently in the *most extreme* and *least extreme* trial-types. We followed this interaction up with two further 2x2 ANOVAs, one on the *most extreme* trial-types and one on the *least extreme* trial-types. For the least extreme trial-types there was a main effect of *task* [$F(1, 76) = 14.6$, $p < .001$, $\eta = .16$] – where performance on the absolute task was worse than on the relative task – but no other main effects or interactions were significant. For the most extreme trial-types, however, the main effects of *task* and *load* were non-significant [$p > .1$] but the *task* x *load* interaction was significant [$F(1, 76) = 11.66$, $p < .01$, $\eta = .13$]. Follow-up Bonferroni-corrected *t*-tests confirmed that this interaction was driven by the asymmetrical effect of cognitive load; high cognitive load significantly impaired performance on the absolute task [$t(76) = -2.58$, $p < .05$] but significantly improved performance on the relative task [$t(76) = 2.57$, $p < .05$].

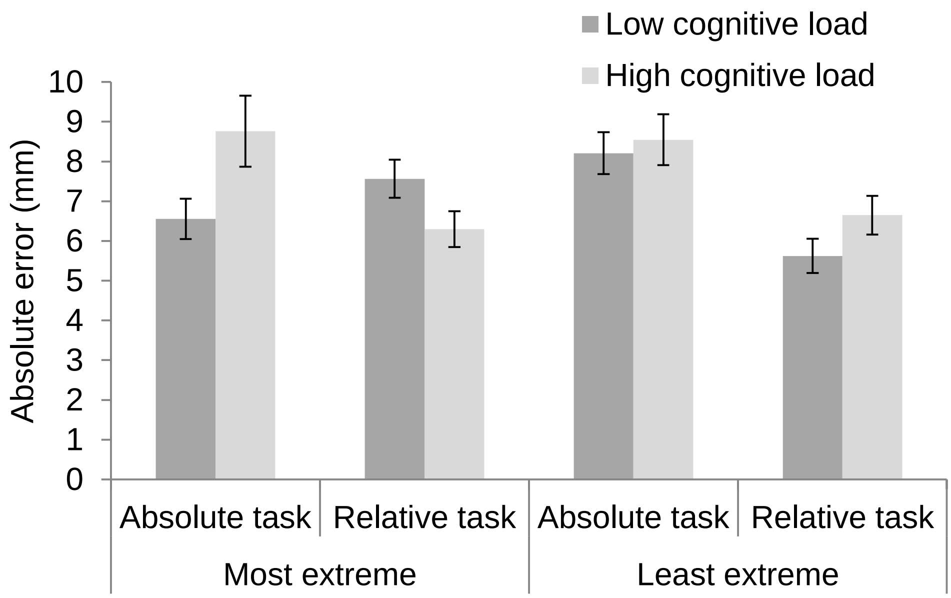



**Figure 30.** *Mean absolute error (mm) for the most extreme (89 – 179 mm and 179 – 89 mm) and the least extreme (102 – 153 mm and 153 – 102 mm) trial-types for the absolute and relative tasks under low and high cognitive load (Experiment 9). Error bars represent one standard error of the mean.*

5.3.2.2 Percentage error (%)

As in Experiment 8, we repeated the original analysis – with all five trial-types – using percentage error as our dependent variable (see Table 10). There was still a main effect of *task* [$F(1, 76) = 5.11$, $p < 0.05$, $\eta = .06$] and *trial-type* [$F(4, 304) = 29.59$, $p < .01$, $\eta = .28$] but not of *load* [$p > .1$]. Crucially, the interaction between *task* and *load* was significant [$F(1, 76) = 3.96$, $p = .05$, $\eta = .12$], which suggested that the effect of cognitive load was not uniform across tasks (see Figure 31). Performance in the relative task was unaffected by high cognitive load [$p > .05$]. There was a trend for performance in the absolute task to be impaired by high cognitive load, although this follow-up *t*-test was only marginally significant [$t(76) = -1.8$, $p = .08$, one-tailed].

We repeated the analysis using only the *most extreme* and *least extreme* trial-types, as we did when analysing absolute error (mm). The data were entered into a 2x2x2 ANOVA with *task* (absolute vs. relative), *cognitive load* (low vs. high), and *trial-type* (most extreme vs. least extreme) as the factors (see Figure 32). The three-way interaction between *task, load* and *trial-type* was significant [$F(1, 76) = 17.81$, $p < .001$, $\eta = .19$] and therefore ran two further ANOVAs, one on the most extreme trial-types and the other on the least extreme trial-types. For the least extreme trial-types there were no significant main effects or interactions [$p > .05$]; for the most extreme trial-types, however, there was a significant interaction between *task* and *cognitive load* [$F(1, 76) = 14.9$, $p < .001$, $\eta = .16$]. Follow-up *t*-tests confirmed the pattern observed in the data for absolute error (mm): the percentage error was larger under high than low cognitive load in the absolute task [$t(76) = -2.42$, $p < .05$] but smaller under high than low cognitive load in the relative task [$t(76) = 3.45$, $p < .05$].

**Table 10**. *Percentage error (mm) in line reproduction made for each trial-type for each task under both low and high cognitive load (Experiment 9).*

| | Size of first and second frames | | 89 – 179 mm | 102 – 153 mm | 127 – 127 mm | 153 – 102 mm | 179 – 89 mm |
|---|---|---|---|---|---|---|---|
| Absolute Task | Low Cognitive Load | *M* | 11.33 | 13.89 | 9.93 | 14.09 | 16.7 |
| | | *SE* | *1.17* | *1.46* | *0.89* | *1.16* | *1.47* |
| | High Cognitive Load | *M* | 14.78 | 14.12 | 9.95 | 14.42 | 18.34 |
| | | *SE* | *1.52* | *2.37* | *0.97* | *1.15* | *1.41* |
| Relative Task | Low Cognitive Load | *M* | 8.67 | 11.21 | 8.35 | 10.53 | 25.21 |
| | | *SE* | *0.68* | *1.26* | *0.98* | *1.21* | *2.47* |
| | High Cognitive Load | *M* | 7.79 | 15.86 | 8.50 | 10.79 | 17.81 |
| | | *SE* | *0.65* | *1.43* | *0.9* | *1.24* | *1.91* |

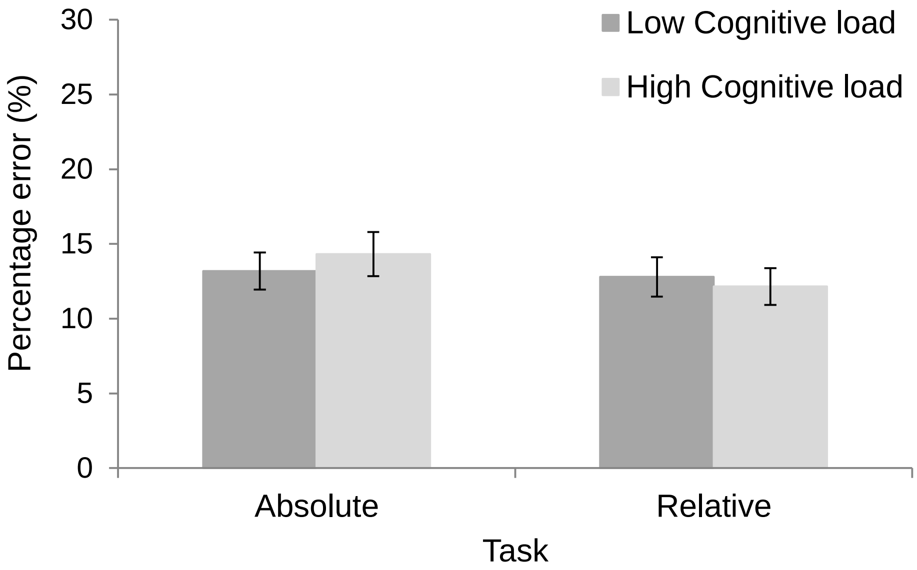



**Figure 31**. *Percentage error (%) for the absolute task and relative task under both low and high cognitive load for all trial-types combined (Experiment 9). Error bars represent one standard error of the mean.*

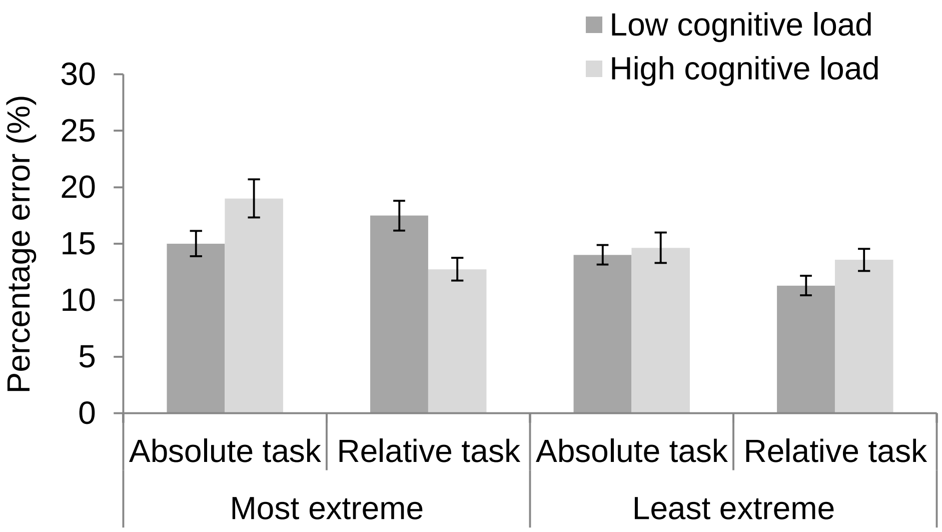



**Figure 32.** *Combined percentage error (%) in line for the most extreme (89 – 179 mm and 179 – 89 mm) and the least extreme (102 – 153 mm and 153 – 102 mm) trial-types for the absolute and relative tasks under low and high cognitive load (Experiment 9). Error bars represent one standard error of the mean.*

### 5.3.3 Discussion

As in Experiment 8, our participants were better at the relative task than the absolute task – regardless of cognitive load – which suggests that on the whole global salience remains stronger than local salience when a cognitive load manipulation is added to the task. We predicted that high cognitive load would impair performance on the absolute task as it would make it more difficult to ignore the salient global context when reproducing the line in isolation. We aligned this with Ahmed and de Fockert's (2012) finding which suggested that cognitive load makes it more difficult to ignore irrelevant but salient global information when performing a local-selection task with hierarchical patterns. This is what we found, but only when we looked at the trial-types where the difference in size between the first frame and test frame was most extreme (and there was arguably most room for error). When we looked at these trial-types only, high cognitive load not only significantly impaired performance on the absolute task but significantly improved performance on the relative task.

In Experiment 10, we created a pared down version of the FLT where we used only the 'most extreme' trial-types. This was to ensure that that the effect of cognitive load on selection remains when the 'least extreme' trial-types (and the 127-127 mm trial-type) are no longer included.

## 5.4 Experiment 10

In Experiment 9, we demonstrated that cognitive load impaired performance on the absolute task and improved performance on the relative task. However, this was only when we looked at the trial types where the first frame and test frame differed the most in size. With the present experiment we aimed to replicate the findings of Experiment 9 using only the 89-179 mm and 179-89 mm trial-types. This was to ensure that the effect of cognitive load observed in Experiment 9 is not limited to situations in which the most-extreme trial-types are intermixed with the least-extreme trial types. As we deliberately used fewer trial types, and as order did not contribute significantly to any interactions, we also felt that we could recruit fewer participants in E10 compared to E9.

### 5.4.1. Method

#### 5.4.1.1 Participants

Fifty-five participants (37 females, 18 males; 29.03 years,) were either members of staff at the Science Museum, London, UK, or were volunteers from Goldsmiths, University of London, UK, and participated in exchange for snacks. The study was approved by the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

#### 5.4.1.2 Design

The design was identical to that in Experiment 9, with the exception that there were now only two levels of trial-type (89-179 and 179-89 mm).

#### 5.4.1.3 Apparatus and stimuli

The apparatus and stimuli were identical to in Experiment 9.

#### 5.4.1.4 Procedure

The procedure was identical to that in Experiment 9. As fewer trial-types were used, the FLT now included only two trials in the absolute task and two trials in the relative task, meaning that the Experiment was 8 trials long (four trials performed under low cognitive load and four under high cognitive load).

### 5.4.2 Results

As for previous experiments, participants were excluded from the analysis if they were judged to have lapsed into accidentally performing the wrong task. The data from only two participants were excluded on this basis. For Experiments 8 and 9, we conducted two separate analyses, one for the absolute magnitude of error (mm) and one for the percentage error (%). In the present experiment, we used only the percentage error (%)

in our analysis as the correct line lengths are dramatically different in the 89-179 mm (correct line length is 125 mm) and 179 – 89 mm (correct line length is 15 mm) trial-types for the relative task. As a result, a 1 mm absolute error is very different in both of these trial-types in terms of percentage error that it represents (0.8% and 6.7% respectively). Values for absolute error are however reproduced in Table 11.

**Table 11**. *Mean absolute magnitude of error (mm) in line reproduction made for each trial-type for both the absolute task and relative task under both low and high cognitive load (Experiment 10).*

| | Size of first and second frames | | 89 – 179 mm | 179 - 89 mm |
|---|---|---|---|---|
| Absolute Task | Low Cognitive Load | *M* | 8.74 | 6.15 |
| | | *SE* | *1.56* | *0.61* |
| | High Cognitive Load | *M* | 11.92 | 7.11 |
| | | *SE* | *2.29* | *0.59* |
| Relative Task | Low Cognitive Load | *M* | 10.21 | 3.62 |
| | | *SE* | *0.95* | *0.45* |
| | High Cognitive Load | *M* | 9.94 | 3.43 |
| | | *SE* | *1.13* | *0.41* |

Percentage error data were entered into a 2x2x2 within-subjects ANOVA with *task* (absolute vs. relative), *cognitive load* (low vs. high cognitive load) and *trial-type* (89-179 mm and 179-89 mm) as the within-subjects variables. As order did not interact with any factors in Experiment 9, we excluded it from the present analysis.

Descriptive statistics for the percentage magnitude of error can be seen in Table 12. The main effect of *task* was marginally significant [$F(1, 52) = 3.03$, $p = .09$, $\eta^2 = .6$]; there was a trend for performance to be worse overall in the absolute task [$M = 19.16$, $SE = 1.78$] than in the relative task [$M = 15.84$ %, $SE = 1.29$]. The main effect of *cognitive load* was non-significant [$p > .1$]. The main effect of *trial-type* was significant and was qualified by a significant interaction with *task* [$F(1, 52) = 10.09$, $p > .01$, $\eta^2 = .16$] but after Bonferroni-correction no pairwise-comparisons were significant.

Importantly, the interaction between *task* and *cognitive load* was significant [$F(1, 52) = 4.74$, $p < .05$, $\eta^2 = .08$; see Figure 33]. Bonferroni-corrected follow-up *t*-tests revealed that performance on the absolute task was impaired by high cognitive load [$t(52) = -2.19$, $p < .05$; one-tailed] whereas performance on the relative task was unaffected by cognitive load [$p > .1$]. The interaction between *task*, *cognitive load* and *trial-type* was non-significant, indicating that the effect of cognitive load on performance was the same for both the 89-179 mm and 179-89 mm trial-types.

**Table 12**. *Mean percentage error (%) in line reproduction made for each task-type for each task under both low and high cognitive load (Experiment 10).*

| | Size of first and second frames | | 89 – 179 mm | 179 - 89 mm |
|---|---|---|---|---|
| Absolute Task | Low Cognitive Load | *M* | 14.24 | 19.72 |
| | | *SE* | *2.54* | *1.96* |
| | High Cognitive Load | *M* | 19.6 | 23.07 |
| | | *SE* | *3.68* | *1.92* |
| Relative Task | Low Cognitive Load | *M* | 8.36 | 24.28 |
| | | *SE* | *0.76* | *3.03* |
| | High Cognitive Load | *M* | 7.95 | 22.77 |
| | | *SE* | *.91* | *2.77* |

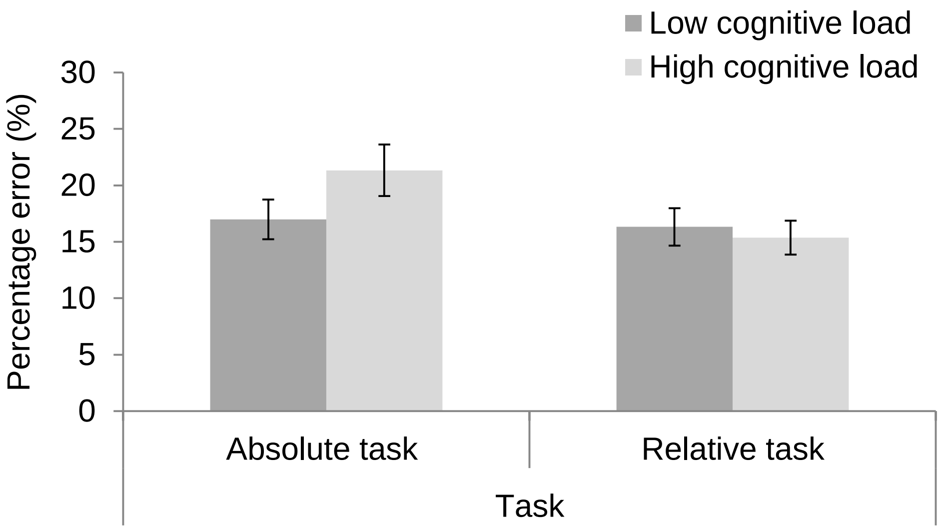



**Figure 33.** *Percentage error (%) in relation to the length of the original line for the 89-179 and 179-89 trial-types combined for the absolute and relative tasks under low and high cognitive load (Experiment 10). Error bars represent one standard error of the mean.*

### 5.4.3 Discussion

The present experiment replicated the finding from Experiment 9 showing that high cognitive load significantly impairs performance in the absolute task. However, there is no longer evidence to suggest that cognitive load improves performance on the relative task. Combining findings from Experiments 9 and 10, we suggest that cognitive load makes it more difficult to ignore irrelevant-yet-salient global information.

## 5.5 Experiment 11

With the previous three experiments, we have demonstrated a pattern of findings consistent with the suggestion that the connected FLT elicits strong global salience. Under these conditions we have presented evidence to suggest that cognitive load impairs performance on a task of local selection (the absolute task). We suggest that cognitive load makes it more difficult to ignore the salient global context when selecting the local line element. This is consistent with Ahmed and de Fockert's (2012) finding that performance on a task of local selection deteriorates with cognitive load when using hierarchical patterns. Having replicated this finding with the FLT, with the present experiment we wanted to replicate the effect that we observed in Experiment 7, namely that cognitive load *impairs* performance on a global-selection task when local detail is salient.

The strong global salience of the stimuli in the FLT has been attributed to the fact that it is easier to perform a task in which there is a visible frame of reference (Zhou et al., 2008). Furthermore, the fact that the local line element is connected to the frame means that the global configuration should be represented as a single entry-level unit (Palmer & Rock, 1994) and thus should have strong global salience. In the present experiment, we reduced global salience – and enhanced local salience – by detaching the line from the frame. Under these circumstances, local salience should be stronger than global salience and cognitive load should make it more difficult to integrate the line into its global context and to perform the relative task.

### 5.5.1 Method

#### 5.5.1.1 Participants

Sixty-one participants (48 females, 13 males; mean age 25.77 years) were recruited from adverts placed around Goldsmiths, University of London, UK. Participants were reimbursed £5. The study was approved by the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

#### 5.5.1.2 Apparatus and stimuli

The apparatus and stimuli were identical to those used in Experiment 10 with the exception that the line was no longer attached to the frame (see Appendix B for the complete stimulus set). The line was still vertical, but was centred in the middle of the frame.

#### 5.5.1.3 Design

The design was identical to that in Experiment 10.

5.5.1.4 Procedure

The procedure was identical to that in Experiment 10.

### 5.5.2 Results

As for Experiment 10, we used only the percentage error (%) in the analysis (absolute magnitude of error can still be seen in Table 13). Participants were excluded if they were deemed to have mistakenly performed the wrong task; on this occasion two participants were excluded on this basis. The data of 59 participants were entered into a 2x2x2 within-subjects ANOVA with *task* (absolute vs. relative), *cognitive load* (low vs. high) and *trial-type* (89-179 and 179-89 mm) as the within-subjects factors. The dependent variable was the *percentage error* (%; see Table 14).

There was a main effect of *task* [$F(1, 58) = 13.07$, $p < .001$, $\eta^2 = .18$]; in this version of the FLT, participants were more accurate on the absolute task [$M = 15.97$ %, $SE = 1.02$] than on the relative task [$M = 23.45$ %, $SE = 1.99$], suggesting that local detail is more salient than global structure. The main effect of *cognitive load* was non-significant [$p > .1$]. There was a main effect of *trial-type* [$F(1, 58) = 35.14$, $p < .01$, $\eta^2 = .38$] which contributed to a significant interaction with *task* [$F(1, 58) = 8.14$, $p < .01$, $\eta^2 = .12$]. After Bonferroni correction, two *t*-tests were significant; error in the 89-179 mm trial-type in the absolute task [*M* = 12.73, *SE* = 1.28] was smaller than the error for both the 89 – 179 mm trial-type in the relative task [*M* = 27.43, *SE* = 3.34] and the 179-89 mm trial-type in the absolute task [*M* = 19.22, *SE* = 1.51].

**Table 13.** *Absolute magnitude of error (mm) in line reproduction made for each trial-type for each task under both low and high cognitive load (Experiment 11).*

| | Size of first and second frames | | 89 – 179 mm | 179 - 89 mm |
|---|---|---|---|---|
| Absolute Task | Low Cognitive Load | *M* | 8.54 | 5.84 |
| | | *SE* | *1.26* | *0.59* |
| | High Cognitive Load | *M* | 7.24 | 6.0 |
| | | *SE* | *0.84* | *0.60* |
| Relative Task | Low Cognitive Load | *M* | 17.32 | 3.76 |
| | | *SE* | *1.29* | *0.54* |
| | High Cognitive Load | *M* | 16.46 | 6.25 |
| | | *SE* | *1.00* | *1.01* |

**Table 14**. *Percentage error (%) in line reproduction made for each trial-type for each task under both low and high cognitive load (Experiment 11).*

| | Size of first and second frames | | 89 – 179 mm | 179 - 89 mm |
|---|---|---|---|---|
| Absolute Task | Low Cognitive Load | *M* | 13.78 | 19.08 |
| | | *SE* | *2.04* | *1.86* |
| | High Cognitive Load | *M* | 11.67 | 19.35 |
| | | *SE* | *1.36* | *1.92* |
| Relative Task | Low Cognitive Load | *M* | 13.85 | 25.08 |
| | | *SE* | *1.03* | *3.59* |
| | High Cognitive Load | *M* | 13.17 | 41.69 |
| | | *SE* | *0.8* | *6.71* |

Most importantly, the interaction between *task* and *cognitive load* was significant [see Figure 34; $F(1, 58) = 6.54$, $p = .01$, $\eta^2 = .1$]. Follow-up *t*-tests suggest that cognitive load exerts asymmetric effects on the absolute and relative tasks; high cognitive load impairs performance in the relative task [$t(58) = -2.23$, $p < .05$; one-tailed] but does not significantly affect performance in the absolute task [$p > .1$]. The interaction between *task*, *cognitive load* and *trial-type* was marginally non-significant [$p = .08$], indicating that the effect of cognitive load on performance was not significantly different for both the 89-179 mm and 179-89 mm trial-types. However, the data indicate that the interaction between task and cognitive load was driven by the 179 – 89 mm trial-type.

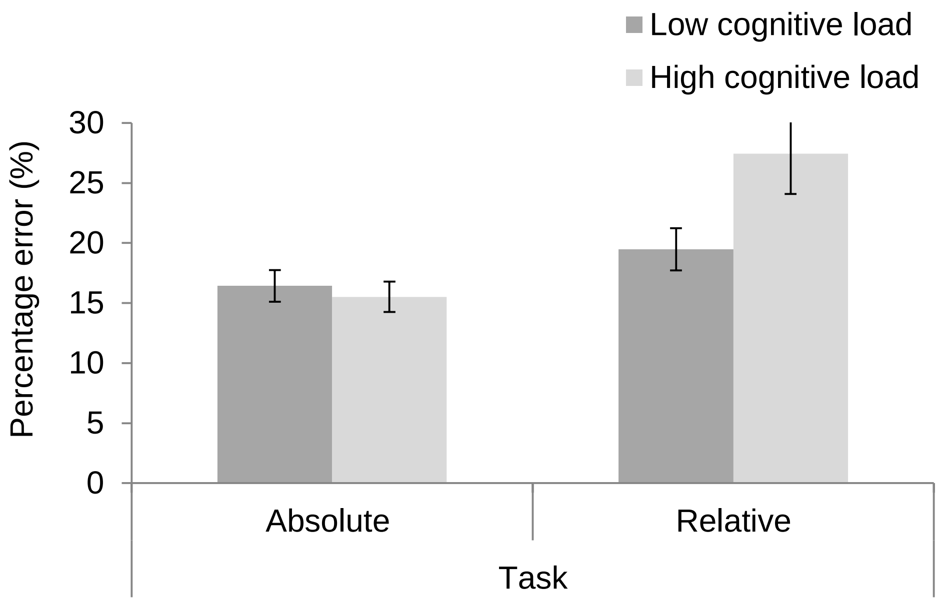



**Figure 34.** *Percentage error (%) in relation to the length of the original line for the 89-179 and 179-89 trial-types combined (Experiment 11). Error bars represent one standard error of the mean.*

### 5.5.3 Discussion

The present experiment has provided evidence to suggest that the effect of cognitive load on the standard FLT is driven by the fact that the line is connected to the frame;

when the line is detached from the frame, as it was in the present experiment, performance is better on the absolute task than on the relative task and it is the relative task that suffers under high cognitive load. This is consistent with our suggestion that cognitive load should impair performance on a global-selection task when local salience is strong. Thus, we have provided further evidence to support the assertion that cognitive load can impair global processing when local salience is strong.

## 5.6 Discussion of Chapter 5

In Experiments 8-11, we have provided further evidence to suggest that the effect of cognitive load on selection of hierarchical information depends on stimulus-driven factors which affect local-global salience. The contribution of the present chapter is to show this in stimuli other than hierarchical patterns. The present thesis challenges the assumption that high cognitive load always makes processing more global (Ahmed & de Fockert, 2012) and instead suggests that the effect of cognitive load depends on the relative salience of local and global information. In Chapters 2 to 4, we presented a series of experiments using hierarchical patterns (e.g., Kimchi & Palmer, 1982; Navon, 1977) to demonstrate that cognitive load does not always make processing more global but can make processing more local if local salience is strong. With the experiments presented here we wanted to demonstrate that the effect of cognitive load on selection of hierarchical information is not just limited to hierarchical patterns. Furthermore, as hierarchical patterns lack grouping properties such as closure and connectedness that are present in real-world objects (Navon, 2003), we wanted to show that cognitive load can affect hierarchical selection in stimuli that are more akin to real-world objects. Thus, in Experiments 8-11, reported in the present chapter, we used another selection task – the Framed Line Test (FLT; Kitayama et al., 2003) – to test the effect of cognitive load on processing of objects in which local information is either connected to or disconnected from the global context. Our data suggest that global salience in the connected FLT is strong and that cognitive load makes it more difficult to select local information from its surrounding global context (Experiments 9 and 10). When, however, the local line element is disconnected from the surrounding frame, selection of global structure is impaired. This provides further evidence to suggest that the effect of cognitive load on the processing of hierarchical visual information is complex and does not simply make people 'more local' or 'more global'; rather, its effects are influenced by stimulus-driven factors which determine local-global salience.

In the present experiments we used the FLT to provide a counterbalance to previous work in which the effect of cognitive load on hierarchical processing was explored using hierarchical patterns (Experiments 1-7; Ahmed & de Fockert, 2012). We chose the FLT to do this as it is a selective-attention task in which local or global information has to be selected whilst ignoring information at the other level (in the absolute and relative tasks, respectively). Specifically, we aligned the absolute task with local-selection tasks and the relative task with global-selection tasks in the selective-attention hierarchical-patterns paradigm. In Experiments 9-11, we provided evidence to suggest that cognitive load affects selection of hierarchical information in the FLT in the same way that it affects selection of local and global information in hierarchical patterns. In Experiments 9 and 10, participants performed the original version of the FLT under low and high cognitive load. Global salience of these stimuli was strong – as evidenced by more accurate performance on the relative task than the absolute task – and cognitive load made it more difficult to ignore irrelevant global structure while performing a local-selection task (the ‘absolute task’). In Experiment 11, we detached the line from the frame and demonstrated that local salience became stronger than global salience. Critically, we demonstrated that cognitive load impairs performance on the relative task, consistent with cognitive load making it more difficult to ignore the absolute length of the salient local element (when integrating it into its global context in the relative task). This is in line with our findings from the selective-attention hierarchical-patterns task in Experiment 7, where we demonstrated that cognitive load makes it more difficult to ignore salient local information when performing a global-selection task.

Importantly, in the present chapter we were successful in manipulating global salience in a stimulus viewed for an unlimited duration. Real-world vision does not result from a series of briefly presented stimuli and in the experiments presented in this chapter we have shown that closed and connected stimuli (as in the connected the FLT) can have strong global salience at unlimited exposure durations when the line element is connected to the frame; as soon as the line is disconnected from the frame, however, the local line element becomes more salient than its global context. Thus, it was manipulation of the relationship between individual elements and their place in the whole that affected global salience, rather than exposure duration *per se.* This demonstrates that unlimited exposure durations do not always enhance local salience under high cognitive load, contrary to the findings reported in previous experiments using hierarchical patterns (Experiments 2 and 3).

By manipulating the relationship between the (local) line and (global) frame it is possible to create two stimuli with identical local elements which vary only in the extent to which the line is related to the global context. In the connected FLT (utilised in Experiments 8, 9 and 10) the line is connected to the frame; the fact that performance on the relative task is typically better than on the absolute task is consistent with global salience being stronger than local salience. As the line is an integral part of the overall whole (Pomerantz & Garner, 1973), cognitive load impairs selection of the local line element. Disconnecting the line from its strong global context is effortful and thus high cognitive load impairs performance on a task of local selection (the absolute task). However, when the line is detached from the frame, participants now find the relative task more difficult than the absolute task (Experiment 11) and it becomes cognitively demanding to integrate the line into its global context (Kimchi, 1998, 2000) and thus performance on a task of global selection (the relative task) is impaired under high cognitive load.

Kitayama et al. (2003) developed the FLT as a way to test the assumption that an individual's culture shapes the way in which they process the visual world, suggesting that some cultures foster more holistic or global ways of processing while others more analytic or local. They invoked the more analytic and holistic cognitive styles of ‘Westerners’ and ‘East Asians’ respectively to explain superior performance on the absolute task compared to the relative task in Westerners, and superior performance on the relative task compared to the absolute in East Asians. Our participants were either students at Goldsmiths, University of London, UK, or employees of the Science Museum, London, UK, and all lived in London, UK. Although they were of mixed ethnic and cultural origin, we classed our participants as Western and as such would be presumed to perform better on the absolute task than the relative task. However, in Experiments 8, 9, and 10, where the line was attached to the surrounding frame, we failed to replicate Kitayama et al.’s (2003) findings that the local task was performed better than the relative task. Indeed, across of all the *connected* FLT studies reported in this chapter, our participants were better at the relative task than the absolute task. It is possible that classifying individuals as ‘Western’ simply because they reside in London, UK, is ignoring the influence that cultural background could have on hierarchical processing (although both Kitayama et al., 2003, and Caparos et al., 2012, have shown that host culture and environment respectively can influence local-global processing style). However, our participants’ superior performance in the relative over the absolute task also supports the assertion that, regardless of cognitive load, performance will always be more accurate when there is a visible frame of reference (Zhou et al., 2008) and that selection of local elements is more difficult when they form part of a configuration compared to when they are presented in isolation (Pomerantz & Garner, 1973).

Our data provide more information about the FLT more generally. Kitayama et al. (2003) stated that “the FLT is specifically designed to assess both the ability to incorporate and the ability to ignore contextual information within a single domain that is arguably nonsocial” (p. 202); however, the present research has suggested that the original FLT measures “the ability to incorporate and the ability to ignore contextual information” *when global salience is strong.* In Experiments 8-10, we showed that our participants were better at incorporating the local line into its global context on the relative task than they were at isolating the line element from its surrounding frame in the absolute task. However, when we disconnected the line from the frame in Experiment 11, we saw that our participants were better at copying the line in isolation than they were at integrating it into its context. This is further evidence to suggest that measures of hierarchical processing need to be considered in the light of the relative salience of local detail and global structure.

If cognitive load affects the ability to isolate local detail from salient global environments then it suggests that cognitive load could impair performance on other tasks of hierarchical processing, such as the embedded figures test (EFT; Witkin, Oltman, Raskin & Karp, 1971). In the EFT, participants are required to find a small part which is embedded in a whole figure. Success on this task depends on the ability to dis-embed the part from its strong global context; the findings from the present study suggest that cognitive load may make it more difficult to ignore salient holistic properties and may make it more difficult to dis-embed the part from its global context.

Thus, cognitive load may make it more difficult to isolate the 'trees' from the 'forest', if the tree is deeply embedded in the forest.

In the present chapter, we have presented a series of experiments which demonstrate that the effect of cognitive load on hierarchical processing is influenced by the relative salience of local and global information. Importantly, we have shown this in stimuli which were presented for an unlimited exposure duration. Our next – and final – study will demonstrate that cognitive load can potentially make the world more confusing if salient yet irrelevant contextual/holistic information is incompatible with local detail.

# CHAPTER 6 - GRAPHIC CONSTRUCTION

## 6.1 Introduction

In Chapters 3, 4 and 5, we presented a series of experiments to demonstrate that the effect of cognitive load on the selection of hierarchical information is influenced by stimulus-driven factors that affect local-global salience. We explored the generalisability of Ahmed and de Fockert's (2012) finding that cognitive load enhances global processing; specifically, we wanted to show that cognitive load does not *always* make processing more global. We did indeed show that high cognitive load increases interference from irrelevant local information on a global-selection task when local salience is stronger than global salience (Experiments 7 and 11). We also provided further evidence to show that cognitive load can increase interference from irrelevant global information on a local-selection task when global salience is strong (Ahmed & de Fockert, 2012; Experiments 9 and 10). These findings suggest that the effect of cognitive load on hierarchical processing is influenced by the physical properties of the environment. In Experiments 9 and 10 (presented in Chapter 5), we presented evidence to suggest that connectedness is a strong determinant of local-global salience and that cognitive load increases interference from global information when local elements are connected and increases interference from local information when elements are disconnected. The local elements in real-world objects are often connected (Navon, 2003) and thus global salience should be stronger than local salience when viewing conditions are favourable. There are times, however, when viewing conditions are suboptimal – when objects are partially occluded, or in poor lighting – and on these occasions strong global salience might also be confusing. In the present chapter we present a single experiment to again show that cognitive load can increase interference from salient global information on a local selection task, but use stimuli in which the global structure is incompatible with the local elements. We explore the effect that cognitive load has on processing of 2D representations of 3D objects and use a graphic construction (copying) task to show that cognitive load can impair selection of local detail in times when global structure is salient and confusing.

We chose to utilise a copying task to investigate this assumption as, when copying an object, a decision must be made as to how the global picture should be segmented into parts for copying (van Sommers, 1989). Van Sommers calls this *chunking* and suggests that it operates in a hierarchical fashion; specifically, major global components are copied before chunks lower down the hierarchy and at the bottom of the hierarchy are the most local details. Copying is a complex cognitive operation that has been said to depend on the interplay between the perceptual system and a graphic production system; thus, when the *output process* begins, the individual's internal representation of the picture must be graphically reproduced. The fact that graphic construction – or copying – is a hierarchical process suggests that copying tasks could allow exploration of the effect of cognitive load on hierarchical processing. Specifically, cognitive load should make it harder to focus on local detail if the global structure is particularly salient, which is likely in the case of connected objects. Much of our interaction with the world takes place with graphically presented information, either on paper or on a screen. Cognitive load – which can also be induced by cognitive demands associated with the material on the paper in front of us (Leutner, Leopold & Sumfleth, 2009) – could hinder our understanding of visual materials.

Our findings from Experiments 9 and 10, as well as the findings of Ahmed and de Fockert (2012), have shown that cognitive load makes it more difficult to ignore irrelevant-yet-salient global information. Thus, in a copying task, if the global structure is incompatible with the local detail then chunking the global structure into constituent parts for copying should become more difficult and copying should be impaired. To investigate this assumption, we compared performance on a copying task in which the global structure was compatible with local detail, against performance on a copying task in which global structure was *incompatible* with local detail.

We tested this idea by utilising a copying task in which participants have to reproduce both ‘possible’ and ‘impossible’ figures. ‘Possible’ figures are (connected) 2D representations of 3D objects that can exist in 3D space. ‘Impossible’ figures, however, are (connected) 2D representations of 3D objects that cannot exist in 3D space (see Figure 35 for an example). One feature of objects defined by connectedness is that they allow us to address *holistic* (or configural) properties which result from the interaction between component parts (e.g., Garner, 1978; Kimchi, 1992, 1994) and combine to form something qualitatively different than just a sum of parts (e.g., Köhler, 1935). With holistic properties come *emergent features* (Pomerantz, Sager & Stoever, 1977), properties that exist only as a relationship between individual elements and are absent when each part is presented in isolation. With impossible figures, the features that emerge from the interaction between local elements are confusing. For example, the middle prong in an impossible trident which emerges through the interaction between an oval connected to two straight lines (Figure 35) causes confusion for the perceiver when they try to reconcile it with the object it belongs to. Accordingly, the ability to perceptually isolate individual line elements and ignore the confusing global structure will make impossible objects less confusing.

**Figure 35.** *An example of a 'possible' (left) and 'impossible' (right) figure. The trident on the left can exist in 3D, whereas the figure on the right cannot.*

Evidence has shown that typically-developing individuals are slower to copy impossible figures than possible figures as they find it difficult to ignore the salient – and confusing – global whole (Mottron, Belleville & Ménard, 1999). Evidence to support this comes from the finding that autistic individuals, who have been shown to exhibit atypical hierarchical processing, find impossible figures no more difficult to copy than possible figures (Mottron et al., 1999). Individuals with autism are said to have a *hierarchisation* *deficit* which describes the idea that they do not organise global structure and local detail 'hierarchically'; instead, they assign equal weight to local and global information (Mottron & Belleville, 1993). Mottron and Belleville (1993) described a case study of an autistic individual, EC, who showed an absence of hierarchical structuring of the visual world. Whereas – all else being equal – typical individuals are biased toward global structure, EC was impaired on a task of global selection and his performance was facilitated in a task in which success depended on the ability to ignore confusing contextual information. Mottron and Belleville suggested that levels of hierarchical information are processed independently in individuals with autism, that is, local information is processed separately from global information, rather than in the context of the global structure in which it is embedded.

Whereas the hierarchisation deficit exhibited by autistic individuals means that they integrate component parts into a perceptual whole to a lesser extent than typical controls do, the opposite effect may be apparent for typical individuals under high cognitive load. Specifically, cognitive load should make it *more* difficult for typical individuals to copy impossible figures than possible figures as it should make it harder to ignore the confusing salient global structure. In contrast, as the global structure of possible figures is compatible with its local detail, we would not expect cognitive load to impair performance on a task in which possible figures are copied. In the present experiment we ran Mottron et al.'s (1999) possible- and impossible-figures task with a cognitive load manipulation. We predict that copying of impossible figures should be worse than copying of possible figures, regardless of cognitive load. However, participants under high cognitive load should find it even more difficult to copy impossible figures than those under low cognitive load, as they should find it more difficult to ignore the confusing global whole when copying each local element.

## 6.2 Experiment 12

Impossible figures are named as such because they cannot exist in 3D space. Perceptually, the interrelations between the local elements produce emergent properties which are not concordant with the global whole, and thus confusion arises. As the local elements are connected and form a closed figure in both possible and impossible objects, global salience of impossible objects is likely to be strong. However, as the salient global structure of impossible objects is incompatible with its local detail then copying should be impaired, whereas the salient *compatible* global structure of possible objects should not impair copying. Thus, in the present experiment we predicted that cognitive load should make it more difficult to ignore the confusing global whole in impossible objects and copying performance should be disproportionately impaired for impossible compared to possible objects.

## 6.2.1 Method

### 6.2.1.1 Participants

Twenty-six participants (mean age = 22.6 years; 24 females, 2 males) participated in the experiment and were all first-year-undergraduate psychology students at Goldsmiths, University of London, UK. Participation was rewarded with course credit. The study received ethical approval from the Department of Psychology Ethics Committee at Goldsmiths, University of London, UK.

### 6.2.1.2 Design

A 2x4x2 mixed design was used. The repeated-measures independent variable was *possibility of figure* (*possible* vs. *impossible*). The independent-measures variable was *cognitive load* (*low* vs. *high*; remember one digit vs. remember six digits). Participants were alternately assigned to the low or high cognitive load conditions. The dependent variable was the time, in seconds, that it took to copy each figure.

### 6.2.1.3 Apparatus and stimuli

The stimulus set consisted of four possible figures and their impossible counterparts (see Figure 36 for the complete stimulus set). Stimuli were printed in black ink on pieces of white A4 paper and were positioned so that they were centred in the top half of the paper in portrait mode. Impossible figures were the same size as their possible counterparts, with the exception that the relationship between the line elements was changed. The nature of the figures meant that they differed in size but all stimuli fitted within a 7 x 5 cm imaginary box. Participants were to copy the figures in the space in the lower half of the page. For the digit task, digits were printed in black in on white card. For the low cognitive load manipulation the numbers 1-9 were printed on separate pieces of card (one card for each number). The numbers were shuffled for each trial and one was drawn randomly. For the high cognitive load manipulation six numbers from 1-9 were drawn, without replacement, using a program developed for a previous experiment. 40 of these combinations were printed on white card and one six digit number was selected for each trial.

#### 6.2.1.4 Procedure

Participants sat at a table in a well-lit room and were informed that they were to copy a series of line drawings whilst remembering digits. Participants were alternately assigned to either the low- or high-cognitive-load conditions; those in the low-cognitive-load condition were informed that they would perform the task whilst remembering one digit, and those in the high-cognitive-load condition were to perform the task whilst remembering six digits. Participants were informed that some of the shapes would seem confusing but that they should try to copy them as best they could. Faithful replications of the figures were not required, but it was stressed that copies should contain all of the features contained in the original drawing. There was no practice session.

For the test session, each trial ran as follows. Participants were presented with either one digit (low cognitive load) or six digits (high cognitive load) depending on which condition they had been assigned to. The digit(s) were presented on a piece of card for three seconds and were then removed. The experimenter then immediately placed a piece of paper in front of the participant in portrait mode; the original figure was printed in the middle of the top half of the page, and the participant was required to copy the figure beneath it in the (empty) lower half of the page. When participants were satisfied with their drawing they were required to write the digits that they had been remembering at the bottom of the page. As soon as the paper was in front of the participant, the experimenter started the stop watch; the stop watch was stopped when the participant had completed the drawing and started to write down the digit(s). The experimenter then removed the paper and proceeded to the next trial. There were eight unique figures (four possible figures and four impossible figures) and each was drawn at random and presented only once, totalling eight trials.

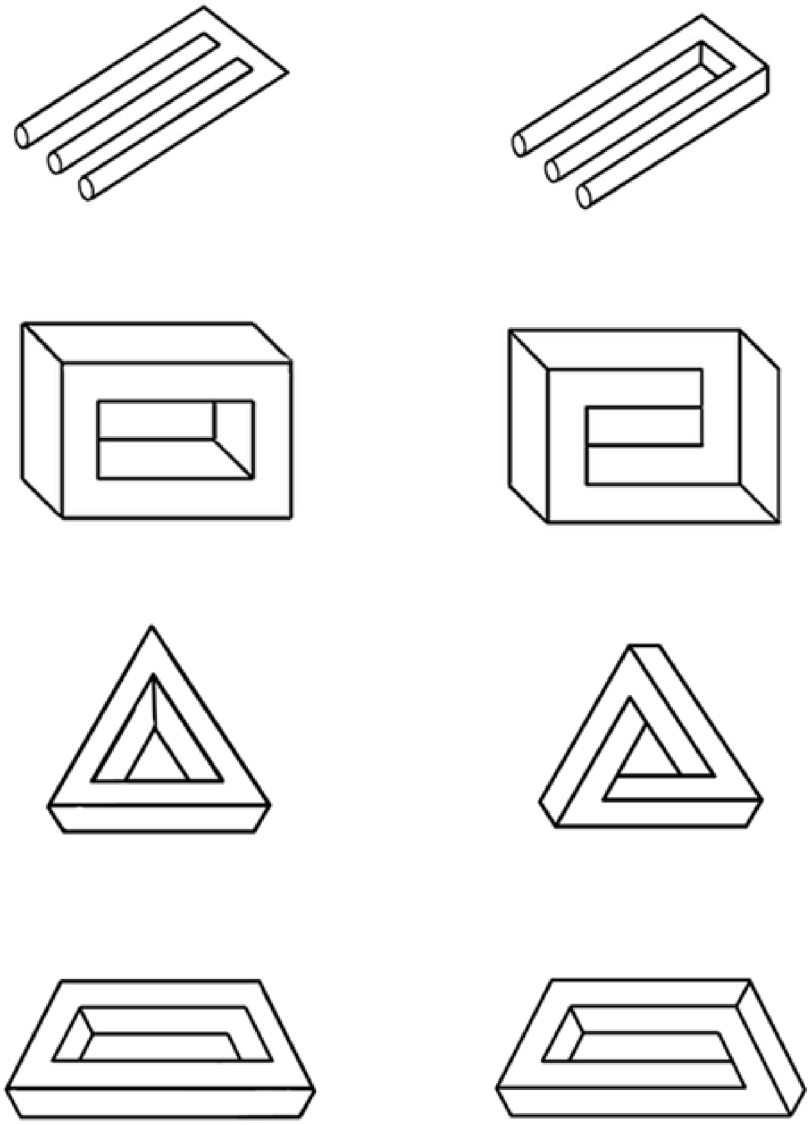


**Figure 36.** *The stimulus set used in the present experiment. The figures on the left are the possible objects and the figures on the right are their impossible counterparts. Possible figures can be constructed in 3D, but impossible figures are impossible to construct in 3D. From the top, we refer to these figures as tridents, cuboids, triangles and rhomboids. These images are not to scale.*

### 6.2.2 Results

Participants were removed from the analysis if their copying time exceeded 120 s. No participants exceeded this threshold. Participants were also excluded from the analysis if they omitted components when copying the figures. All participants copied the figures accurately. Finally, participants were excluded from the analysis if they failed to recall the single digit in the low-cognitive-load condition or if the failed to recall at least five of the digits in the correct order in the high-cognitive-load condition. No participants fell below this threshold and so the data of all 26 participants were used for the final analysis.

Data were entered into a 2 x 2 mixed ANOVA, with *possibility* (possible vs. impossible) as the within-subjects factor and *cognitive load* (low vs. high) as the between-subjects factor. The time it took to copy each figure, in seconds, was the dependent variable.

There was a significant main effect of *possibility* [$F(1, 24) = 175.08$, $p < .001$, $\eta^2 = .88$]; participants copied possible figures ($M = 21.09$ s, $SE = 1.22$) far quicker than they copied impossible figures ($M = 38.34$ s, $SE = 2.38$). There was also a significant main effect of *cognitive load* [$F(1, 24) = 6.14$, $p < .001$, $\eta^2 = .2$] which showed that participants under high cognitive load ($M = 33.38$ s, $SE = 2.15$) were slower overall at the copying task than were participants under low cognitive load ($M = 20.91$ s, $SE =$

1.15). Most importantly, the interaction between *possibility* and *cognitive load* was significant [$F(1, 24) = 6.45$, $p < .05$, $\eta^2 = .21$; see Figure 37]. Follow-up *t*-tests which were Bonferroni-corrected for multiple comparisons indicated that, whilst cognitive load had no significant effect on copying times of possible figures [$p > .1$], those under high cognitive load were significantly slower to copy impossible figures than those under low cognitive load [$t(24) = -2.6$, $p < .05$].

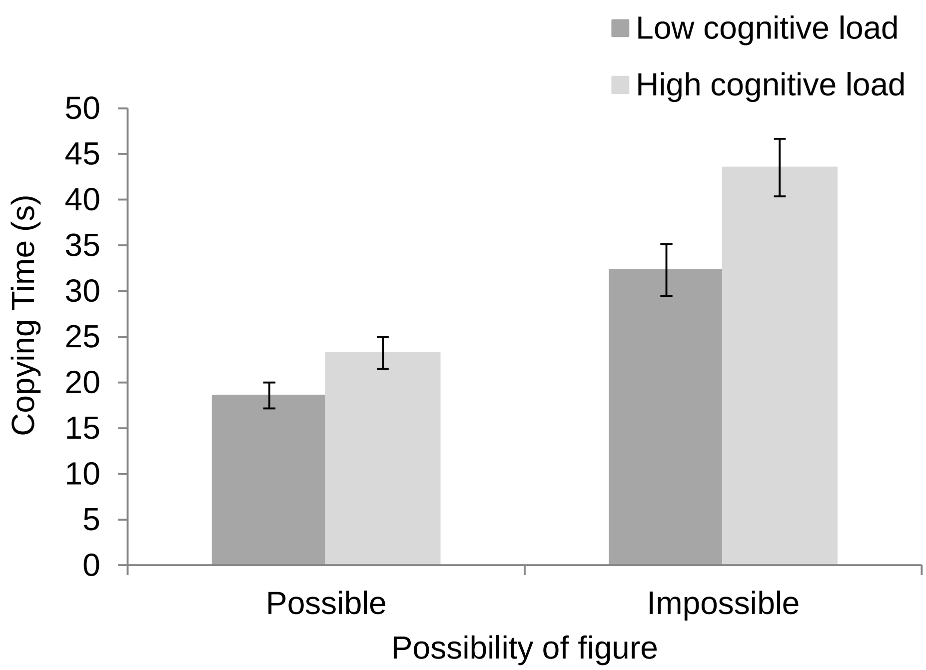



**Figure 37.** *Copying time (seconds) for possible and impossible figures under both low and high cognitive load (Experiment 12). Error bars represented standard errors of the mean.*

## 6.3 Discussion of Chapter 6

The present thesis has argued that the effect of cognitive load on the selection of hierarchical information will depend on the salience of the stimulus. If global information is salient, then cognitive load will make global information more difficult to ignore, whereas local information will be harder to ignore when local detail is most salient. In the present experiment we continued to explore the effect of cognitive load on processing of objects in which local detail and global structure are connected; specifically, we wanted to show that cognitive load might make the visual world more confusing if salient global information is incompatible with local detail. We demonstrated that cognitive load can make it more difficult to ignore confusing salient global information. In the present study, participants copied both 'possible' and 'impossible' figures and the time taken to do this was recorded. We found that all participants were slower to copy the impossible figures than the possible figures. Crucially, we also showed that while cognitive load had no significant effect on the speed of copying of possible figures, individuals under high cognitive load were significantly slower than those under low cognitive load at copying impossible figures. This finding provides further evidence to suggest that cognitive load can impair performance on a local-selection task when global salience is strong.

In the present experiment, we showed that high cognitive load not only impairs performance on a local-selection task when global salience is strong but also makes the visual world more confusing, to the extent that understanding depends on isolating local detail from a salient, but confusing, global context. By their very definition, impossible objects are not ‘real-world’ stimuli – as they are impossible to construct in three dimensions – but they allow illustration of how cognitive load could make the visual world more difficult to understand in times of ambiguity. When the visual field is parsed into likely object candidates, the brain chooses the simplest interpretation (as exemplified in the Gestaltist’s ‘Law of Prägnanz’). Mostly, the arrangement of local detail is congruent with the global whole. However, there may be times when global structure is ambiguous, for example, when the visual input is degraded (in times of low light or shadow) or when the visual scene is particularly cluttered. In times such as these, the findings of the present experiment suggest that cognitive load may make it more difficult to resolve this ambiguity and isolation of local detail could be impaired.

We have conceptualised the impossible figures task as a selective attention task, as participants are required to ignore the confusing global structure in order to efficiently copy the local detail. However, it is also possible that the impossible figures task could be used as a measure of perceptual bias. Van Sommers (1989) suggested that people copy the global aspects of a figure before the local detail; this can be aligned with the suggestion that, all else being equal, global information is prioritised over local information (e.g., Kimchi, 1992). The strong global salience of connected objects would make this possibility more likely. In the present experiment we simply timed how long each drawing took to complete. If we had also used a video camera to record each trial, we may have seen that cognitive load affected the likelihood that global structure is copied before local detail. As cognitive load enhances the salience of local detail and reduces the salience of global structure (see Experiments 2 and 3, presented in Chapter 2) it is possible that high cognitive load may make it more likely that participants will begin drawing local information before they draw global information.

Indeed, alongside the possible/impossible-objects task, Mottron et al. (1999) ran a second copying task which could arguably be classed as a measure of perceptual bias. In this task, autistic and typical participants copied a series of objects. Whereas typical individuals tended to copy the most global aspects of the picture before filling in the details (e.g., Rey, 1959), autistic individuals copied relatively fewer global features and relatively more local features in the first part of the copying task in comparison to typical individuals, reflecting their locally-oriented processing style. It is interesting to consider what might happen if we were to run the object-copying task with participants under cognitive load. We would expect individuals under low cognitive load to perform like Mottron et al.'s (1999) typical individuals and copy the global aspects of the figures before the details. However, as cognitive load reduced the salience of global information and increased the salience of local information, it could be that high cognitive load would reduce the number of global properties that were copied in the first stages of the drawing and may encourage participants to copy more local details in the initial part of the copying task. This is an intriguing suggestion and raises the possibility that copying tasks could serve as a measure of both attentional selection and of perceptual bias.

In conclusion, in the present chapter we have provided evidence to suggest that cognitive load makes the hierarchical visual world more confusing when the isolation of local detail is required to resolve ambiguity. More broadly, the current experiment provides further evidence that cognitive load impairs local selection when global salience is strong.

# CHAPTER SEVEN – GENERAL DISCUSSION

The present thesis explored the effect of high cognitive load on the processing of hierarchical information. Recently, it has been shown that high cognitive load improves global selection and impairs local selection; this has been interpreted as cognitive load causing a "shift towards global processing" (p. 1404; Ahmed & de Fockert, 2012). The present thesis probed in more depth the assumption that high cognitive load always causes a shift towards global processing. We distinguished between the effect of high cognitive load on perceptual bias (which describes how hierarchical information is prioritised; Chapter 2) and on attentional selection (which describes the facility for selecting the level of hierarchical information relevant to the task at hand; Chapters 3, 4, 5 and 6). We also explored the effect that stimulus-driven determinants of local-global salience could have on the effect of cognitive load on hierarchical processing.

The main contribution of the present work is to show that cognitive load affects both perceptual bias and attentional selection and that its effects are exerted on these processes through separate mechanisms. High cognitive load affects perceptual bias by decreasing global salience, we suggest because the increased demands of coping with high cognitive load affect relative activation of the (local-dominant) left and (global-dominant) right hemispheres. High cognitive load also affects cognitive-control processes involved in selection, making it more difficult to ignore irrelevant, yet salient, hierarchical information; if global information is more salient than local detail then high cognitive load will increase interference from irrelevant global information (on a local-selection task), whereas if local information is more salient than global structure then high cognitive load will increase interference from irrelevant local detail (on a global-selection task). Thus, high cognitive load does not make people ‘more global’ or ‘more local’; instead, the effect of cognitive load depends on i) whether the task addresses bias or selection; and ii) the salience of local and global information.

Below, we first summarise our findings that we presented across Chapters 2-6. We consider the separate effects of cognitive load on both perceptual bias and attentional selection and discuss the mechanisms through which cognitive load may exert its effects. We also consider how the effect of cognitive load on perceptual bias may feed into the effect of cognitive load on selection. We discuss the importance of stimulus-driven salience when considering the effect of cognitive load on hierarchical processing and we consider how this must be taken into account when researching individual differences in hierarchical processing more generally. We also discuss the limitations of comparing performance on different measures of hierarchical processing.

## 7.1 Overview of findings

### 7.1.1 Local-global perceptual bias

Chapter 2 addressed the effect of high cognitive load on perceptual bias. Specifically, we investigated whether high cognitive load would make participants more or less likely to prioritise global structure over local detail. Participants performed a similarity-matching version of the hierarchical-patterns task (Kimchi & Palmer, 1982) whilst under low (remember one digit) or high (remember six digits) cognitive load. Our data showed that when exposure durations were unlimited participants were less likely to match patterns at the global level under high cognitive load in comparison to low cognitive load. Global salience was still determined by stimulus-driven factors to an extent, as global matching increased with pattern-density (see Figure 38). We appeal to a relative hemispheric activation account to explain our data (discussed later in this chapter). We conclude that high cognitive load reduces the global bias and enhances the salience of local elements.

Interestingly, increased local salience was seen only when exposure durations were unlimited; when exposure durations were limited, cognitive load had no effect on global-local matching. To explain this we invoke findings with hierarchical pattern stimuli showing that global information is most salient in the early stages of visual processing but decays over time (e.g., Paquet & Merikle, 1984). We suggest that the strong salience of global structure at limited exposure-durations masked the effect of cognitive load to reduce global bias, with the result that there was no observable effect of cognitive load at limited exposure-durations. However, the effect of cognitive load at unlimited exposures is important given that unlimited exposures are arguably more representative of real-world viewing conditions. We conclude that high cognitive load can make people more likely to see the ‘trees’ for the ‘forest’.

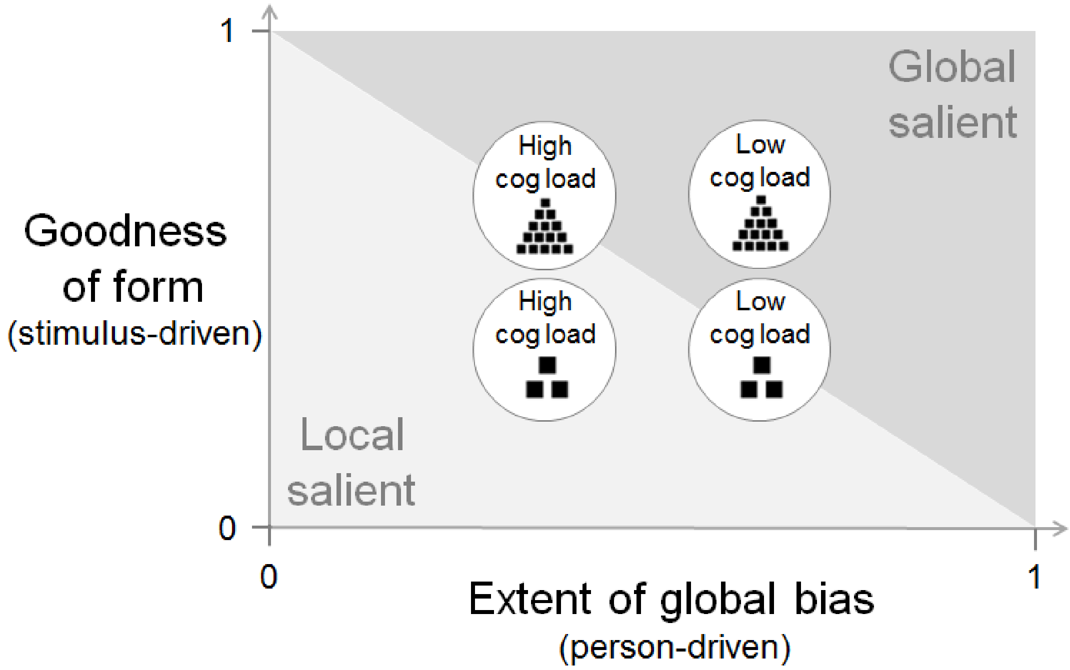



**Figure 38.** *Schematic representation of how physical stimulus properties (goodness of form: perfect form = 1, no form = 0) and person-driven disposition (extent of global bias: complete global bias = 1, complete local bias = 0) interact to determine what is most 'salient in the final percept' (Kimchi, 1992, p 26). We have positioned our findings from Experiment 2 (unlimited exposures) in Chapter 2 as an example. Cognitive load determines where on the x axis the bias is positioned when exposures are unlimited; low cognitive load is positioned toward the global end while high cognitive load is towards the local end. Stimulus-driven factors determine positioning on the y axis. Global salience is determined by a combination of positioning on the x and y axes.*

### 7.1.2 Selection of hierarchical information

In Chapter 3 onwards, we turned our attention to the effect that cognitive load might have on attentional selection of hierarchical information with a view to challenging Ahmed and de Fockert's (2012) assertion that cognitive load should *always* facilitate global processing. We hypothesised that cognitive load should make it more difficult to ignore the most salient level of hierarchical information: if global salience is strong then cognitive load should make it more difficult to ignore irrelevant global information on a local-selection task, whereas if local salience is strong (and global salience is weak) cognitive load should make it harder to ignore irrelevant local information on a global-selection task (see Figure 39 for a schematic representation). We suggest that Ahmed and de Fockert only observed a “shift towards global processing” under cognitive load because they used hierarchical patterns with strong global salience. In Experiments 4-7 (described in Chapters 3 and 4) we endeavoured to show that high cognitive load can cause a shift towards *local* processing when local salience in hierarchical patterns is strong.

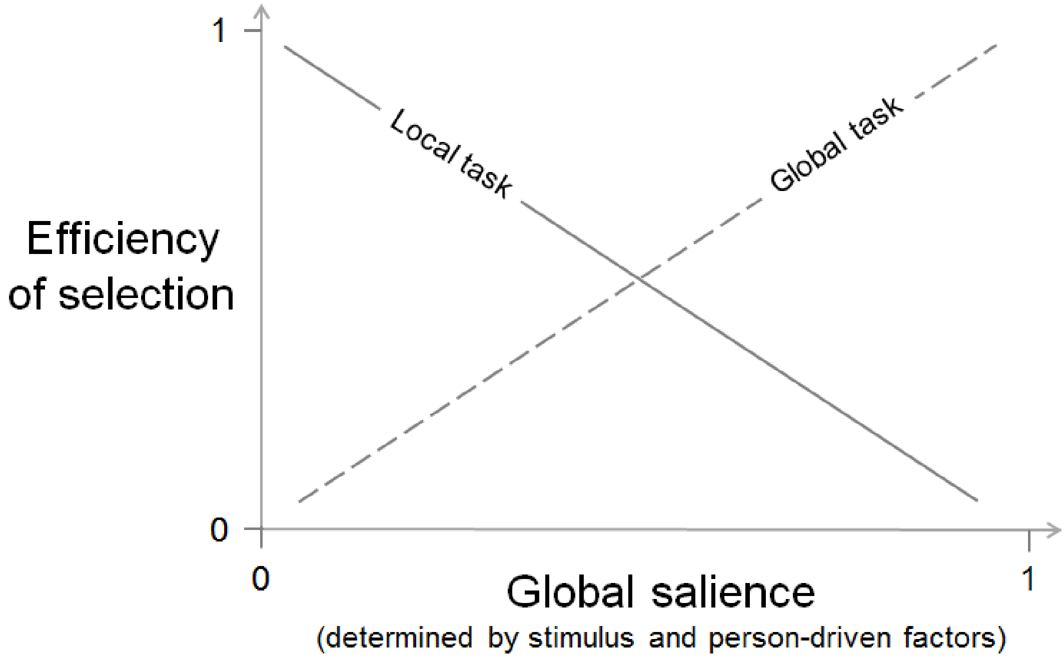



**Figure 39.** *Schematic representation of how global salience determines efficiency of selection both a local and global selection task. As global salience increases, local salience decreases. Likewise, local salience increases as global salience decreases.*

In Experiments 4 and 5, global salience was manipulated by varying exposure duration. Exposure duration was chosen because the findings from Experiments 1 and 2 had shown that global salience was stronger than local salience under high cognitive load at limited exposure durations (our patterns were matched at the global level ~60% of the time in Experiment 1) but that local salience was stronger than global salience under high cognitive load at *unlimited* exposure durations (~40% global matches). We ran a selective-attention version of the hierarchical-patterns task (Navon, 1977) using exposure duration as a manipulation of global salience, reasoning that high cognitive load should make it more difficult to ignore global information salient at limited exposure durations but should impair the ability to ignore local information salient at unlimited exposure durations. Thus, it was expected that cognitive load should increase interference from global information (on a local-selection task) at limited durations but increase interference from local information (on a global-selection task) at unlimited durations.

A trend in the predicted direction was observed in Experiment 5 (described in Chapter 3) but this was not significant. It was reasoned that the unlimited exposure durations may not have been long enough to significantly increase salience of local detail over global structure, as participants responded much quicker to the ‘unlimited-exposure’ patterns in Experiment 5 (~650 ms) than they did in Experiment 2 (~1350 ms). This suggests that the selective-attention hierarchical-patterns task, as a speeded-response task, does not lend itself well to manipulations of exposure duration. Instead, in Experiments 6 and 7 (reported in Chapter 4) a limited-exposure version of the selective-attention hierarchical-patterns task was used and local salience was increased by manipulating the density of hierarchical patterns. Kimchi (1998, 2000) has suggested that very low density patterns are initially represented in terms of their local detail whereas high density patterns are initially represented in terms of their global structure. Furthermore, the findings from Experiments 1-3 replicated Kimchi and Palmer's (1982) observation that global salience decreases as the number and density of elements within a hierarchical pattern decreases. Thus, we ran two experiments, one with low-density hierarchical patterns (Experiment 7) and one with medium-density patterns (Experiment 6; these were the same stimuli as those used in Experiments 4 and 5 where we had seen no effect of cognitive load on selection of hierarchical information) and expected cognitive load to increase interference from irrelevant local detail *only* in response to low-density patterns with strong local salience.

In Experiments 6 and 7, we also changed how we manipulated cognitive load. In Experiments 1-5, cognitive load was imposed by having participants remember one (low cognitive load condition) or six (high cognitive load condition) digits. In Experiments 6 and 7, however, we manipulated cognitive load through task-switching (e.g., Monsell, 2003) as this allowed us to explore the effect of low and high cognitive load on the same participants within the same block of trials. This was to increase ecological validity and to avoid strategic confounds which can occur when a single task is performed for an entire block of trials.

In Experiment 7, it was found that low-density patterns had stronger local than global salience (even when presented for a limited duration) and that cognitive load (induced by task switching) significantly impaired global selection; specifically, cognitive load significantly increased interference from local elements on a global-selection task. When the same experiment was run with medium-density patterns (Experiment 6), however, there was no evidence to suggest that local salience was stronger than global salience and cognitive load did not asymmetrically increase interference on the local- and global-selection tasks. It was concluded that high cognitive load can make it more difficult to ignore local detail when local salience is strong.

Hierarchical patterns were used in Experiments 1-7 (in Chapters 2, 3 and 4) to address the effect of cognitive load on hierarchical processing. However, hierarchical patterns lack certain grouping principles, such as connectedness, which are integral to the structure of real-world objects. By moving away from hierarchical patterns it was hoped that it would be possible to explore the effect of cognitive load on stimuli which are more akin to real-world objects. In Experiments 8-11 (reported in Chapter 5) the Framed Line Test (FLT; Kitayama et al., 2003) was used to explore whether the effect of cognitive load on selection of hierarchical information would remain if stimuli with different grouping principles were used. It was reasoned that while we would see a “shift towards global processing” (Ahmed & de Fockert, 2012) if global salience was strong, we would also see a shift towards local processing if local salience was strong.

The FLT tests the ability to either isolate a local line element from the global frame that it is connected to (the absolute task), or integrate the line into the surrounding frame (the relative task). The grouping principle of connectedness suggests that the line and frame should be treated as a single entry-level unit and global salience should be very strong. Indeed, high cognitive load impaired performance on the absolute task (a task of local selection) and made it more difficult to isolate the line element from the frame (Experiments 9 and 10), a finding arguably analogous to that of Ahmed and de Fockert (2012). By disconnecting the line from the frame in Experiment 11, however, local salience was enhanced and cognitive load was shown to impair performance on the relative task (a task of global selection). This finding is arguably analogous to the finding in Experiment 7 with hierarchical patterns in the present thesis. We conclude that the effect of cognitive load on selection of hierarchical information is not restricted to hierarchical patterns but could be applicable to a wider range of hierarchical information. Whether cognitive load increases interference from local or global information – and thus whether cognitive load makes us more local or more global – depends on stimulus-driven factors that determine local-global salience. In hierarchical patterns, the findings from Experiments 1-7 (presented in Chapters 2-4) showed that these stimulus factors include exposure duration and pattern-density, while in the FLT, the findings presented in Experiments 8-11 (Chapter 5) showed that connectedness is important in modulating salience.

The experiments presented in Chapters 4 and 5 showed that cognitive load can make it more difficult to ignore salient local information. However, as the majority of real-world objects are defined by strong grouping principles such as connectedness (Navon, 2003) it is likely that global salience will be stronger than local salience in real-world objects under optimal viewing conditions and the most common effect of cognitive load, when attending to a discrete object, will be to increase interference from global structure when attending to local detail. In Chapter 6, we presented a final experiment (Experiment 12) to show that high cognitive load may cause confusion when the global form of an object is incompatible with its local detail. We had participants perform a copying task in which they copied both ‘possible’ figures (objects that can exist in 3D) and ‘impossible’ figures (objects that cannot exist in 3D) as quickly but as accurately as possible whilst under low or high cognitive load. Successful performance of the impossible-figures task requires that participants ignore the confusing (but salient) global form. We found that participants under high cognitive load were significantly slower to copy impossible figures than those under low cognitive load, whereas cognitive load had no effect on copying time of possible objects. We reasoned that high cognitive load made it more difficult to ignore the confusing global structure.

The findings detailed in the present thesis have provided two key observations. We have shown that high cognitive load does not always benefit global processing (as was suggested by Ahmed and de Fockert, 2012) but that the effect of cognitive load on hierarchical processing depends on i) whether perceptual bias or attentional selection is involved; and ii) the salience of global and local information. Thus, cognitive load does not make people more global or more local, but rather cognitive load will interact with both task-demands and the relative salience of local and global information. In the following sections, the mechanisms that could underlie the observed effects of cognitive load on perceptual bias and attentional selection, and the extent to which they interact in order to determine local and global salience and hierarchical processing, are discussed.

## 7.2 Hierarchical perceptual bias and selective attention

Hierarchical perceptual bias and attentional selection are often conflated. For example, in the cross-cultural literature, perceptual bias – indexed by the extent to which culture determines whether individuals are "attuned" (p. 201; Kitayama et al., 2003) to focal objects or contextual information – is presumed to also determine performance on attentional selection tasks; individuals who engage in holistic, interdependent cultures (such as East Asian cultures) have been shown to perform better on tasks of global selection than those who are engaged in cultures that are more analytic (such as Western cultures; e.g., Kitayama et al., 2003). While it makes intuitive sense that perceptual bias should also feed into selection, Caparos et al. (2013) have shown that bias does not *always* determine selection; the Himba, a remote population in Namibia, have a markedly local bias in comparison to Westerners but experience less interference on global- as well as local-selection tasks than do Westerners. Caparos et al. suggested that perceptual bias and attentional selection may be governed by separate mechanisms and specifically that performance on tasks of attentional selection may be governed by cognitive control.

The findings in the present thesis support the suggestion that perceptual bias and attentional selection are governed by separate mechanisms; the present findings not only lend support to the well-established assertion that cognitive control affects attentional selection and the ability to ignore salient distraction (e.g., Lavie et al., 2004) but also suggest that cognitive load could affect perceptual bias through affecting relative hemispheric activation. The left hemisphere is thought to be dominant for local information processing and the right hemisphere dominant for global information processing (e.g., Fink et al., 1996, 1997; Martinez et al., 1997; Van Kleeck, 1989). Thus, the activation of the left and right hemispheres in the resting state could determine the relative weight given to local and global information when approaching the world. Evidence has shown that activation of the right hemisphere is higher than of the left when participants are preparing to respond to visual information (e.g., Warm, Matthews & Parasuraman, 2009; Stroobant & Vingerhoets, 2000) and this could explain why participants exhibit a global bias under low cognitive load. As task-difficulty increases, right-hemisphere activation drops and hemispheric activation becomes bilaterally symmetrical (Helton et al., 2010). This suggests that the left-lateralised local mechanism becomes activated to the same extent as the right-lateralised global processing mechanism. We suggest that exactly this happens as cognitive load increases. In sum, we suggest that cognitive load alters the relative activation of the local-dominant left and global-dominant right hemispheres (see Figure 40), thereby reducing the global bias by reducing the extent to which the brain is likely to prioritise global structure over local detail.

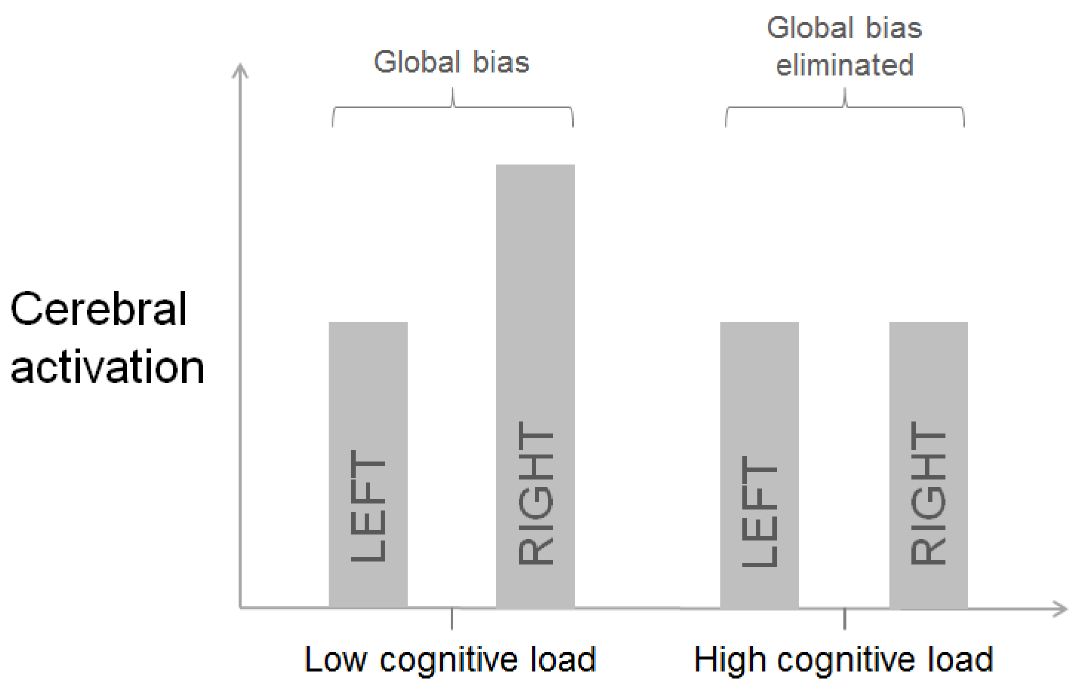



**Figure 40.** *Graphical representation of how cognitive load might affect hemispheric activation and how this might affect perceptual bias.*

A hemispheric-activation account provides a viable explanation for the findings of Experiments 1-3 (presented in Chapter 2) and suggests that cognitive load should always enhance local salience (and decrease global salience). Whether local detail is ultimately most "salient in the final percept" (p 26; Kimchi, 1992), however, is dependent on stimulus-driven factors which determine global salience, such as exposure duration or density in the case of hierarchical patterns. In the similarity-matching-paradigm, global salience reads out as the proportion of matches that are made to the global level of representation. The reader is referred to Figure 38, which uses our findings from the unlimited-exposure-duration similarity-matching task in Experiment 2 to illustrate how salience depends on both perceptual bias (that is, the likelihood that global information will be prioritised over local detail as it may be affected by relative hemispheric activation) and the goodness of form of the stimulus (determined by stimulus density in this instance).

In Figure 38, the *x* axis determines the preparedness of the brain to prioritise global structure over local detail. The likelihood that information will be represented in terms of its global structure increases as the scale moves towards '1' and decreases as it moves towards '0'; equally, the likelihood that information will be interpreted according to its local detail *decreases* as the scale moves towards '1' and *increases* as the scale moves towards '0'. Our findings from Experiments 2 and 3 (presented in Chapter 2) suggest that cognitive load makes it less likely that hierarchical information will be interpreted in terms of its global structure, so that perceptual bias is positioned towards '1' under low cognitive load but moves towards the '0' end of the scale under high cognitive load. The *y* axis denotes the goodness of form. In Experiments 1-3 it was shown that – regardless of cognitive load – global salience increased as pattern density increased and thus high-density patterns will be positioned more towards '1' than low-density patterns which will be positioned more towards '0'. For the FLT (presented in Chapter 5), positioning will be towards the top of the axis when the line is connected to the frame but towards the bottom when the line is disconnected from the frame. This reflects a stimulus-driven change in goodness of form while local-global bias remains constant. Our data are consistent with the suggestion that local-global salience is modulated by the point at which the person-driven bias and stimulus-driven form factors intersect.

The idea that local-global salience depends on a combination of person-driven factors (such as perceptual bias) and stimulus-driven factors that may affect local-global salience suggests that it is not possible to have an absolute measure of perceptual bias; instead, it is only possible to observe relative differences in the extent to which individuals prioritise global structure over local detail. We discussed this possibility in Chapter 2, where we suggested that use of the terms 'global bias' and 'local bias' should be avoided in absolute terms. This is especially important when comparing between-group differences in perceptual bias, as whether the 'trees' are ultimately more salient than the 'forest' depends to an extent on stimulus-driven factors which affect global salience. Our findings presented in Chapter 2 illustrate that cognitive load reduces the likelihood that hierarchical information will be interpreted in terms of its global structure over its local detail, but it would be incorrect to assert that individuals under low cognitive load show a 'global bias' while individuals under high cognitive load show a 'local bias'. Instead, we can conclude that cognitive load makes it less likely that people see the 'forest' than the 'trees' by reducing the global bias; thus cognitive load reduces global salience, and enhances local salience, but whether local detail or global structure is most "salient in the final percept" (Kimchi, 1992)  is influenced by stimulus-driven factors which affects local-global salience.

In Chapter 3, it was proposed that the effect of cognitive load on local-global salience through perceptual bias could also determine the effect of cognitive load on attentional selection. This is an important consideration as the idea that cognitive load makes it more difficult to ignore salient hierarchical information is central to the present thesis. In

Experiments 4 and 5, we explored the possibility that cognitive load could affect the perceptual bias by enhancing the salience of local detail and thus impair performance in a global-selection task. The stimuli that were used in Experiments 4 and 5 were dictated by our findings in Experiments 1 and 2; there, it was shown that global salience was stronger than local salience in medium-density patterns at limited exposure-durations under both low and high cognitive load, but at unlimited exposure-durations cognitive load reduced global salience so that local detail was more salient than global structure. Thus, under high cognitive load global salience should be stronger than local salience at limited exposures but local salience should be stronger than global salience at unlimited exposures. This being the case, we reasoned that high cognitive load, in comparison to low cognitive load, would increase interference from global information (on a local-selection task) at limited exposures but would increase interference from local information (on a global-selection task) at unlimited exposures. We saw a trend in the predicted direction, although this was not statistically significant.

We suggest that the stronger global salience of the FLT and the limited-exposure hierarchical patterns tasks (Experiments 4-10) masked the effect of cognitive load on perceptual bias. In the limited-exposure hierarchical-patterns task, the sudden onset of hierarchical patterns may have masked the effect of cognitive load to make perceptual bias less global. Equally, the FLT (Kitayama et al., 2003) has very strong global salience by virtue of the fact that the local detail is connected to the global context; in this instance, cognitive load may have reduced global perceptual bias and salience but it is likely that global structure was still far more salient than local detail, as evidenced by the fact that the relative task was still easier to perform than the absolute under high cognitive load. Indeed, it is probably often the case that stimulus-driven factors which increase global salience are so strong that only those observers with an extremely low tendency to prioritise global information over local information would show stronger local than global salience. Brain damaged individuals would be an example of this; for instance, Behrmann and Kimchi (2003) reported a case of a visual agnostic patient (R. N.) who had great difficulty deriving the global whole of a hierarchical pattern while identification of local detail remained intact.

The findings reported in Experiments 1, 2, 3, 4 and 5 show that the extent of global salience in a measure of perceptual bias does not necessarily indicate whether a global or local advantage will be observed in a selective-attention hierarchical-patterns task. In Experiment 1, medium-density patterns were matched at the global level approximately 60% of the time under both low and high cognitive load. However, when these same stimuli were used in a selective-attention task in Experiments 4 and 5 (using both limited- and unlimited-exposure versions of the task) they were responded to with a local advantage, meaning that responses were quicker to the local level than the global level and more interference was experienced from local detail (on a global-selection task) than from global structure (on a local-selection task). The latter findings imply that local salience was stronger than global salience which is at first sight hard to reconcile with the findings from the matching paradigm using the same stimuli. This could have been for several reasons. Sustained attention to global structure has been associated with increased right-hemisphere cognitive fatigue (Helton et al., 2009). This may have decreased global salience and enhanced local salience, which was reflected in a local advantage. The selective-attention task was also likely more cognitively demanding than the similarity-matching paradigm and this may have imposed a further cognitive load which may have enhanced local salience. Finally, the selective-attention and similarity-matching tasks also differed in the way in which patterns were presented. In Experiments 1 and 2, medium-density patterns were intermixed with low-density and high-density patterns. In Experiment 4 and 5, however, medium-density patterns were presented alone in a block. This could have affected global and local salience. Against this, however, when we ran a matching paradigm on medium-density patterns in isolation (not reported here) we found that the strength of global salience was the same as when medium-density patterns were intermixed with other densities in Experiment 2.

The fact that patterns can be prioritised in terms of their global structure on a bias measure but selected more efficiently on the basis of their local detail is particularly problematic when making cross-experimental comparisons; by looking only at data from Experiments 1 and 4, it could have been concluded that participants had a global bias but a local advantage and therefore that perceptual bias does not necessarily indicate performance on a selection task. Thus, it is necessary to exercise caution when generalising local-global salience from a measure of perceptual bias to local-global salience in a selective-attention task. It may be that the findings from Experiments 1-5 are only contradictory because global salience was not particularly strong in the medium-density hierarchical patterns used in those studies. When findings using stimuli with strong local salience are compared – such as the low-density stimuli in Experiments

1 and 7 – findings in bias and selection paradigms are more harmonious. Specifically, participants made approximately 45% global matches to low-density stimuli presented for a limited duration under high cognitive load in Experiment 1 (indicating that local salience was greater than global salience) and showed a local advantage to these same patterns when presented as part of a limited-exposure selection task under high cognitive load in Experiment 7. This shows that the extent to which measures of perceptual bias and attentional-selection converge is dependent in part on stimulus-driven factors that determine relative global and local salience.

The findings reported in the present thesis illustrate the importance of accounting for stimulus-driven determinants of global salience when making cross-experimental comparisons about the relationship between perceptual bias and attentional selection. For example, comparing performance on a bias measure to performance on a selection task may be completely uninformative if the physical properties of the stimuli differ in any number of ways. If a person were to show a local bias on a measure of perceptual bias and a global advantage on a selection task this does not necessarily mean that a contradictory pattern in performance has been observed. Rather, it could just be that there was particularly strong stimulus-driven local salience in the bias measure and strong stimulus-driven global salience in the selection task. Thus, it is critical that differences between paradigms and the stimuli that they use are taken into account when making cross-experimental comparisons about hierarchical processing.

We have suggested that cognitive load affects local-global perceptual bias and attentional selection of hierarchical information through separate mechanisms; specifically, it may be that cognitive load affects perceptual bias by affecting relative hemispheric activation, while it affects selection by impairing cognitive control and making it more difficult to ignore salient hierarchical information. We now turn our attention to individual differences in cognitive load and cognitive control that could affect the processing of hierarchical information. In particular, it is important to distinguish between cognitive load – that is, demand being placed on cognitive resources – and working memory capacity, which indicates the amount of resource that an individual has available in the absence of cognitive load.

## 7.3 Individual differences

Throughout this thesis we have manipulated the availability of cognitive resources by imposing a cognitive load on perceivers while they perform a task of hierarchical processing. However, the availability of cognitive resources does not just depend on the presence or absence of cognitive load as there is also variation in the baseline amount of cognitive resources that an individual has at their disposal. This is also known as working memory capacity (WMC) and has been shown to underpin functions like working memory and to be closely related to the capacity for executive control (Engle & Kane, 2004; McCabe, Roediger, McDaniel, Balota & Hambrick, 2010). Tasks such as the *operation span*, or OSPAN (Turner & Engle, 1989), provide an index of WMC.

Research with WMC tasks has shown that WMC varies from person-to-person and suggests that the availability of cognitive resources (and subsequently the ability to ignore behaviourally irrelevant information) is subject to individual differences; individuals with low WMC are less able to maintain task goals in working memory and are less able to handle response conflict than those with high WMC (Engle & Kane, 2004; Kane & Engle, 2003), a finding which mirrors the effects of high and low cognitive load on task performance respectively (e.g., see de Fockert, 2013, for a review).

Thus, this suggests that the amount of baseline cognitive resource that an individual has at their disposal (operationalised as WMC) could also affect how efficiently hierarchical information can be selected without interference from irrelevant hierarchical information. Throughout the present thesis we have suggested that cognitive load should make it more difficult to ignore the most salient level of hierarchical information as it depletes cognitive resources and impairs the ability to prioritise behaviourally relevant stimuli (e.g., Lavie et al., 2004); in line with this, individuals with low WMC – who have less cognitive resource available to them than those with high WMC – should find it harder than those with high WMC to select global information when the local level is salient, and harder to select local information when the global level is salient. Thus, we should see the effect of high and low cognitive load on processing of hierarchical information mirrored in those with low and high WMC respectively. However, we suggest that the change in perceptual bias with cognitive load reported in Experiments 2 and 3 was due to increasing task difficulty and its effect on hemispheric activation, rather than availability of cognitive resources *per se* and so it is unlikely that WMC should affect relative hemispheric activation. Thus, WMC should have no effect on perceptual bias. Indeed, we have data which suggest that participants with low and high WMC do not differ in their extent of global bias as measured by responses to hierarchical patterns on an unlimited-exposure similarity-matching task (see Figure 41). The fact that cognitive load has an effect on both perceptual bias and selection whereas availability of cognitive resource (operationalized through WMC) may only have an effect on selection is an important distinction to make, because cognitive load and WMC can otherwise read-out in identical ways. For example, individuals under high cognitive load and individuals with low WMC will perform a task of cognitive control more poorly than individuals under low cognitive load or those with high WMC (e.g., Lavie et al., 2004; Engle & Kane, 2004).

Sometimes, however, individual differences in hierarchical processing may be due to individual differences in cognitive load rather than capacity. An example of this may be depression. There is evidence to suggest that clinical depression incurs a high cognitive load, as depressed individuals find it more difficult to direct cognitive resources to behaviourally-relevant stimuli and prevent task-irrelevant processing (Jones, Siegle, Muelly, Haggerty & Ghinassi, 2010). This may be due to increased rumination in depressed individuals (Beevers, 2005). Indeed, it has been suggested that depression in itself is akin to multi-tasking (Bredemeier, Berenbaum, Brockmole, Boot, Simons & Most, 2012) which, as was discussed in Chapter 4, is associated with a high cognitive load (Yeung & Monsell, 2003). Interestingly, individuals with high levels of depression have been found to process hierarchical information differently to those with low levels of depression. It has been shown that increases in depression decrease the likelihood of making a global match in a similarity-matching task (Basso, Schefft, Ris & Dember, 1996) which suggests that depressed individuals are less globally biased than their non-depressed counterparts. Furthermore, in a selective-attention version of the hierarchical-patterns task, de Fockert & Cooper (2013) showed that individuals with high levels of depression responded to both local and global information equally quickly, while individuals with low levels of depression were faster to respond to global structure than local detail. This again suggests that depression makes it less likely that global structure is prioritised over local detail.

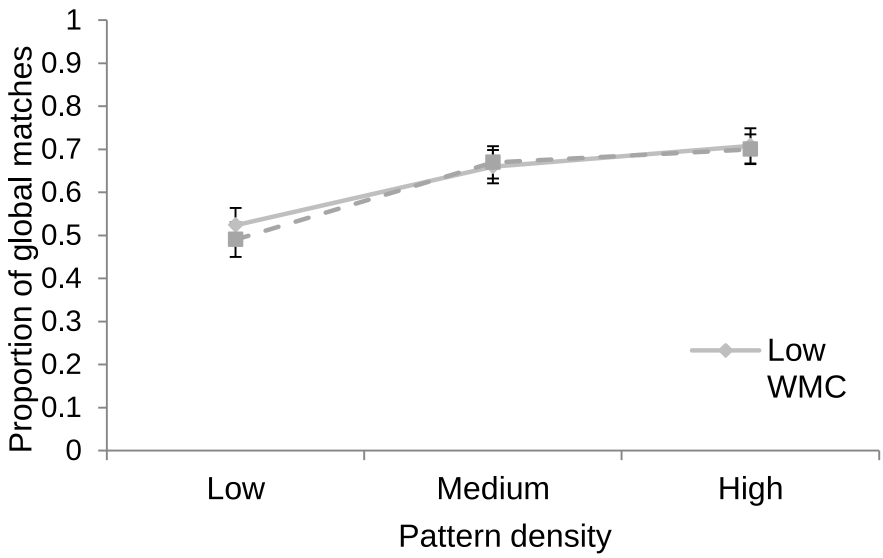



**Figure 41.** *Proportion of global matches made to low, medium and high density hierarchical patterns as a function of WMC-Ospan (unreported data).*

It is possible that the cognitive load associated with depression, whether through increased rumination (Beevers, 2005) or multitasking (Bredemeier et al., 2012), affects relative hemispheric activation and therefore reduce the likelihood that global structure will be prioritised over local detail. De Fockert and Cooper (2013) suggest that their findings show that the detail-oriented cognitive processing style of depressed individuals is also reflected in performance on a hierarchical patterns task. However, this account does not sit easily with the higher cognitive load of depressed individuals (compared to non-depressed individuals) which, according to Ahmed and de Fockert (2012), should cause a “shift towards global processing” and should increase interference from irrelevant global structure on a local-selection task and decrease interference from local detail on a global-selection task. This pattern of findings was not observed in de Fockert and Cooper and lends further support to our suggestion that cognitive load does not *always* make processing more global.

Another example of a cognitive state that can impose a cognitive load is social power. This refers to the ability of an individual to “control their own outcomes” (p. 621; Fiske, 1993). It has been suggested that the mental world of powerless individuals differs greatly from the powerful, so that they are hyper-vigilant in the face of uncertainty (Keltner et al., 2003) and are at the mercy of others (Galinsky et al., 2003). They have also been shown to have impaired executive functioning in comparison to powerful individuals (Smith et al., 2008) and to find it more difficult to ignore distracting information on an attentional orienting task (Slabu, Guinote & Wilkinson, 2013). Thus, powerless individuals may approach the world in a hyper-vigilant state compared to the powerful and are also likely to be operating under higher cognitive load.

Interestingly, a study exploring the effects of social power on hierarchical processing (Guinote, 2007) has provided evidence to suggest that powerless individuals are sometimes more local than powerful individuals but at other times are more global. In a series of experiments, Guinote (2007) ran both an unlimited-exposure selective-attention version of the hierarchical-patterns task (Navon, 1977) and the original version of the FLT (Kitayama et al., 2003) on participants who had been experimentally manipulated to feel either powerful or powerless. On the selective-attention hierarchical-patterns task it was found that powerless individuals were quicker to respond to local detail than global structure, while powerful individuals responded to both local and global information the same. This suggests that powerless individuals exhibited a local advantage on the selection task and implies that local information was more salient than global information for powerless individuals. However, when participants performed the FLT – a task with strong global salience – it was found that powerless individuals were better at the *relative* task than the absolute task, whereas the powerful performed both tasks equally well. This suggests that powerless participants found it more difficult to select local information than powerful participants and experienced more interference from the salient global structure, a pattern seemingly at odds with findings on the selective-attention hierarchical-patterns task.

Guinote (2007) explained this pattern in performance by suggesting that powerless individuals do not select between relevant and irrelevant information; instead, they process all information in the environment. This is in contrast to powerful individuals who more readily select relevant information at the expense of irrelevant information. In the FLT, Guinote suggested that powerless individuals were more likely to attend to the global context even when it was irrelevant (and thus performance deteriorated in the absolute task in comparison to powerful participants) and in the selective-attention hierarchical patterns task were more likely to attend to the local detail that comprised the global whole (thus responding quicker to local detail than global structure). However, in light of the findings in the present thesis we suggest that Guinote's findings can be reinterpreted in terms of the effects of cognitive load on hemispheric activation and on cognitive control.

Powerless individuals have been shown to be hyper vigilant (Keltner et al., 2003), a state which is associated with high right hemisphere activation (Duschek & Schandry, 2003; Helton et al., 2007; Hitchcock et al., 2003; Stronbant & Vingerhoets, 2000). Evidence to support this assertion comes from studies that have shown that participants primed with powerlessness have relatively higher right hemispheric activation than participants who are primed to feel powerful (Boksem, Smolders & Cremer, 2012) and that powerless individuals bias attention more to the left side of space in comparison to powerful individuals, a finding which is also indicative of higher right than left hemisphere activation (Wilkinson, Guinote, Weick, Molinari & Graham, 2010). Higher right hemispheric activation, however, should mean that powerless individuals show a global advantage in a selective-attention hierarchical patterns task, as the right hemisphere is dominant for global information processing, but in Guinote's (2007) study this was not the case; here, powerless participants were faster to respond to local detail than global structure. To explain this, we suggest that powerless individuals may be operating with elevated right hemisphere activation in the absence of task demands. When they are then required to perform a cognitively-demanding task, such as the selective-attention hierarchical-patterns task, hemispheric activation becomes bilateral (Helton et al., 2010) and local salience is enhanced. This would explain why Guinote's (2007) powerless individuals were quicker than powerful individuals to respond to local detail than global structure in an unlimited-exposure selective-attention hierarchical patterns task.

The impaired executive functioning associated with powerlessness (Smith et al., 2008) should then make it more difficult for powerless individuals to ignore salient local or global information. Guinote (2007) did not report interference scores on the selective-attention hierarchical patterns task so we cannot examine whether powerlessness is associated with increased interference from salient information on this task; if this information were presented, however, in line with the arguments presented in this thesis we would predict that powerless individuals should experience more interference from irrelevant local detail on a global-selection task than do powerful participants. On the FLT, we do have this information. Whereas powerful participants performed the absolute and relative tasks equally well, powerless participants were significantly worse at the absolute task than they were at the relative task. These findings suggest that powerless participants are less able to ignore irrelevant salient global information than the powerful. If powerless and powerful individuals were to perform a disconnected version of the FLT, as we did in Experiment 11 (reported in Chapter 5), we suggest that powerless individuals should now be *worse* at the relative task than the powerful.

It is interesting to consider how powerful and powerless individuals may differ on a measure of perceptual bias, such as the similarity-matching hierarchical-patterns paradigm presented in a series of experiments in Chapter 2. The fact that powerless individuals show higher right hemisphere activation than powerful individuals (Boksem et al., 2012; Wilkinson et al., 2010) suggests that the powerless may have a stronger global bias than the powerful, as global information processing is lateralised to the right hemisphere. However, as the hyper-vigilance of powerless individuals means that right hemisphere activation is likely to be at ceiling, they will possibly be more affected by additional cognitive load than will powerful individuals. This means that a lower amount of cognitive load may be needed in order for hemispheric activation to become bilateral in powerless individuals in comparison to the powerful; indeed the very act of matching stimuli based on perceived local-global similarity (such as the similarity-matching paradigm; Kimchi & Palmer, 1982) may be sufficient.

The fact that vigilance more generally may interact with task difficulty to determine perceptual bias, and therefore local-global salience, is important as the need to remain vigilant is necessary in many diverse scenarios; notable examples are military settings (McBride, Merullo, Johnson, Banderet & Robinson, 2007), monitoring automated machines (Molloy & Parasuraman, 1996), and baggage screening in airports (Hancock & Hart, 2002). If the task to be performed is cognitively demanding, this could affect relative hemispheric activation and enhance the salience of local information and reduce the salience of global information. Thus, any number of situations that require vigilance may also incur a cognitive load which may affect how hierarchical information is prioritised. This could mean that difficult vigilance tasks may make it more likely that individuals will be distracted by irrelevant local detail and may miss the 'big picture'.

The present section has considered the effect that individual differences in vigilance, cognitive load, and working memory capacity might have on both perceptual bias and on attentional selection. In experimental scenarios, the possibility that a multitude of individual differences could affect both perceptual bias and attentional selection of hierarchical information suggests that performance on hierarchical processing tasks could be driven in part by the characteristics of the participant sample. For example, if the experimental setting caused participants to become more vigilant then the associated cognitive load could produce a pattern in performance that would be different to performance in a more relaxed experimental setting. Furthermore, individual differences in baseline vigilance, for example, could affect performance between participants. Considering that any number of individual differences could have an effect on hierarchical processing, it is important to consider the extent to which individual differences in our own participant samples could have influenced performance on hierarchical processing tasks.

In Chapter 5 we discussed the extent to which culture has been shown to affect local-global processing style (e.g., Kitayama et al., 2003). The majority of participants tested across all 12 experiments reported in the present thesis were either first-year psychology undergraduate students at Goldsmiths, University of London, UK or employed as Visitor Experience assistants at the Science Museum, London, UK. They were mainly young, were predominantly female, and for the purposes of the present research we classified these individual as 'Westerners' as they all lived in London, UK. That our participant samples were fairly homogenous is positive because it reduces the extent to which individual differences could influence task performance. However, by defining participants as 'Western' solely because they live in London, UK we could be ignoring potentially important individual cultural differences that could affect hierarchical processing. For example, participants may have recently moved to London from overseas and thus may only recently begun to engage in 'Western' culture. Research has suggested that being born into a certain culture does not solely determine hierarchical processing; second generation Asian-Australians have been shown to exhibit a strong global advantage which is more similar to East Asians living in Asia than their Caucasian-Australian counterparts (McKone et al., 2010). Indeed, differences in hierarchical processing have been shown even within cultures; for example, members of farming and fishing communities in Turkey's Black Sea region exhibit a stronger global processing style compared to herders living in the same region (Uskul et al., 2008). Counter to this, however, is evidence that suggests that individuals that move to another country adopt the local-global processing style of the host culture (Kitayama et al., 2003) and that even a single visit to an urban environment can be enough to change the extent to which global structure is prioritised over local detail (Caparos et al., 2012).

Thus, a multitude of cultural and environmental factors could influence person-driven salience of hierarchical information, and thus could influence the effect that cognitive load has on hierarchical processing.

Aside from culture, it is likely that the 'default setting' with which observers approach visual information (Dale & Arnell, 2013) is determined by a host of individual differences. 'Western' individuals may be less global than 'Eastern' individuals; however, other factors within a culture such as vigilance, depression or social power could interact to determine exactly where the 'default setting' is placed. It is possible that the effect of certain individual differences on hierarchical processing could outweigh others. For example, although 'Westerners' are said to be more locally-biased than 'Easterners', it is possible to imagine a scenario where the hierarchical processing style of a hypervigilant 'Easterner' resembles that of a less-vigilant 'Westerner'. This suggests that while it is important to account for individual differences when exploring the effect of cognitive load on hierarchical processing, it might not be possible to control for all factors that could be affecting local-global processing. Furthermore, considering that cognitive load could interact with individual differences to determine hierarchical processing (see the example of powerlessness above), it is likely that the effect of cognitive load on local-global processing results from an interaction between many different individual differences.

The present section has considered the effect that individual differences such as vigilance, cognitive load, and working memory capacity might have on both perceptual bias and on attentional selection. It is important to state that individual differences in hierarchical processing should not automatically be equated with individual differences in cognitive load; however, our findings can be extrapolated to suggest that when individual differences in cognitive processing *do* incur a high cognitive load, differences in hierarchical processing should be observed. Indeed, it is possible that individual differences may be a stronger manipulation of cognitive load than the secondary digit-span task often utilised in experimental situations. In the following section, we consider the effect that cognitive load could have on hierarchical processing in real-world scenarios.

## 7.4 How might cognitive load affect real-world vision?

Thinking beyond the laboratory, the findings presented in this thesis suggest that cognitive load may fundamentally impact how individuals process the hierarchical visual world. Humans are subjected to varying amounts of cognitive load. Whilst differences in cognitive load could be transitory, they could also be prolonged and could fundamentally alter how individuals perceive their environment, both in terms of how they approach the world (perceptual bias) and how well they can work with the hierarchical information in the environment (attentional selection). Cognitive load may not only decrease the tendency to see the ‘forest’ instead of the ‘trees’ but may also make it more difficult to attend to global structure if local detail is particularly salient or more difficult to attend to local detail if global structure is particularly salient.

One consequence of this may be to affect the understanding of graphical or written information, which is ubiquitous in the environment. Words are perceptual wholes and thus cognitive load could potentially affect how well words are understood. A phenomenon referred to as ‘orthographic satiation’ in Chinese characters (Cheng & Lan, 2011; Cheng & Wu, 1994) and ‘Gestaltzerfall’ of Japanese kanji characters (Ninose & Gyoba, 1996, 2002) shows that prolonged viewing of these characters makes them more difficult to understand. For example, Ninose and Gyoba (1996) demonstrated that kanji characters could be recognised very quickly by experienced readers but after prolonged viewing (in the region of 25 s) an uncertainty about the orthographical correctness of the perceptual whole emerged. They suggested that kanji are initially represented within the visual system as perceptual wholes but that their structural cohesiveness is disrupted by prolonged viewing. The findings presented in this thesis have also shown that cognitive load affects the representation of hierarchical information, by reducing global salience and enhancing local salience (see Chapter 2). Thus, it is possible that cognitive load will enhance local salience in kanji – and perhaps words in other writing systems – by affecting hemispheric activation, which could ultimately make words more difficult to read.

The idea that cognitive load may make reading more difficult is problematic when we consider the fact that differences in situational factors related to reading, such as text difficulty or reading ability, can impose differences in cognitive load. For example, the task of learning to read is cognitively demanding and as such may disrupt the structural cohesiveness of words which is fundamental to reading. Additionally, individuals with dyslexia or those who are less skilled readers may experience a greater cognitive load when reading, which may negatively affect the representation of words as perceptual wholes and hinder the task of reading still further.

Reading is just one example of a real-world scenario in which cognitive load could affect the processing of hierarchical information. Another real-world consequence of the effect of cognitive load on hierarchical processing could be its effect on face processing. Faces are represented holistically (e.g., Tanaka & Farah, 1993) and it has been shown that recognition of a previously-seen face is worse when recognition follows performance of a local-selection task and better when it follows performance of a global-selection task (McCrae & Lewis, 2002). In a single experiment, McCrae and Lewis had participants view a 30 s video of a simulated robbery. Participants then performed either a local-selection hierarchical-patterns task, a global-selection hierarchical-patterns task, or an unrelated task as a control condition. In a subsequent facial-recognition test, it was found that participants who had performed the local-selection task performed worse than the control participants (30% vs. 60% accuracy respectively) whereas those who had performed the global-selection task performed better on the recognition test than the control participants (83% vs. 60% accuracy respectively). This finding suggests that face recognition is improved as processing becomes more global. It is interesting to consider how cognitive load might affect face processing. Work in the present thesis has shown that cognitive load enhances local salience and reduces global salience; because faces are represented holistically (e.g., Tanaka & Farah, 1993), cognitive load could potentially impair face recognition by making it more difficult to represent faces as a whole. However, the holistic nature of faces means that they may have strong global salience; this being the case, the strong global salience of the face as a whole might mask the effect of cognitive load to reduce global salience.

Ultimately, when interacting with the world humans are interacting with objects which exist in complex scenes rich in visual information. Sometimes the scene as a whole may be appreciated, while other times attention may need to be focused on individual objects (e.g., Treisman, 2006). Importantly, the contents of a scene cannot simply be divided into ‘global structure’ and ‘local detail’; rather, objects exist within nested hierarchies in which visual information may be classed as global structure in one scenario (i.e., a tree is a global structure which consists of local branches, leaves and a trunk) but as local detail in another (i.e., a tree is a local detail in the context of a forest). The work presented in this thesis suggests that the effect of cognitive load on scene processing should depend on the analysis that is required. If the scene as a whole is to be appreciated, then cognitive load might reduce global salience and enhance local salience (by affecting hierarchical perceptual bias) and weaken the relationship between objects in a scene. This might make it more likely that people will ‘miss the big picture’. However, if individual objects are of interest then the effect of cognitive load will depend on the salience of the stimulus. As discrete objects tend to have strong global salience (Navon, 2003) then cognitive load may enhance the processing of global structure and impair the processing of local detail. The findings presented in this thesis should ultimately be extended to whole scenes. As cognitive load varies from both person-to-person, and can vary within an individual across time, exploring the effect that cognitive load has on scene perception could be of fundamental importance to establishing the effect that cognitive load could have on real-world vision.

## 7.5 Conclusions

The present thesis explored the effect of cognitive load on processing of hierarchical information. Across a series of 12 experiments we showed that cognitive load does not *always* make people more global, as was suggested by Ahmed and de Fockert (2012), but rather the effect of cognitive load depends on i) whether the task is addressing perceptual bias or attentional selection, and ii) stimulus-driven factors which affect local-global salience. We have presented findings to show that cognitive load affects perceptual bias and makes it more likely that hierarchical information will be interpreted in terms of its local detail and less likely that information will be interpreted in terms of its global structure (Experiments 1-3, presented in Chapter 2). In Chapters 3-6, a series of experiments showed that the effect of cognitive load on attentional selection is influenced by stimulus-driven factors which affect local-global salience; cognitive load increases interference from local information on a global-selection task when local salience is strong (Experiments 7 and 11) and increases interference from global information on a local-selection task when global salience is strong (Experiments 9, 10 and 12). Our findings have provided further evidence to support the suggestion that perceptual bias and attentional selection operate through separate mechanisms (Caparos et al., 2013); we suggest that perceptual bias could be influenced by relative hemispheric activation, whereas selection of hierarchical information is governed by cognitive control. In conclusion, we suggest that cognitive load does not simply make people 'more local' or 'more global' but that its effects depend on whether the task is addressing perceptual bias or attentional selection, as well as on stimulus-driven factors which affect local-global salience.

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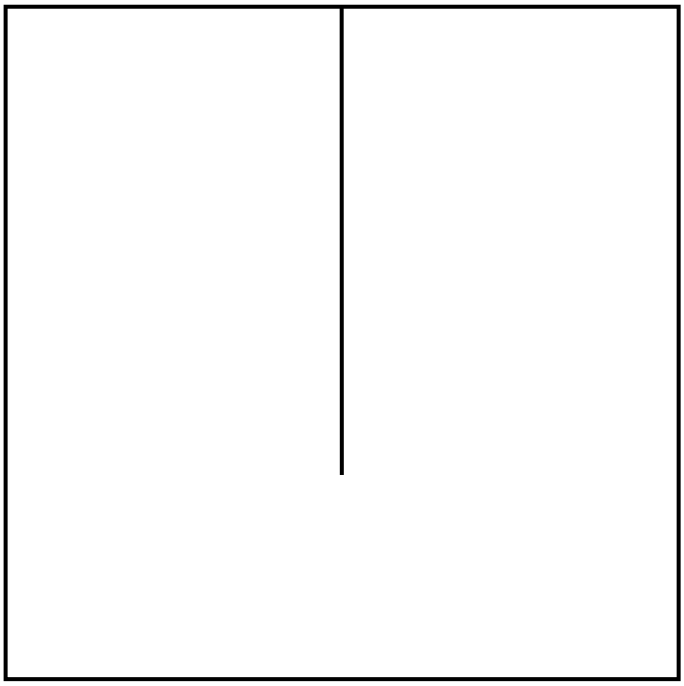
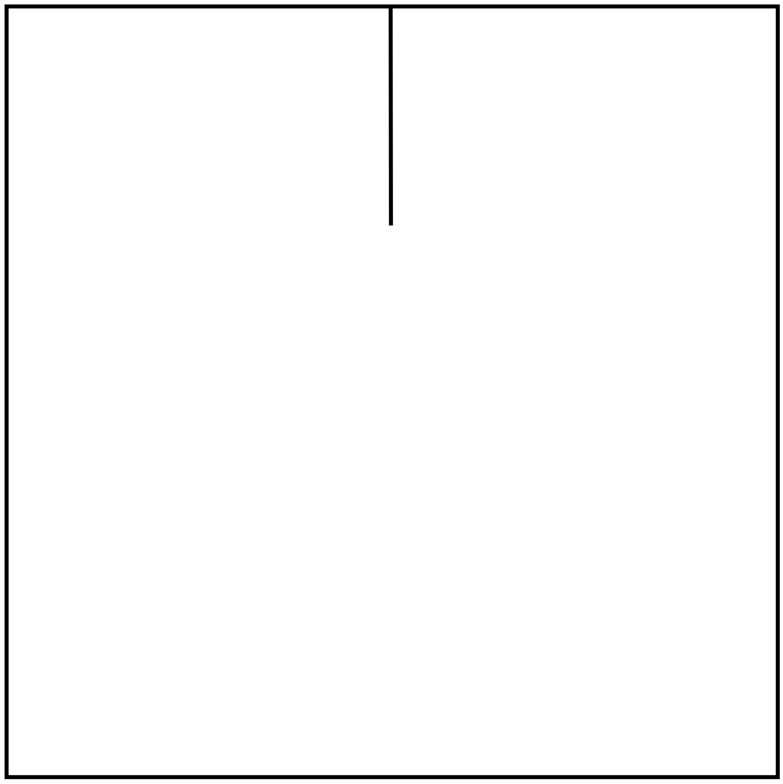
## Appendix A: Stimuli used in the connected FLT

1. Trial-type 1: 89 mm frame and line



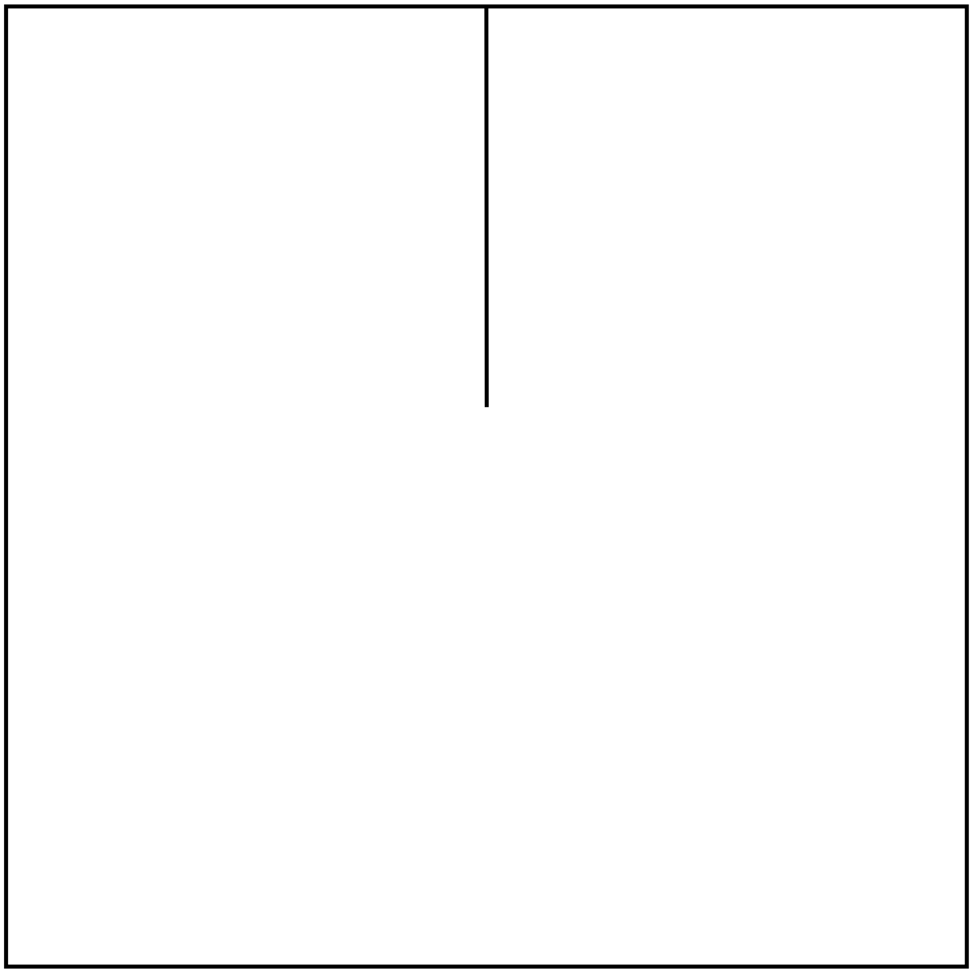
2. Trial-type 1: 179 mm test frame

3. Trial-type 2: 102 mm frame and line

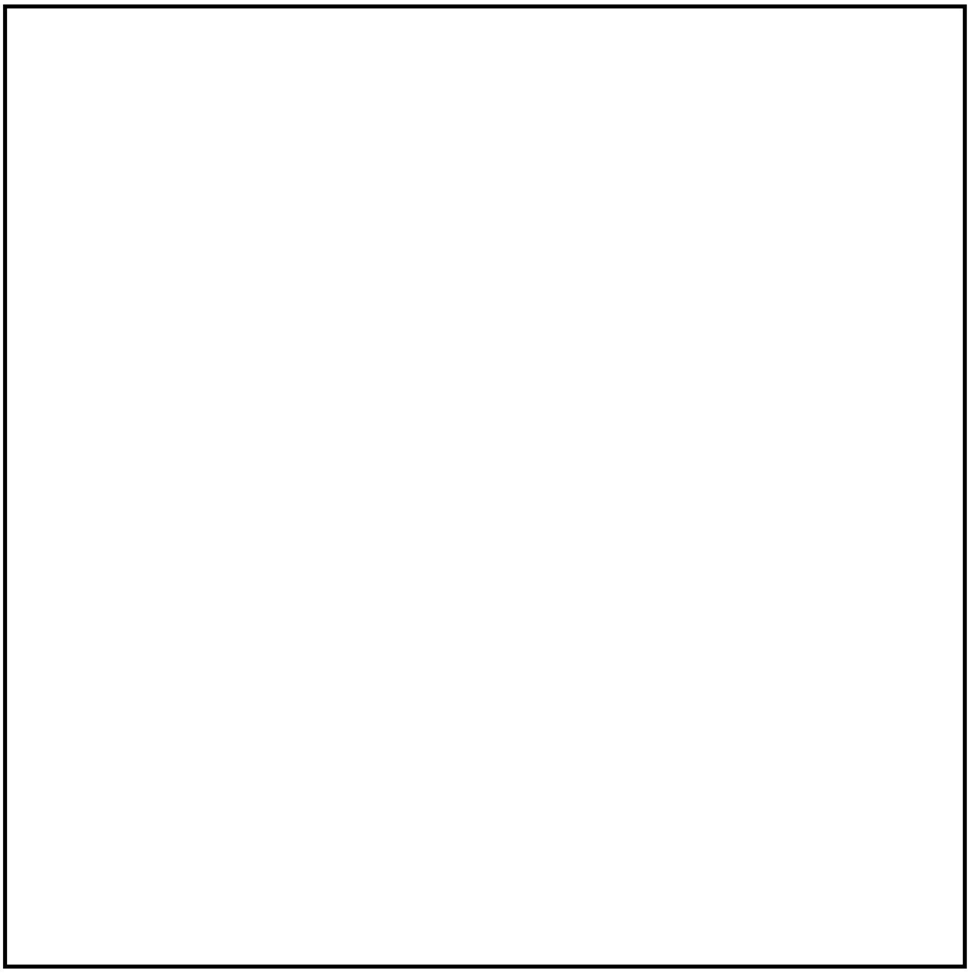


4. Trial-type 2: 153 mm test frame

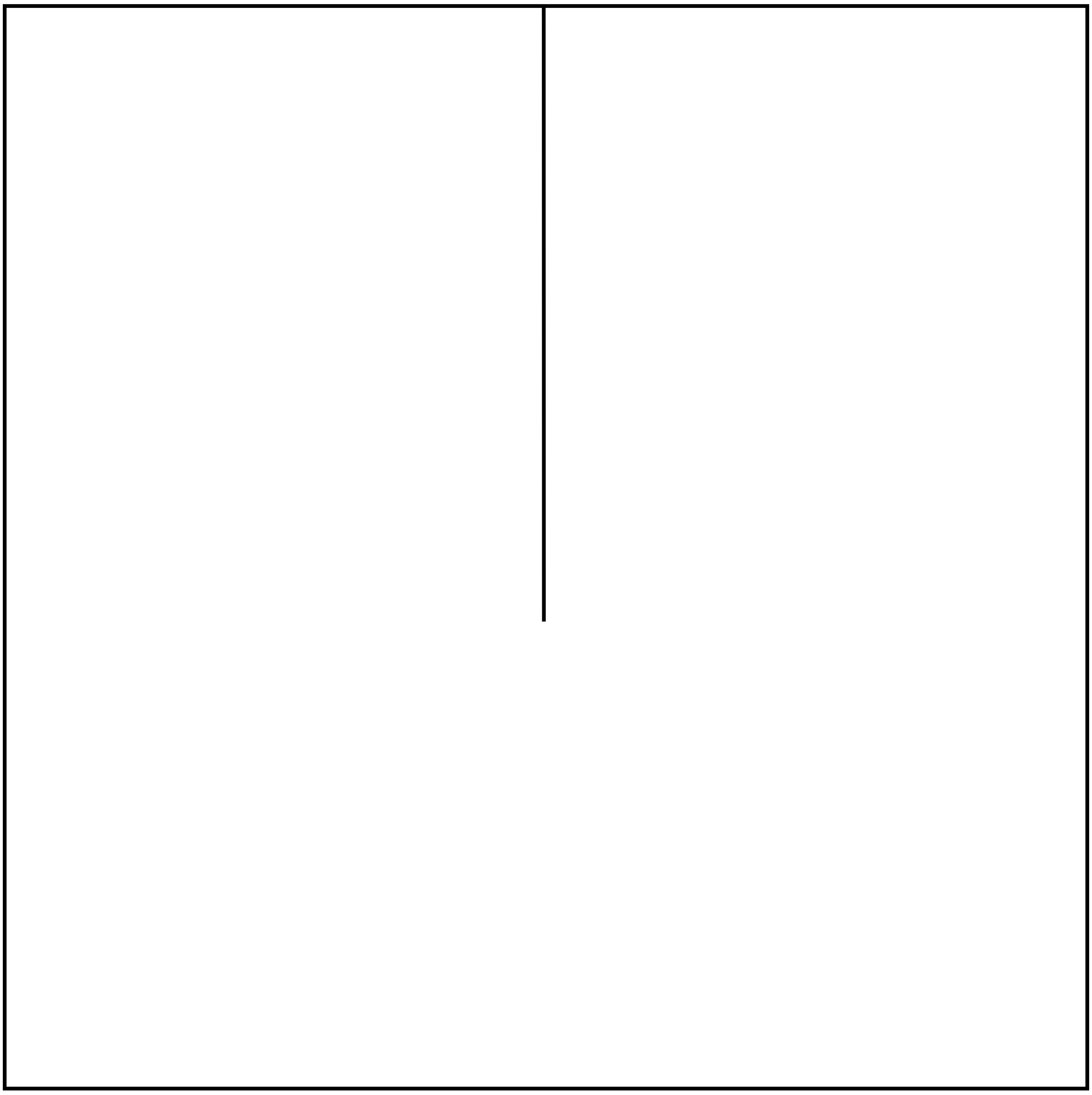
5. Trial-type 3: 127 mm frame and line



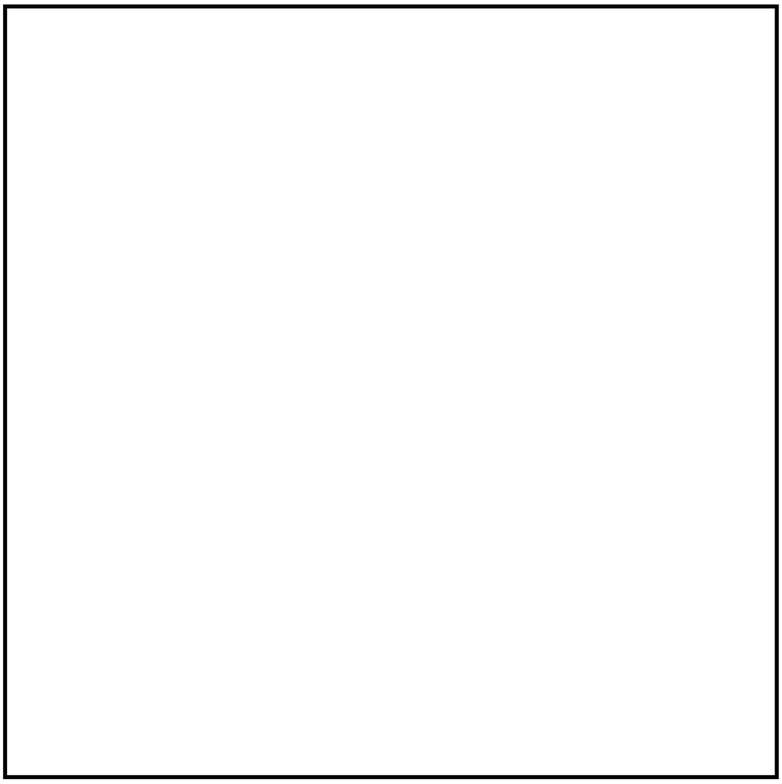
6. Trial-type 3: 127 mm test frame



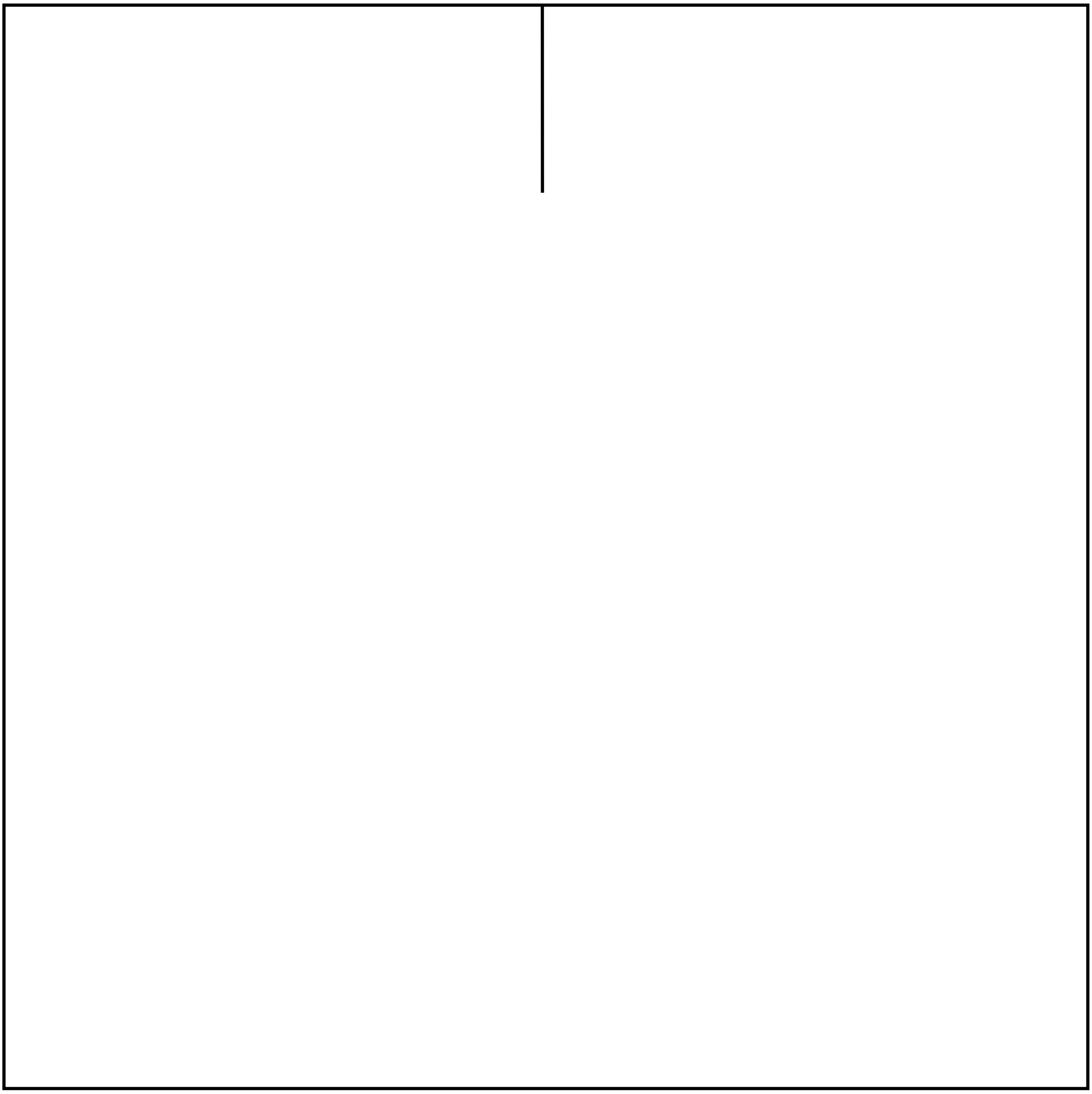
7. Trial-type 4: 153 mm frame and line



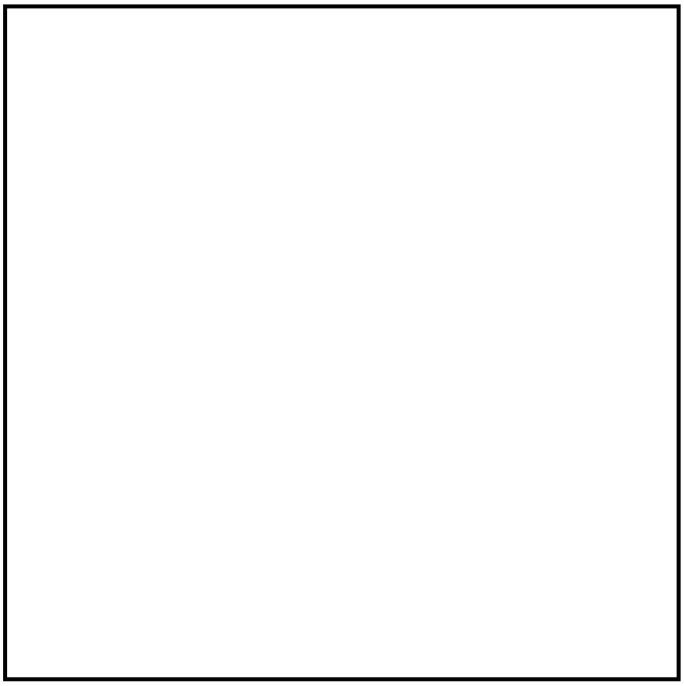
8. Trial-type 4: 102 mm test frame



9. Trial-type 5: 179 mm frame and line

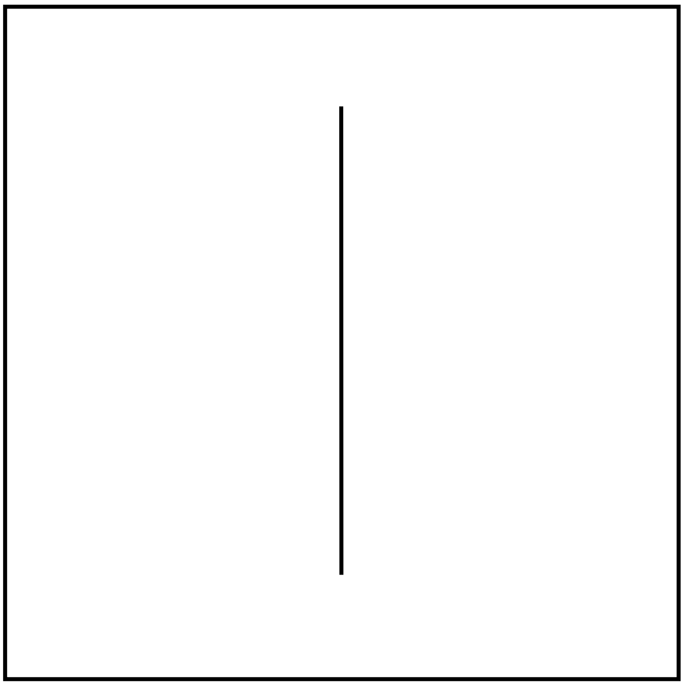


10. Trial-type 5: 89 mm test frame



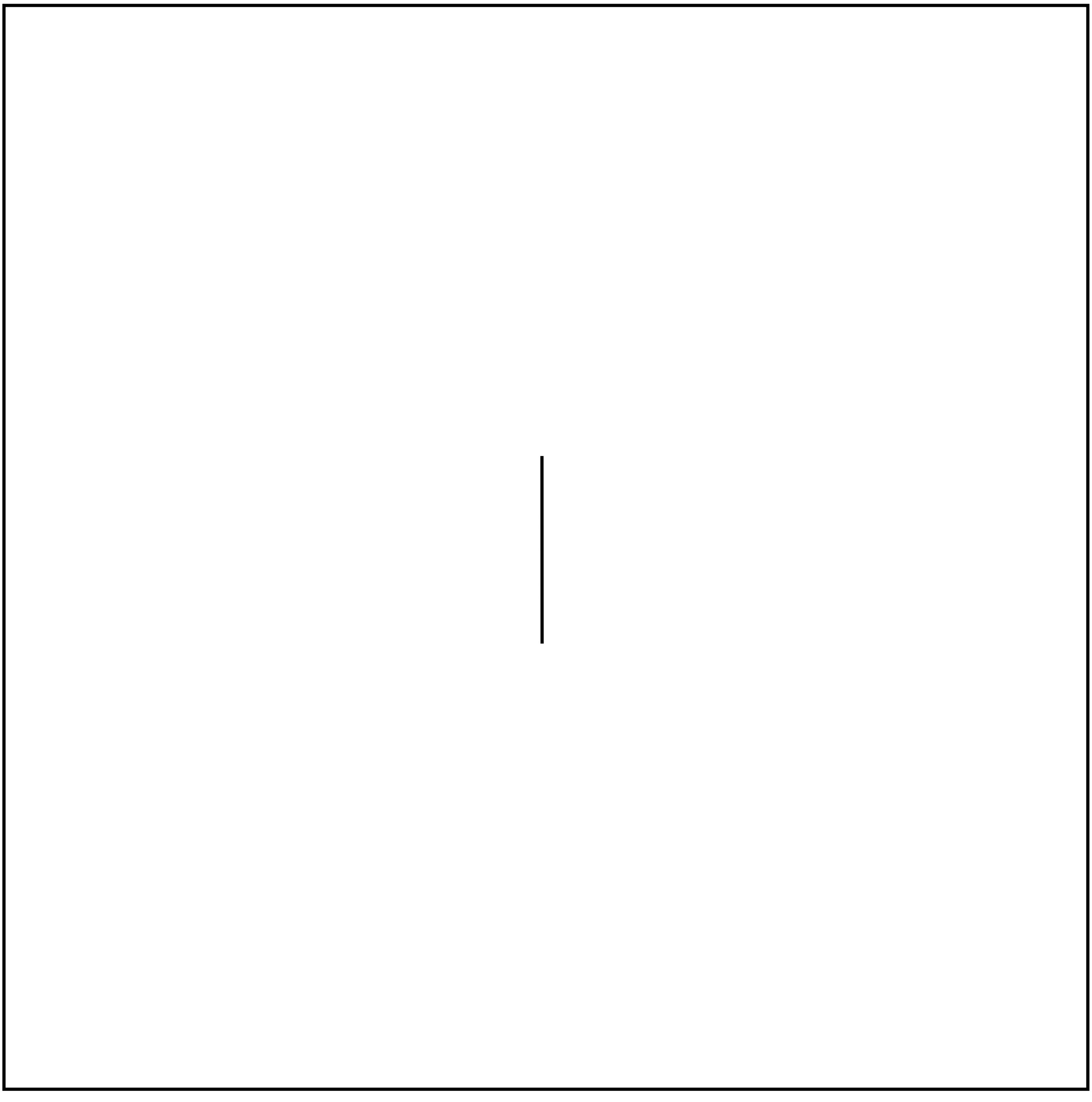
## Appendix B: Stimuli used in the disconnected FLT

1. 89 mm frame and line



2. 179 mm test frame

3. 179 mm frame and line



4. 89 mm test frame