WORKING MEMORY, SELECTIVE VISUAL ATTENTION, AND HIERARCHICAL PERCEPTION

by

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Abstract

Previous research has shown that stimuli held in working memory can guide spatial allocation of attention, even when the stimuli are irrelevant to a subsequent search task. Responses are speeded when the content in working memory matches a target, and are slowed when the content matches a distractor (Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005). The relevant literature reflects on whether or not this top-down process of attentional capture from working memory is an automatic mechanism where attention gets deployed without a need for voluntary effort, and on the neural process of this endogenous control working in conjunction with bottom-up exogenous factor. So far there have not been any explorations into how the working memory might influence non-spatial selection of attentional selection, whilst also testing for the automaticity of working memory. Using Navon stimuli, I explored if and how various types of items held in working memory affect the perception of visual targets non-spatially, at local and global levels in compound letters. The data show that information in working memory biases the selection of hierarchical forms whilst priming does not, that irrelevant part of memory item also influences attentional selection, that the specific type of attentional mode (distributed vs. focused) plays an important role in selection, and that it is not easy to eradicate the top-down working memory effect.

Acknowledgement

I am not really a fan of such often inflated words as ‘perfect’ or ‘the best’, but to be honest these are the kind of words I must use to refer to Glyn Humphreys. He is an enthusiastic, committed, approachable, and always helpful supervisor, simply perfect in every respect. He made my three-year PhD life a truly enjoyable course of learning. It is hard to imagine a hypothetical supervisor who could possibly be better than Glyn.

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CHAPTER 1

Introduction

Selective Visual Attention – Top-down vs. Bottom-up

A simple reflection on biological reality tells us that we are unable to, and probably do not need to, attend to every object present in our visual world, and that we perceive only parts of visual data available. Selective visual attention refers to the process of attending to a certain part of the visual information available at the expense of other (unattended) information. This process is a vital cognitive ability for any behaving agent in a complex world, for there is a need to be able to efficiently select the most relevant information that matches the current behavioural goal. The mechanism of this important process, broadly, is the topic of the present thesis. How does the brain deploy attention? What factors are there to influence the process of attentional deployment? Specifically what facilitates and inhibits this process?

Visual attention can be drawn to sensory inputs received by retina, to facilitate their later processing in the brain. This happens in a stimulus-driven, 'bottom-up' manner, without necessarily requiring voluntary effort (Yantis & Jonides, 1990). However, this stimulus-contingent process does not always influence perception and ensuing action in an invariant manner. Processing can also be altered by goal-directed, 'top-down' mechanisms. For example, a salient visual stimulus can be effectively ignored (or even not perceived) when we consciously look for some other target that is more relevant (e.g., Simons & Chabris, 1999; Rock, Linnett, Grant, & Mack, 1992). Any type of visual search task, in an experimental setting as well as in everyday life, will require the optimal balance of these two processes. We need to be able to make best use of bottom-up stimuli available, whilst making sure that we select what best meets our goals and purposes.

How each of these different attentional operations might work individually or jointly has been investigated vigorously (Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, 1994; Theeuwes, 2004; Kim & Cave, 1999; Lamy, Tsal, & Egeth, 2003; Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992). Some researchers have shown that completely irrelevant singletons distract attention away from a target, overriding any top-down effort in search, and from this it has been argued that attention is controlled in a purely bottom-up manner (Theeuwes, 1992, 1994; Mulckhuyse, Talsma, & Theeuwes, 2007). As an alternative account, Folk et al. (1992) put forward the conceptual framework of 'contingent orienting', a hypothesis that the bottom-up attraction of attention does not occur automatically but is dependent on the 'attentional control setting'. They had their participants search for a target after a spatial cue, which was either a single highlighted cue in one condition or, in a second condition, a uniquely coloured cue displayed with other non-coloured cues. The target was sometimes a character in black presented alone with no other stimuli, and at other times a character in a colour that was uniquely different from the distracters displayed together. The task was to make a forced-choice response to the identity of the character. The data showed that there was a benefit when the target fell where the cue had been flashed, which did not differ between the two cue conditions, but the magnitude of the cost varied as a function of the relations between the critical property of the cue and that of the target - the cost for invalid cues occurred only when the cue and the target shared the same property. Folk and colleagues suggested that a task would require a preceding internal setting for task-relevant features and that irrelevant bottom-up information would influence attention only when this information shares its properties with the task-relevant features. According to their explanation, the data indicate that bottom-up cueing of attention might not be entirely autonomous but is contingent on top-down guidance.

There is neurophysiological evidence that the visual system is predisposed towards salient stimuli and, given no top-down factor, attentional selection would be made on the basis of the bottom-up input (van Zoest, Donk, & Theeuwes, 2004; Mathôt, Hickey, & Theeuwes, 2010). In contrast, a different body of recent work emphasises the importance of top-down process – which may change even basic perceptual representations. For example, directing attention to a specific location in space appears to alter the phenomenal perception of stimulus contrast (Carrasco, Ling, & Read, 2004). In addition, when attention is focused on a location, the thresholds for luminance and colour contrast are lowered (by about 30-70%) compared to when it is divided (Morron, Denti, & Spinelli, 2002). These results indicate that top-down attentional control can influence early visual processing, and thus that the directing attention endogenously can influence what was once thought of as early pre-attentive stages of processing. Some researchers even point out the anatomical fact that there are more feedback connections than feedforward inputs (Salin & Bullier, 1995), which might indicate possible bigger role of top-down process than bottom-up counterpart in attentional selection.

Attentional selection is a deeply interesting cognitive process, which stands right at the centre of our moment-to-moment experience, memory, learning, and ultimately making best possible decisions for survival. As illustrated above, this crucial process comes about through the interplay between external and internal factors. And this interaction steers us in our constant selective perceiving of the space and objects around us.

Space-based and Object-based Attention - Psychological and Neurobiological Explorations

Work on spatial selection began with the elegant paradigm developed by Posner (1980) (see Figure 1.1). Posner showed that we are faster in detecting stimuli when our spatial attention is already committed to the particular area where the stimuli are located, relative to when attention is committed elsewhere (contrasting valid with invalid cue trials). Using variations of this paradigm, a long line of studies has shown that, when attention is focused on a particular spatial location, there occurs a modulation in the perceptual process so that detection of a visual target is most efficient when the target falls in the cued area (Posner & Cohen, 1984; Posner, Petersen, Fox, & Raichle, 1988 Luck, Heinze, Mangun, & Hillyard, 1990; Yamaguchi, Tsuchiya, & Kobayashi, 1995).

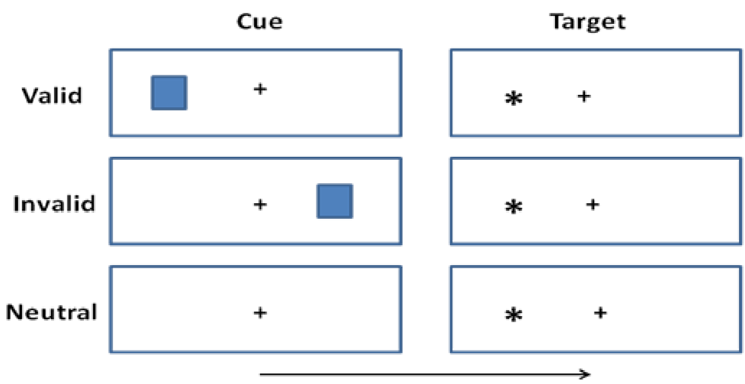


Figure 1.1. An illustration of typical 'Posner' paradigm. The speed of RTs is in the order of Valid – Neutral – Invalid, with the Valid being the fastest.

A possible analogous mechanism also has been considered and much investigated, dealing with the attentional selection of objects and features, as opposed to space. A considerable body of research has proposed that attention and perception occur more on the basis of objects, rather than space (Duncan, 1984; Duncan & Humphreys, 1989; Egly, Driver, & Rafal, 1994; Humphreys, Olson, Romani, & Riddoch, 1996; Brefczynski and DeYoe, 1999; Martinez et al., 1999). Furthermore, when attention is directed to a specific object, all visual features of the object are processed simultaneously, with the features of attended objects being processed more efficiently than the features of other unattended objects (Duncan, 1984; Vecera and Farah, 1994). For example, Duncan (1984) had participants view two overlapping objects, each of which varied on two feature dimensions. When the participants were asked to discriminate the two features, they were better at reporting features belonging to the same object than features belonging to two different objects. The disparity in performance here cannot be attributed to spatial factors, because the two objects overlapped in space – more likely the effects reflect the switching of attention from one object to the other, which induces a cost for the two-feature, two-object condition. Supporting the argument made by Duncan (1984), Egly and colleagues (1994) showed that whilst there was an attentional benefit from spatial cueing, there was an additional benefit when the target was a part of the same object, rather than a part of a different object. For example, under conditions in which both targets were equal-distance away from the cue, the cost of spatial mis-cueing was reduced when the cue and target fell within the same object.

Object-based attentional processes have also been explored in functional imaging studies. O’Craven, Downing, & Kanwisher (1999) presented overlapping faces and houses to participants, sometimes moving one of the stimuli. These stimuli are of interest because they selectively activate distinctive anatomical locations in the brain - the fusiform face area (FFA) and the parahippocampal place areas (PPA), respectively. The task was to selectively attend to the face or the house, or sometimes to just the motion itself. O'Craven et al. observed activations in the relevant brain area (FFA or PPA) corresponding to the specific moving object when each was attended to, and also in MT area. Interestingly, activation occurred in stimulus-specific processing regions (the FFA and PPA) in the appropriate attentional condition, even in a condition in which participants did not have to actually identify the object in motion. These results show that attention facilitates processing of all features that belong to an attended object, and that objects can be separately represented and attended without involving spatial selection.

Quite a few studies so far have reported both different and common brain areas linked to space-based and object-based attention. For both modes of attention there are often common activations in the medial superior parietal cortex, the lateral inferior parietal cortex, and the prefrontal cortex. Differential activation in left striate and prestriate cortices has been reported for object-based attention, and activations in the right prefrontal cortex and the right inferior temporal-occipital cortex under conditions where spaced-based attention is manipulated (Fink, Dolan, Halligan, Marchall, & Frith, 1997; Vandenberghe, Gitelman, Parrish, & Mesulam, 2001; Yantis, Schwarzbach, Serences, Carlson, Steinmetz, Pekar, & Courtney, 2002; Yantis & Serences, 2003)

Although there is still a long way to go to reach a full understanding of the nature of selective visual attention, some important aspects of the mechanism by which attention affects processing have been recently clarified. Evidence from single-cell and brain-imaging studies shows that directing attention to a particular visual stimulus changes neuronal responses across a range of areas (Corbetta, Miezin, Dobmeyer, & Shulman, 1990; Treue, 2001). Notably, a neuron’s contrast-response threshold is lowered with attentional direction so that it is possible to respond to a stimulus that is otherwise too weak to drive neuronal output (Morrone, Denti, & Spinelli, 2002; see Reynolds & Chelazzi, 2004, for a review). We also know which areas and neuronal networks are involved in attentional processing. The majority of early neurobiological research on visual attention suggested that attention influenced only intermediate and late stages of visual processing. However there is a considerable amount of recent data suggesting that visual attention involves perhaps all areas of visual cortex from lateral geniculate nucleus to parietal, temporal, and even frontal regions (Chelazzi, Miller, Duncan, & Desimone, 1993; Treue & Maunsell, 1996; Kanwisher & O’Craven, 1998; O’Connor, Fukui, Pinsk, & Kastner, 2002; Cook & Maunsell, 2002; Saenz, Buracas, & Boynton, 2002; Schall, 2002; Moore & Armstrong, 2003).

These data indicate that attentional selection might be an all-brain global processing event that modulates both selective perception and selective action to visual information at both early and late stages. The data also fit with the notion that feedback processes of top-down modulation plays more significant part in visual perception than was once speculated (Pessoa, Kastner, & Ungerleider, 2003; Bullier, 2001).

Biased Competition Model

One of the most influential accounts of visual selection, which captures the idea of interacting bottom-up and top-down processes is 'biased competition' theory (Chelazzi et al., 1993; Duncan & Desimone, 1995; Chelazzi, Duncan, Miller, & Desimone, 1998; Reynolds, Chelazzi, & Desimone, 1999; Lee, Itti, Koch, Braun, 1999). At a neuronal level, biased competition proposes that visual attention is a process of competitive selection: when multiple stimuli fall in a visual receptive field, each stimulus will have initial representation in parallel, but depending on their critical informational value/strength (e.g., a salient feature, a feature that is voluntarily searched for, etc.), a relatively stronger representation will win the attentional selection to be processed further. The evidence suggests that neural responses caused by multiple stimuli simultaneously presented within one receptive field are not equal to the sum of the individual responses from each of the stimuli when they are present alone – they interact and suppress each other mutually, rendering the overall neuronal response to the weighted average. An example comes from functional imaging work by Beck and Kastner (2005, 2007). While performing an attentionally demanding task at fixation, their participants were presented with four peripheral stimuli. These stimuli were shown either consecutively one after another in one condition, or simultaneously in another condition (so that the combined physical stimulation would be the same, integrated over time). They found out that suppressive interactions among the four stimuli were not shown in the consecutive condition but were in the simultaneous condition. It was noteworthy that the suppressive interaction in the simultaneous condition occurred even without attention being allocated to the stimuli (as the participants were busy doing a demanding visual task), which means that the inter-stimulus interactions and competition arose automatically. Interestingly, these suppressive effects in the simultaneous condition were reduced when participants were cued to attend to one of the stimuli. Competition was reduced for the attended item.

The biased competition account holds that visual perception does not occur through a single mechanism that controls the whole process of selection from the beginning till the end – it arises from interactions between different mechanisms (a stimulus-driven process vs. a goal-directed process, perhaps the requirements for action, and so forth). What then may modulate these bottom-up and top-down processes and interactions? How is the on-going competition resolved? The biased competition model proposes that resolution is produced through an 'attentional template', an item that will be kept online via the process of working memory, which is used as a guide for selecting the right target among multiple competing stimuli.

Working Memory and Attention

Working memory (WM) is a process of maintaining information that is newly registered or summoned from long-term memory. It is the memory of currently relevant information that is held for a brief duration of time. Biased competition theory proposes that the competition amongst different visual stimuli, and between the bottom-up and top-down 'drivers' of attention is resolved by the contents currently held in WM. Evidence shows that neurons respond with elevated activity for the cue-related contents of WM and this state can be maintained so that the relevant neurons respond than others when matching stimuli are re-presented. For example, in the single-cell study of Chelazzi et al. (1993), a monkey was cued with a ‘good’ stimulus (one that elicited strong neuronal responses) or a ‘poor’ stimulus (one that elicited little response). The animal had to remember this and then, after a delay period, make a single saccade to an item that matched the memory cue in a subsequent search display. The search display contained both the cue-matching target and a non-matching distracter. Cells in inferior temporal (IT) cortex showed a sustained activation during the delay after the cue, which was stronger for the good stimulus cue than the poor one. In addition, activation in these cells rose rapidly when the target was re-presented, reaching asymptote earlier than if the cue was not held in memory. These observations suggest that a template held in WM can bias incoming activation to favor a matching stimulus.

A large body of previous research has proposed that prefrontal cortex (PFC) may be the ‘source’ area for top-down control of attention (Pessoa & Ungerleider, 2004: Corbetta & Shulman, 2002; Pessoa, Kaster, & Ungerleider, 2003; Postle, 2005; Lepsien & Nobre, 2006; Courtney, Ungerleider, Keil, & Haxby, 1997). The PFC is known to be an ‘executive control’ area, directly involved in various cognitive control processes, such as memory, decision making, and task-switching (Curtis & D’Esposito, 2003). Quite a few brain-imaging studies have revealed that there are delay activities in the PFC when a WM task is performed (Courtney, Ungerleider, Keil, & Haxby, 1997; D’Esposito, Cooney, Gazzaley, Gibbs, & Postle, 2006; Kastner et al., 2007; Sakai, Rowe, & Passingham, 2002). There is also supporting evidence that, anatomically, the PFC has reciprocal connections with almost all extrastriate visual cortices (Barbas & Pandya, 1989; Ungerleider, Gaffan, & Pelak, 1989; Webster, Bachevalier, & Ungerleider, 1994), and that cooling the PFC disrupts delay activity in

IT cortex (Fuster, Bauer, & Jervey, 1985). Such evidence suggests that the PFC provides feedback to the visual cortex in the form of WM in order to guide attentional selection.

Recent behavioural research on WM and its effect on selective attention provides data that are consistent with the above neurophysiological evidence, whilst also suggesting that attentional cueing from WM can be dissociated from executive control (Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005; Soto, Humphreys, & Heinke, 2006; Olivers, Meijer, & Theeuwes, 2006; Soto & Humphreys, 2008, 2009). In these studies, participants are typically asked to hold one item in WM and then perform a different search task. After the search task, memory for the initial item is re-tested. The WM and search tasks are thus distinct. The effects of WM on selection are then tested by re-presenting the WM cue in the search display – either close to the target or close to a distracter (on neutral trials, the item in WM does not re-appear in the search display). When there is a match between a WM item and a search target (a valid trial), RTs are fastest, and they are slowest when a WM item matches a distracter (an invalid trial). In the first study of this kind, for example, Downing (2000) had his participants hold one stimulus (a face) in WM and then search for another target in a second display. Prior to the search target, the face in WM and a new face were presented, and the target then could fall at the same location as one of the stimuli. RTs were faster when the target appeared where WM cue fell (on valid trials), compared with when the target appeared where the novel face fell (on invalid trials).

Interestingly, the WM item does not necessarily need to match the target to influence attentional selection - it can capture attention inadvertently in an automatic manner.

For example, Soto et al. (2005) had their participants remember a coloured shape and look for a slanted line target after a delay (see Figure 1.2 for an illustration). They found a benefit to search when the shape held in WM contained the target, and a cost when the shape contained a distracter, in comparison to the neutral baseline. They further showed that irrelevant items in WM influenced the fastest RTs and the first saccades in search, and this pattern of data held even when the memory cue never contained the target when it re-occurred, indicating that there was automatic guidance from WM as a top-down attentional control process. To test whether this effect of the cue is due to WM and not solely to bottom-up priming from the initial presentation of the stimulus, Soto and colleagues have included a priming baseline condition, where the visual presentations are matched to those in the WM condition but participants do not have to hold the cue in WM. In Soto et al. (2005) participants were simply asked to look at the cue in the priming condition. In subsequent studies, the conditions involve a ‘two step’ presentation of the cue. In the WM condition the task remains to hold it in memory. In the priming condition, participants judge if the two presentations show the same item or not. If the same item is shown, then the subsequent search task is performed. If different items are displayed, then participants do not perform the search. This two-step procedure necessitates that participants process the cue but maintenance in WM is not demanded. In each case, effects on the subsequent direction of attention are reduced (and sometimes eliminated) in the priming condition.

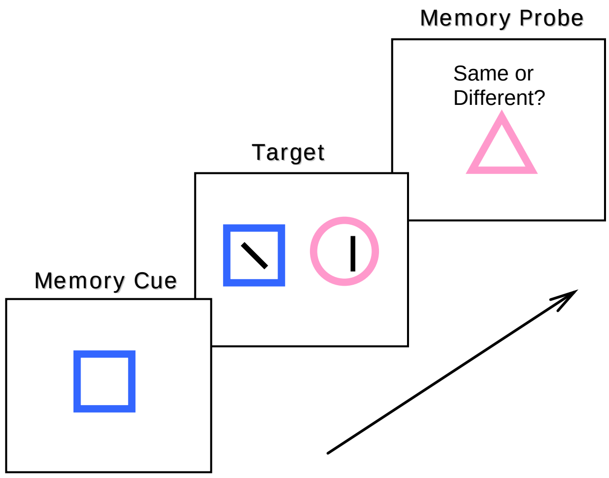


Figure 1.2. A simplified illustration of Soto et al. (2005) paradigm.

The distinction between cueing from WM and priming is also supported by neuroimaging data. Soto, Humphreys and Rotshtein (2007) carried out essentially the same experiment as above, but scanned participants as they performed the tasks. Under the WM condition they found a network of regions (the superior frontal gyrus, the parahippocampal and lingual gyri) that showed increased activation when the cue re-appeared in the search display. This enhanced activation occurred irrespective of whether the cue was valid or invalid for the search task and may represent matching between the cue and a memory representation. Interestingly, in the priming baseline, these regions showed a decreased response, relative to when the cue was not re-presented. This is a form of repetition suppression effect (Kourtzi & Kanwisher, 2001) and likely stems from facilitated perceptual processing of the search display following the earlier processing of a matching cue. In addition, the orbito-frontal region BA10 and regions of the thalamus showed a differential response when the cue was re-presented and validly cued the target (compared with neutral and invalid trials). These same regions showed no effect of the cue re-presentation in the priming condition. These validity effects may reflect a signal for selective attention to be summoned to the location where both the cue and the search target appear (on valid trials). The contrasting results from priming and cueing from WM clearly indicate that separate processes may be involved in these two conditions, and that there is a distinct WM-based effect, separate from the influence of bottom-up priming.

However, the hypothesis that there is automatic attentional capture from WM is not without its opponents (Downing & Dodds, 2004; Woodman & Luck, 2007). Woodman and Luck (2007), for example, reported that WM item did not capture attention automatically in their study where they did not include any valid trials. They suggest that, when effects of WM capture occur they are due to participants deliberately trying to attend to the memory item in the search display. Indeed, their data showed that participants (at least sometimes) avoided attending to the WM items, since RTs were speeded on invalid relative to neutral trials – this speeding would occur if participants systematically attended away from the re-presented cue (see also Downing & Dodds, 2004; Han & Kim, 2009). Woodman and Luck thus argued that the contents of WM could be used in a flexible manner for facilitation or inhibition of processing, rather than exerting automatic effect that one cannot voluntarily control.

Some possible explanations have been offered that might account for the contradictions in the data so far reported (Oh & Kim, 2004; Olivers, 2009). The effects might differ because of a number of potentially crucial factors: whether target items change from trial to trial (Downing & Dodds, 2004; Woodman & Luck, 2007) or remain the same across all trials (Soto et al, 2005; Soto & Humphreys, 2007, 2008); whether there is an articulatory suppression task used (Downing & Dodds, 2004) or not (Soto et al, 2005); whether the memory cue and the target share similar features

(Woodman & Luck, 2007) or not (Olivers et al, 2006; Soto el al, 2005); or how long the interval is between the cue and the target (see Han & Kim, 2009). Capture of attention from WM occurs most strongly when: (i) the search item is maintained across trials, (ii) when there is not a secondary task performed on a trial (e.g., no articulatory suppression), and (iii) when the memory item sometimes cues the target so there is not a dis-incentive to inhibit the memory cue. Olivers (2009) proposes that the effects are most pronounced under conditions where participants do not have to prioritise the search task (e.g., when the search target is constant), when participants may not keep separate a representation of the cue and a representation of the search template, in WM. When the target template and the memory cue are not 'compartmentalised' in memory, the cue can modulate subsequent selection.

Although the above studies have elucidated many of the conditions under which information in WM can direct attention, there remain many questions. One particular question is whether information in WM can direct non-spatial selection or whether it only influences spatial attention. This was the starting place for the work presented in this thesis. To address the issue, the experiments did not utilize a visual search task but rather a task requiring the selection of 'local' level and 'global' stimuli in hierarchical stimuli. As is explained in the following section, hierarchical stimuli can be useful for exploring issues on non-spatial selection.

Perception of Hierarchical Stimuli

In his seminal work, Navon (1977) put forward a hypothesis that the global properties of an object are processed faster than the local elements, and that the global element interferes with the recognition of the local element more than the reverse. To examine this, Navon used alphabetical letters in which a large global stimulus was made up of multiple small (local) letters. He found that overall RTs were faster to global than to local forms, and that responses to the local forms were affected by conflicting responses at the global level but not the opposite. Subsequent work has shown that the dominating effect from the global level of a form, as opposed to the local level, varies depending on featural specifications, such as the distance between local elements (Kimchi & Palmer, 1982; Lamb & Robertson, 1988; Huberle & Karnath, 2006), the overall visual angle of the form (Kinchla & Wolfe 1979), and the spatial frequency of the form (Shulman, Sullican, Gish, & Sakoda, 1986). These other results not withstanding, the literature overall is generally consistent with ‘global precedence’ (see Kimchi, 1992 for a review).

Beyond the literature on hierarchical shape perception, there is other evidence for rapid assimilation of global information from the world. Studies in scene recognition, for example, suggest that scene identification can occur very fast based on the ‘gist’ extracted globally from the scene (Oliva & Torralba, 2001, 2006; Sanocki, 1993; Oliva and Schyns, 2000; Sanocki & Epstein, 1997). This process happens more rapidly than the perception of each individual (local) part that comprises the whole scene. Also anatomically, the magnocellular pathway (known to carry motion-related and low-contrast coarse visual information) transfers data much faster in the visual system from the large retinal ganglion cells to the large cells in the LGN, and on to the primary visual cortex, V1, compared to the other parvocellular pathway that carries colour-related high-contrast fine data (Maunsell & Gibson, 1992; Nowak &

Bullier, 1997; Bullier, 2001). Thus overall data from across different studies seem to suggest that visual perception is perhaps globally biased by default.

As noted above, a significant amount of evidence suggests that WM can direct spatial selection but it is still an unanswered question whether WM also influences non-spatial attentional selection. To address this issue, the experiments in the current thesis adopted hierarchical Navon stimuli to utilise a task requiring the selection of 'local' level and 'global' stimuli in the hierarchical stimuli. In relation to selective attention, the perception of hierarchical stimuli is interesting for at least two reasons. One is because hierarchical forms can provide a means of studying the non-spatial deployment of attention. With global-local forms, target selection may require more than fixing on 'attentional window' on an area of space. When an attentional window is fixed on a global level, then the stimulus at local level will be processed along with the global stimulus, whereas the selection of the global shape would require some other process, such as filtering by spatial features (Shulman, Sullivan, Gish & Sakoda, 1986; Hübner, 1993, 1996). Experiments reported in this thesis assess whether stimuli making up hierarchical forms are selected by fixing an attentional window or by directing activating their letter identities. For example, in Chapter 3 I report experiments assessing whether holding the size of a stimulus in working memory can cue selection of hierarchical forms and in Chapter 2 I evaluated whether holding a letter identity in WM influenced selection. Which means of cueing hierarchical letter perception is most effective can inform us about how the selection of such forms takes place. To the extent that hierarchical forms are not selected by spatial attention, then the cueing effects on these forms will also provide new information on whether cueing from WM goes beyond spatial selection and directly modulates object and feature selection.

A second reason to study selection of hierarchical forms relates to some of the earlier results. In some prior studies (notably those of Soto and colleagues; e.g., Soto et al., 2005, 2010) the WM item constituted more of a ‘global’ stimulus than the search target. For example, in Soto et al. (2005) the memory item was an outline shape and the search target was a tilted line which appeared within the outline shapes presented in the search display. It is at least possible that the WM stimulus captures attention because there is a bias towards the global properties of a display. Using hierarchical stimuli, this can be directly tested. For example, if there is a bias to the global form, then valid cueing will be strongest to targets appearing at the global level, while invalid cueing will be strongest when targets fall at a local level (and the cue matches a non-target at the global level).

In Chapter 4 I not only studied the effects of cueing on the selection of hierarchical stimuli but also how hierarchical stimuli were coded and use in memory. In this case participants were set to remember a hierarchical stimulus, and I then examined how this stimulus modulated the selection of a subsequent target in a hierarchical form. For example, is there representation of both levels of a hierarchical form in memory? Does this occur even when only one level has to be maintained? To the best of my knowledge there have been few prior studies of how hierarchical stimuli are coded in memory, and hence this thesis provides a first step on this road.

Directed Forgetting

WM is considered a process for temporary maintenance, a mechanism to hold a new or old (from long-term memory) pieces of information on-line as a task is being conducted. As discussed above, the pre-activated contents held in WM have been found to guide attentional selection, beating other visual information in competition for attention. This top-down attentional facilitation by WM activation, however, is not the only factor that has been suggested to influence the allocation of attention. Another force to consider is top-down inhibition. Past research indicates that inhibition, along with activation, is important for attentional selection, acting to suppress information that is currently irrelevant to the task at hand, thereby having WM storage contain only goal-relevant information until the completion of the task (Zacks, Radvansky, & Hasher, 1996). Specifically, this helps make selective process efficient by clearing irrelevant information from attention and WM (Zacks, Radvansky, & Hasher, 1996; also see Fawcett & Taylor, 2008). Therefore, attentional selection in terms of inhibition is another plausible top-down effect to consider, which makes it at least as relevant as the questions on how WM activation might facilitate the process of attentional selection. Cognitive effort to inhibit what is already remembered, and if and how it influences the facilitative effects of memory content, are important factors that could influence selection.

Using non-hierarchical forms, I examined these issues in the last part of the thesis. In these experiments I instructed participants to forget an item, and then assessed whether this item subsequently affected attentional guidance. What would happen if one tries to discard memory representations as irrelevant? Would the WM effect of attentional guidance reduce or even disappear? How quickly might the effects dissipate? Would the process be effortful (as in trying to hold information in WM), or relatively effortless?

The current experiments on instructions to forget are perhaps closest to two other sets of results in the literature. One is work on the so-called ‘attentional white bear’ phenomenon – referring to the apparent difficulty of not attending to stimulus one is instructed to ignore. Tsal & Makovsky (2006) studied this phenomenon by measuring participants’ temporal judgment of probes (two dots or a line) which sometimes could appear at the location where expected distractor would be displayed. They found temporal facilitation for the probe that matched the location of the distractor, consistent with participants initially attending to the item they were told to ignore, but then inhibiting it. Quite similar patterns of results have been reported in preview search, where participants are set to ignore old distractors. Here there is evidence of the old distractors initially being attended before their later inhibition (e.g., Humphreys, Jung-Stalmann & Olivers, 2004). If this is a general phenomenon, applicable too to the forgetting of information in WM, then we may find initially increased cueing from WM and only subsequently inhibition of the cue, and consequent decreased cueing effects.

The second paradigm similar to the current ‘forget’ task is directed forgetting (DF) (Bjork, 1989). A typical DF experiment will have participants remember individual stimuli or unitized lists, and then with a following cue, they are instructed to either remember or forget the initial memory lists/items before they perform memory task of another set of list or items. When tested for recall and recognition for the pre-cue items later, participants normally show reliably better performance with to-be-remembered lists (or items) than with to-be-forgotten ones. However, when the test is formatted with list task in particular, to-be-forgotten lists are recognised (though not recalled) just as well as to-be-remembered ones, suggesting a possibility that the critical lists were temporarily suppressed, rather than entirely effaced from memory. Another notable finding is that a critical condition for the DF effect to occur is whether or not there are new items to learn after the forget instruction (Bjork & Bjork, 1993; Conway, Harries, Noyes, Racsmany, & Frankish, 2000): the presence of new items enables participants to focus attention on the items to be remembered and away from the to-be-forgotten items; this shift of attention might be crucial in generating inhibition.

As noted the data on DF suggest that the instruction to forget a stimulus leads to at least temporary suppression, disrupting an item's later recall. In connection with cueing from WM, we might suspect that inhibition might result in facilitated processing even on invalid trials (cf., Woodman & Luck, 2007), since the distractors would be suppressed in this case. It may also depend on some degree of memory load, which facilitates the shift of attention from the items to be forgotten. These possibilities were tested in Chapter 5 here. In addition, in the 'forget' condition, there should be little incentive for participants to deliberately attend to the re-appearance of the original cue in the search display – after all, the instruction is to forget. Due to this disincentive, it should be more difficult to argue that effects of WM on selection are caused by the topping up the memory by attending to the re-appearance of the cue (Woodman & Luck, 2007).

Overview of Present Thesis

The overall central idea of the studies carried out for the present thesis is to look at how information held in WM affects attentional allocation, specifically when the allocation is executed toward the global and local levels in hierarchical stimuli. As discussed above, the contents of WM have been found to guide visual attention in a top-down manner (Downing, 2000; Soto et al, 2005; Soto & Humphreys, 2008, 2009), but so far there have not been any explorations into how the WM might influence attentional selection of hierarchical levels of form.

In addition to the above overall issue and a few other related ones as specifically outlined below, the present thesis also explored inhibitory mechanisms in WM, in the form of intentional forgetting of an item initially being held in WM. We adopted DF paradigm for our study and cued the participants to sometimes forget the pre-cued items before carrying out target search. Then literature on DF suggests that an attempt to forget a stimulus leads to at least temporary suppression of the relevant item. In the present study we explored if forgetting an item currently held in WM will suppress the effect of that item on the subsequent guidance of visual attention. We report our results that provide comparative analyses on WM and forgetting effects of visual stimuli on attentional selection.

In Chapter 2 we had participants carry out a global-local task where they had to detect a target at either local or the global level of a hierarchical compound letter. We assessed if this WM cue could bias the selection of hierarchical forms, and whether this bias was stronger to the global rather than the local level of the stimulus. Also, to test whether effects were due to the items in WM, or to bottom-up priming from mere presentation of the cue, experiments were run in which participants had to identify the cue but not hold it in memory. If bottom-up priming was critical then the data in the priming conditions should match those when the cue was held in WM. Interestingly we report quite different patterns of data in the WM and priming conditions: In the WM conditions, having a cue matching the distracter level of the form disrupted responses to the target. In the priming condition, in contrast, a cue that matched the distracter level facilitated responses to the target. These results highlight the contrast between processes that enhance perception by bottom-up priming and those that guide attention in a top-down manner through WM.

In Chapter 3, we looked at how size information held in WM might affect the perception of hierarchical stimuli. The effects from WM have been observed most frequently on spatial selection tasks, but the effects can occur in non-spatial selection tasks as well. When selecting a target in hierarchical letters, as in this study, a large letter cannot be spatially selected without also selecting the local elements. One way that stimuli in a hierarchical letter might be selected is by fitting an attentional window that is at the appropriate size and resolution for the target that needs to be selected. In this set of experiments, we examined if such an attentional window could be cued by holding a specific size representation in WM. Does holding a stimulus at the size matched to the target facilitate subsequent target selection? A positive finding here would also extend prior results on cueing attention from WM to include size as well as colour, shape, and identity.

In Chapter 4, we used the whole compound letter as a memory item. In some of the studies on global precedence, the data suggest that there is a tendency for a level selected for the response on a prior trial to be carried over to the next trial, so that it is easier to respond to a target that is presented at the same level as before (Ward, 1982). We set out to see if, when only one level is memorized, the specific level of the initially memorized form would be critical to the hierarchical target detection that follows. We ask whether the effects of cueing from a WM representation of a hierarchical figure are maintained if both levels of an initial form are held. Also, we aim to see if the irrelevant part of the memory item (the other level not to be held in memory) would actually be held in WM in an automatic manner and will influence target search. At the same time we try to see if increased memory load (having more than one level to remember) would modulate the cueing effect on the target selection.

Finally, the last empirical Chapter reports work that goes beyond the selection of hierarchical forms to examine intentional forgetting. We adopted the concept of directed forgetting and cued our participants to either remember or forget a pre-cued memory item. Furthermore we varied the intervals between the cue and the target to look at temporal characteristics of memory and forgetting effects. We also examined how facilitation and inhibition from WM and forgetting might be affected by having the number of cue items increased.

CHAPTER 2

Working Memory, Perceptual Priming and the Perception of Hierarchical Forms: Opposite Effects of Priming and Working Memory without Memory Refreshing

Synopsis

Previous research has shown that stimuli held in working memory (WM) can influence spatial attention. Using Navon stimuli, we explored if and how items in WM affect the perception of visual targets at local and global levels in compound letters. Participants looked for a target letter presented at a local or global level while holding a regular block letter as a memory item. An effect of holding the target's identity in WM was found. When memory items and targets were the same, performance was better than in a neutral condition when the memory item did not appear in the hierarchical letter (a benefit from valid cueing). When the memory item matched the distractor in the hierarchical stimulus, performance was worse than in the neutral baseline (a cost on invalid trials). These effects were greatest when the WM cue matched the global level of the hierarchical stimulus, suggesting that WM biases attention to the global level of form. Interestingly, in a no-memory priming condition, target perception was faster in the invalid condition than the neutral baseline, reversing the effect in the WM condition. A further control experiment ruled out that the effects of WM were due to participants refreshing their memory from the hierarchical stimulus display. The data show that information in WM biases the selection of hierarchical forms whilst priming does not. Priming alters the perceptual processing of repeated stimuli without biasing attention.

Introduction

Many everyday tasks require that we select from the environment stimuli that are relevant to our behavioral goals. Normally this process of goal-directed selection may depend on a match taking place between goal-related information in working memory (WM) and incoming stimulus information (Desimone & Duncan, 1995; Duncan, 1998). Evidence supporting the role of top-down guidance of search to targets comes from experiments showing that search benefits by providing participants with fore-knowledge of targets (e.g., Anderson, Heinke, & Humphreys, in press; Wolfe, 2005), and that indeed some targets only 'pop-out' when fore-knowledge is given (Hodsoll & Humphreys, 2001). Recent work suggests that these top-down effects are not confined to holding knowledge of the target, since there can also be effects of irrelevant information in WM. Downing (2000) had participants hold one stimulus in WM and then search for another target. The irrelevant cue in WM could re-appear alongside the target or another item. RTs were faster when the WM stimulus re-appeared at the target's location (on valid trials), compared with when it fell elsewhere (on invalid trials). Importantly this effect did not occur when the cue was presented but did not have to be maintained in memory. Soto, Heinke, Humphreys & Blanco (2005) further showed that irrelevant items in WM influenced the fastest RTs and the first saccades in search, and the effect occurred even when the WM cue was always irrelevant. This last result suggests that an irrelevant WM stimulus can capture attention automatically. Other studies have demonstrated effects even with pop-out targets (Soto, Humphreys & Heinke, 2006).

Interestingly in many of these studies, the WM item constituted more of a 'global' stimulus than the search target. For example, in Soto et al. (2005) the memory item was an outline shape and the search target was an oriented line which appeared within the outline shapes presented in the search display. It could be that the WM stimulus captures attention at least partly because there is a bias towards the global properties of a display, as suggested by the 'global precedence' hypothesis (Navon, 1977), which holds that attention is biased towards global aspects of stimuli. When the WM cue matches early-emerging global properties of the search display, attention may be drawn to the global item matching the item in WM. It may also be that representing a stimulus in WM itself biases selection to the global level of a display, perhaps because the WM load reduces the resources available to process more local elements of a display. The biasing effects of WM on the selection of local and global properties of search displays were examined for the first time here. We had participants carry out a global-local task in which participants had to detect a target at either local or the global level of a hierarchical compound shape (under divided attention conditions: Experiment 2.1), or they had to make a choice decision to a stimulus at one level (under focused attention conditions: Experiment 2.2). Prior to performing this task, participants had to hold an item in memory (as in Downing, 2000; Soto et al., 2005, 2006). We assessed if this WM cue could bias the selection of hierarchical forms, and whether this bias was stronger to the global rather than the local level of the stimulus.

By investigating the selection of hierarchical forms, the study also examines whether irrelevant items in WM influence aspects of non-spatial attention. In prior studies, the WM stimulus has affected shifts of attention to a spatial location where the target could or could not fall. With global-local stimuli, though, selection may require more than fixing on 'attentional window' on an area of space. Specifically, if an attentional window is fixed on a global shape, then the local stimulus will be processed along with the global shape; selection of the global shape would require some other process, such as filtering by spatial features (see Julesz & Papathomas, 1984; Shulman, Sullivan, Gish & Sakoda, 1986; Hübner, 1993, 1996). We examined whether stimuli in WM bias such non-spatial selection processes.

The factors affecting the processing of global and local shapes have been well documented over the past thirty years. Although numerous studies have demonstrated global precedence, with responses speeded to targets at global rather than local levels of form (see Kimchi, 1992, for a comprehensive review), other studies have shown that this depends on a range of factors such as the density and spacing of the local elements (Kimchi & Palmer, 1982; Lamb & Robertson, 1988; Hughes, Fendrich & Reuter-Lorenz, 1990; Huberle & Karnath, 2006), the overall size of the shape (Kinchla & Wolfe 1979; McLean, 1979), the familiarity of the local and global forms (Shalev, Mavorach & Humphreys, 2007) and so forth. Over and above this, it has generally been found that there is stronger evidence for global precedence when participants carry out target identification tasks in a distributed rather than focused mode of attention (Yovel, Yovel, & Levy, 2001; Lux, Thimm, Marshall & Fink, 2006). This was assessed in the contrast between Experiments 2.1 and 2.2 here, with Experiment 2.1 using a distributed attention task (is a 'D' present at either the local or global levels?) and Experiment 2.2 a focused attention task where the target had to be detected at a specific level (identify the local or the global form). Does the contrast between distributed and focused modes of attention influence global precedence, and does this impact on the effects of attentional capture from stimuli in WM? Prior evidence suggests that attention capture from WM may be greater when the task demands a wide rather than a narrow focus of attention. Hernández, Costa & Humphreys (in press) examined the effect of a WM cue on a search task where participants first had to identify either the global shape of the array, or the identity of a local item at fixation, prior to searching for a target. Effects of the validity of the WM cue (whether or not it matched the target) were greater when the global shape first had to be identified (when there was a wide span of attention) compared with when the local item had to be identified first (with a narrow focus of attention). Hernández et al. proposed that attentional guidance from WM is stronger when participants adopt a wide attentional window. Whether this is equivalent to adopting a distributed mode of attention was assessed here by comparing WM cueing under distributed and focused attention modes of a hierarchical form identification task. To evaluate the effects of WM on the selection of hierarchical stimuli, we had participants hold the identity of a letter in WM and then identify a target in a hierarchical (compound) letter. The WM cue could match a stimulus at one level of the hierarchical form, which could be the target (on valid trials) or a distractor (on invalid trials). There were also neutral trials where the WM cue did not re-appear in the hierarchical form. Effects of the WM cue would be shown if a validity effect emerges on performance. To test whether effects were due to the items in WM, or to bottom-up priming from mere presentation of the cue, two experiments were run (Experiments 2.1b and 2.2b) where participants had to identify the cue but not hold it in memory. If bottom-up priming was critical then the data in the priming conditions (Experiments 2.1b and 2.2b) should match those when the cue was held in WM (Experiments 2.1a, 2.1c; Experiment 2.2a). Interestingly we report quite different patterns of data in the WM and priming conditions. In the WM conditions, having a cue that matched the distractor level of the form disrupted responses to the target. This effect was particularly strong under divided attention conditions. In contrast, in the priming condition, a cue that matched the distractor level facilitated responses to the target. These results highlight the contrast between processes that enhance perception by bottom-up priming and those that guide attention in a top-down manner through WM. In a third experiment we tested whether the WM effects reflected participants using the hierarchical stimulus to refresh their memory. As we elaborate in the General Discussion, the contrasting effects can be understood in terms of the neural structures underlying bottom-up and top-down search, which arise even without strategic refreshing of memory.

Experiment 2.1a:
Working Memory, Hierarchical Stimuli, and Divided Attention

Method

Participants 25 students and staff (age range: 19-35) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The experiment was run on a Samsung SyncMaster 920N color monitor with a resolution of 1280×1024 pixels. The stimuli were produced using Adobe Flash (version CS3 Professional) and the test was programmed with E-Prime (version 2.0; PST 2002). For each block, a set of different compound letters were constructed out of 3 English alphabet letters that were randomly selected from a group of letters (A, D, E, M, N, O, S, U, V, and X) (for the examples of a set of compound letters used for a block of trials see Figure 2.1). At a viewing distance of 70cm, the global letters subtended 8.5° × 7.3° and the local letters 0.49° × 0.41°. The visual angle for the block letters (used for memory items) was 4.3° × 3.6°, which was of an intermediate size between the global and local letters of the compound stimuli.

All stimuli were presented in the centre of the screen. Response keys were located on the computer keyboard.

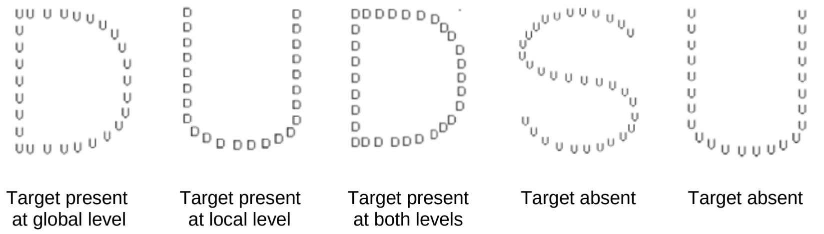


Figure 2.1. Examples of stimuli when target is ‘D’. All letters were in black displayed against white background.

Task and Procedure Figure 2.2 illustrates the experimental conditions and the sequence used in the present study. There were 8 blocks of 62 trials, where each block contained trials from three conditions: valid (when the identity of the memory item matched that of the target item), invalid (when the identity of the memory item was different from the target and represented the stimulus at the other ‘distractor’ level), and neutral (when the identity of the memory item was different from the target and was not present at the non-target level). The target was always the letter ‘D’. Each trial, randomized within the block, began with a fixation cross displayed for 200 msec, which was followed by a block letter for 500 msec. Participants had to remember this block letter. There was then a delay of 1000 msec, a fixation cross for 200 msec, and then the target was displayed for an unlimited period (until response). The task was to respond to the presentation of a target within a compound letter, irrespective of the level it was located at. Memory probe questions on the to-be-remembered items occurred randomly, at the frequency of 8 times per block, at the end of a trial. The memory probe asked participants to decide if the letter shown was the same as or different to the one they held in their memory. Participants were warned about the memory test before the start of the experiment. The instructions emphasized both the accuracy and the speed of response for both the target search and memory tasks. Participants had a practice session of 15 trials at the beginning of the experiment.

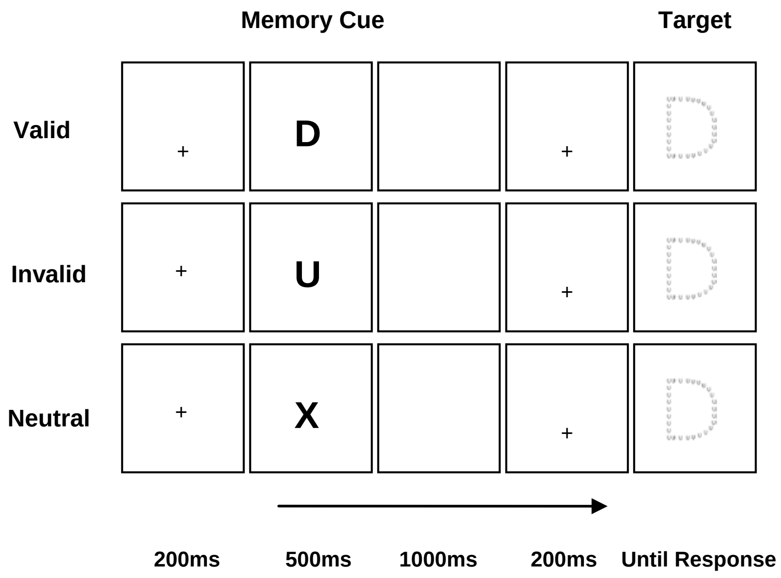


Figure 2.2. The sequence of events on a trial where the target was present at a global level. From top to bottom: Examples of valid, invalid and neutral trials in display.

Results

In all the experiments, only RTs for correct responses in the local-global task were used in the analysis of the search responses. Trials with incorrect responses to memory probe questions, however, were included to secure the largest possible amount of data. The analyses were conducted separately for target-present data and target-absent data as they had different conditions, with the target-absent data having no valid trials.

1) Target-Present Data

Main Effects The error rates for target detection and for memory probe responses were low at 4.1% and 6.2% on average, respectively (see Table 2.1 for the overall data summary). There was no evidence of speed-accuracy trade-off and the accuracy data were not analyzed further. A 2 × 3 ANOVA was carried out on the mean RT data for the global-local task. There were two factors: Target Level (global and local) and Cue-target Validity (valid, invalid, and neutral). The results are shown in Figure 2.3. There was a strong effect of cue-target validity ($F(2,48) = 17.90$, $p < .0001$). Performance was better when the cue and the target were same, relative to when they were different. An effect of target level was not found, but there was a target level × cue-target validity interaction ($F(2,48) = 3.7$, $p = .037$). Pair-wise *t*-tests were conducted to contrast the conditions at the global and local levels separately. At the global level, there was a significant difference between the valid and the invalid conditions ($t(24) = -4.95$, $p < .0001$), and between the valid and the neutral conditions ($t(24) = -4.56$, $p < .0001$). The invalid and the neutral trials did not significantly differ ($t(24) = 1.56$, $p = .132$). At the local level there was a reliable difference between the valid and the invalid ($t(24) = -3.23$, $p = .004$), and between the invalid and the neutral conditions ($t(24) = 2.6$, $p = .015$). The valid and the neutral conditions did not differ ($t(24) = -1.34$, $p = .192$). With valid cues, the responses to the target were significantly faster when it was shown at the global than at the local level ($t(24) = -3.11$, $p = .005$). The invalid and the neutral trials did not differ across the local and global levels ($t(24) = .84$, $p = .41$, and $t(24) = .31$, $p = .76$, respectively). To further assess the changes in the valid and invalid conditions for targets at global and local levels, cost-benefit analyses were performed taking the differences between the valid and invalid conditions at the neutral baseline. The data were evaluated in a 2 × 2

ANOVA with the factors being levels of match to WM (global or local) and the cost-benefit (invalid-neutral or neutral-valid). There was a main effect of match ($F(1,24) = 5.7$, $p = .025$). No effect of validity was found ($F(1,24) = .76$, $p = .39$), and no match × validity interaction ($F(1,24) = 2.1$, $p = .16$). Costs and benefits were overall larger when the WM cue matched the global rather than the local letter.

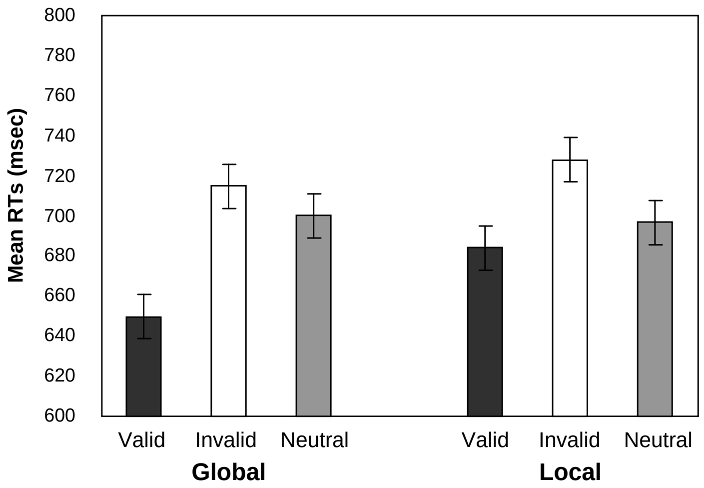


Figure 2.3. Experiment 2.1a: Effect of memory on target perception at different levels. The error bars represent standard errors (the same applies to all figures in this paper).

Effect of Congruency The data were also analyzed to assess the effect of congruency between the global and local levels (when the two levels of each stimulus had same identity vs. when they had different identities). Since there were no congruent trials in the invalid cue condition, invalid trials were not included.

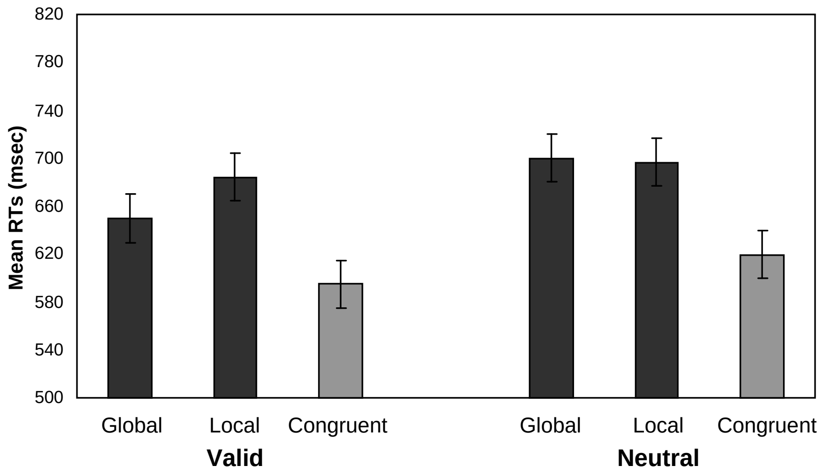


Figure 2.4. Effect of congruency of levels by validity. 'Global' and 'local' refer to the data from incongruent trials with the target respectively at global and local levels.

Valid and neutral trials with congruent target stimuli were compared to those with incongruent target stimuli (see Figure 2.4) by conducting a 2 × 3 ANOVA with two cue-target validity factors (valid and neutral) and three global-local congruency factors (local letter incongruent with the target at the global level; global letter incongruent with the target at the local level; and congruent with the target at both levels). There were main effects of cue-target validity ($F(1,24) = 16$, $p = .001$) and global-local congruency ($F(2,48) = 4.8$, $p = .013$). A cue-target validity × global-local congruency interaction was also found ($F(2,48) = 4.1$, $p = .023$).

t-tests were conducted for the valid and neutral conditions. For the valid condition, there was a significant difference between the global match and local match trials ($t(24) = -3.1$, $p = .005$), and between local match and congruent trials ($t(24)= 2.35$, $p = .027$). The difference between global match and congruent trials did not reach significance ($t(24) = 1.6$, $p = .13$). For the neutral condition, the difference was significant between global match and congruent trials ($t(24) = 2.4$, $p = .026$), and between local match and congruent trials ($t(24) = 2.3$, $p = .032$). There was no significant difference between global match and local match trials (t(24) = .31, p = .76). Congruent valid trials were also faster than congruent neutral trials (t(24) = -2.1, p = .04). That is, there was an effect of the WM cue even when the letters making up the hierarchical form were congruent.

Table 2.1. Error data on target-present trials in Experiment 2.1a (memory) and 2.1b (no-memory).

Experiment	Level	Validity	Search Errors (%)	Memory Errors (%)
Memory	Global	Valid	0.1	1.4
		Invalid	0	1.2
		Neutral	2	0.8
	Local	Valid	0	1.1
		Invalid	0	1.1
		Neutral	2.1	0.6
No-Memory	Global	Valid	0.5	
		Invalid	1.0	
		Neutral	0.2	
	Local	Valid	0.1	
		Invalid	0.7	
		Neutral	0.4	

2) Target-Absent Data

Main Effects The error rates were 3.2% for the search task and 4.2% for the memory task (see Table 2.2 for overall error data). There was again no evidence of a speed-accuracy trade-off (see Figure 2.5). A one-way ANOVA was conducted on the RTs, with the data sorted into three cue conditions: global cue, when the cue matched the global level of the compound letter; local cue, when the cue matched the local level of the letter; and neutral, when the cue did not match either level of the compound letter. There was a strong overall effect of validity (F(2,48) = 10.1, $p < .0001$).

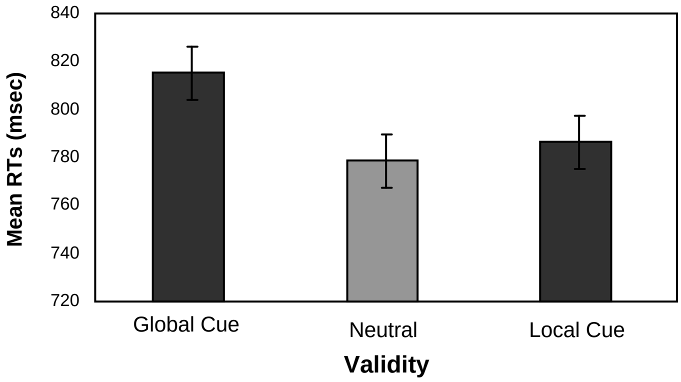


Figure 2.5. Experiment 2.1a: Effect of memory at different levels in target-absent trials.

t-tests indicated that the difference between global cue trials and local cue trials was significant (t(24) = 3.4, *p* = .002). When compared with the neutral condition, the global cue condition was significantly slower (t(24) = -4.5, *p* < .0001), whereas the local cue and neutral conditions did not differ (t(24) = -.9, *p* = .4). Having the cue match a distractor at a global level slowed target-absent trials.

Table 2.2. Error data in target-absent trials for Experiment 2.1a and 2.1b.

Experiment	Validity	Level	Search Errors (%)	Memory Errors (%)
Memory	Valid	Global	1.0	1.4
		Local	1.1	1.7
	Neutral		1.1	1.1
No-Memory	Valid	Global	1.3	
		Local	1.4	
	Neutral		1.2	

Discussion

Previous work has suggested that presenting items held in working memory in a search display affects subsequent target selection (Soto et al., 2005; Downing, 2000;

Pashler & Shiu, 1999). In at least some of these studies, the working memory item was a shape which surrounded the target or distractor items in the search display. This means that the working memory item was more global than the search stimuli, and this global status may be important for the effect. In other words, perhaps working memory directs attention more easily to the global rather than the local aspects of a display. The present study specifically examined the effect of a working memory stimulus on directing attention to the local or global level in a subsequent stimulus. When there was a global target, there was a strong effect of valid cueing from WM: RTs were faster to a global target when it matched the identity of the cue, than when the cue was neutral and did not reappear in the following display. For local targets, valid trials were not reliably faster than neutral. In contrast, the costs of invalid cueing (when the cue matched the item at the distractor level) were reliable for local targets (match to global distractor) but not for global targets (match to local distractor). Overall, both the benefits from valid cueing to the target, and the costs from invalid cueing to a distractor, were greater when the cue matched a target / distractor at the global level. Interestingly this result arose even though there was no overall global bias in the neutral condition. Hence the bias to match the cue at a global level was not because that level was more salient than the local level. It reflects a more specific bias from WM to global level of stimulus representation. In the valid cue condition, the benefit from the cue could arise for two reasons: it could be because the cue guides attention to a matching stimulus, or because the cue pre-activates a response to the target. Note that on valid trials the cue had the identity of the target. The cost to target detection on invalid trials, though, cannot be due to response activation since the cue then did not have the target's identity, not did it activate an alternative response to the target.

There are two ways we can conceptualize performance on invalid trials. One is in terms of the cost of attending to the incorrect level of the hierarchical form. A match between the WM cue and one of the letters in the hierarchical form could cue attention to the level where the match takes place. When the match is to a distractor, this would slow the selection of the target occurring at the other level of the form (on target-present trials). This attentional cueing account is similar to the argument put forward to explain the effects of a WM cue on directing spatial attention, though in that case it is argued that attention is mis-directed to the wrong spatial location rather than the wrong level of form (Soto, Rotshtein, Hodsall & Humphreys, 2008). An alternative proposal is that participants suppress the cue being held in WM (see Woodman & Luck, 2007). Due to the suppression of the cue, RTs are slowed when the cue re-appears in the hierarchical form. One difficulty for this account, however, is that there should be suppression of the WM cue on valid trials too, yet RTs to the hierarchical form were facilitated on such trials. It is also difficult to see why participants should suppress the item in WM given that this item had to be maintained for the memory test. Another reason to query this account is that it does not fit with the neural data on the effects of repeating a WM cue in search (Soto, Humphreys & Rotshtein, 2007), which we discuss in more detail after Experiment 2.1b.

The data also indicate cost effects from re-presenting the cue on target-absent as well as on invalid target-present trials. On absent trials, an invalid cue may be disruptive because it draws attention to a matching item at one level of the stimulus, preventing participants from extracting partial cues for target absence from both levels. Another possibility is that, when the cue matches a stimulus at one level of the search display, a ‘target-present’ response may be primed, which then has to be rejected to respond absent. However, as on target-present trials, the costs on absent responses were greater when the cue matched the global stimulus. In terms of response priming it is not clear why matching the cue at the global level of the search display should particularly disrupt performance. On the other hand, the greater global effect is consistent with the bias from WM to attend to the global level.

As well as finding a cue-target validity effect when the two levels of the hierarchical stimuli were incongruent, there were also effects of validity when the levels were congruent (valid RTs < neutral RTs, for congruent stimuli). This validity effect even with congruent stimuli is notable, given that RTs to the target should be optimal in this case. Interestingly, the valid cueing of attention from WM to the global level of the target (with a local incongruent letter) led to RTs matching those when there was a valid global cue and the local and global levels were congruent. There was thus no reliable extra gain from having the local and global levels match the cue, relative to when only the global level matched.

Although in Experiment 2.1a participants were asked to hold the initial stimulus in working memory, the cue was presented visually on each trial. This presentation could prime the participants' visual system and this bottom-up priming could direct attention to a matching stimulus in the subsequent display. To test this bottom-up account, Experiment 2.1b was conducted. In Experiment 2.1b, the memory requirement was taken out and the test was designed in such a way that, before participants had to look for the target in the compound letter, they were exposed to cues that had to be identified. Effects of bottom-up priming here should be matched to effects in Experiment 2.1a, when the cue had to be held in memory.

Experiment 2.1b:
Priming, Hierarchical Stimuli, and Divided Attention

Method

Participants 25 students and staff (aged between 19 and 27) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal vision.

Apparatus and Stimuli The same apparatus as for Experiment 2.1a was used. All the stimuli (block letters and compound letters) had the same properties as the ones specified in Experiment 2.1a.

Task and Procedure There were 8 blocks of 62 trials. Each trial started with an English alphabetical letter (the same block letters used for Experiment 2.1a) randomly chosen among four different ones used for a block. At the beginning of each block one of the four letters was designated as a letter for a 'no-go' trial, which signaled the participants to ignore the target in the following compound letter in the current trial. When the block letter was different from the designated one, participants were instructed to look for the target. The number of no-go trials was 18 per block. Again, the importance of both the accuracy and speed of response were emphasized.

Results

All the data were, again, divided into target-present and target-absent trials, as in Experiment 2.1a.

1) Target-Present Data

Main Effects The error rate for the global-local task was 2.9% (see Table 2.1 for overall data summary). There was no sign of a speed-accuracy trade-off and the accuracy data were not analyzed further. A 2 × 3 ANOVA was carried out on the mean RT data, with two target levels of stimulus (local and global) and three levels of cue-target validity (valid, invalid, and neutral) as factors. There was no effect of target level ($F(1,24) = 3.17$, $p = .087$), but there was a reliable cue-target validity effect ($F(2,48) = 11.96$, $p < .0001$). The interaction between target level and cue-target validity was not reliable ($F(2,48) = 2.44$, $p = .092$). For valid trials, the data went in the same direction as in Experiment 2.1a. In particular, there was a stronger positive effect of validity for global targets, indicated by a cue-target validity × target level interaction, using data from just the valid and neutral trials ($F(1,24) = 5.9$, $p = .023$). However, in contrast to Experiment 2.1a, invalid trials were faster than neutral trials ($F(1,24) = 4.7$, $p = .039$); this did not differ for local and global targets ($F(1,24) = .057$, $p = .81$). Mean RTs are shown in Figure 2.6.

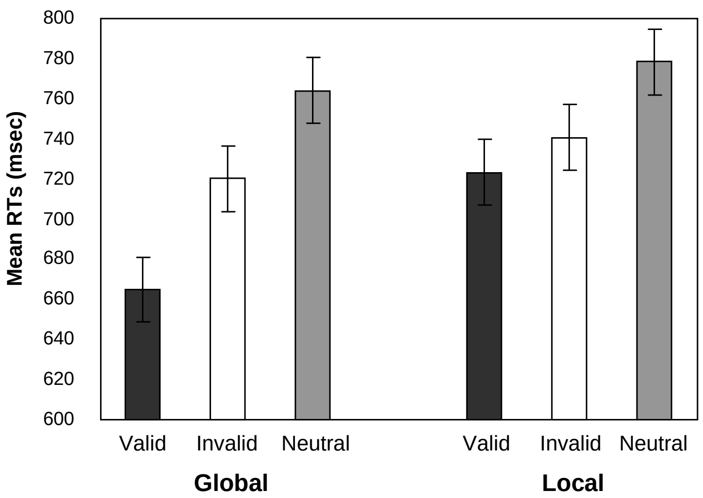


Figure 2.6. Experiment 2.1b: The effect of bottom-up priming on target perception at different levels of form.

Effect of Congruency The effect of congruency between the global and local levels was assessed by comparing trials with congruent, and with incongruent stimuli (all target present). As in Experiment 2.1a, congruent trials were those with the target letter at both levels, and incongruent trials were those with the target letter at just the global or the local level. Performance was compared following valid and neutral cues (see Figure 2.7).

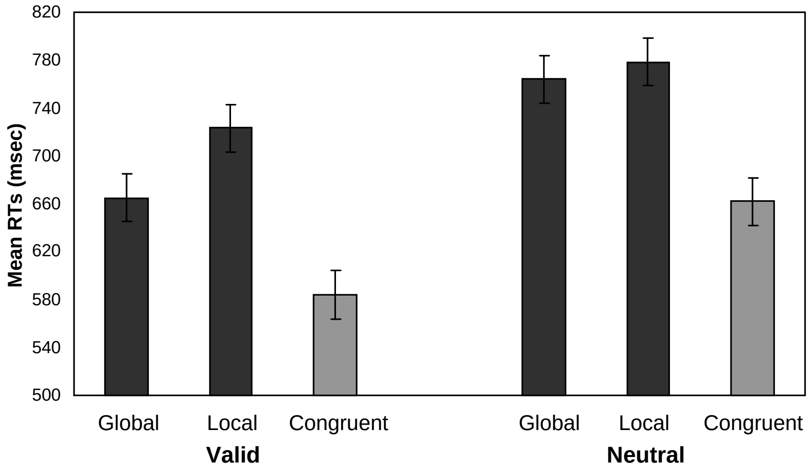


Figure 2.7. Experiment 2.1b: The effects of congruency for valid and neutral cue trials. 'Global' and 'local' here refer to the level at which the target appeared.

There were reliable effects of cue-target validity ($F(1,24) = 42$, $p < .0001$) and target level ($F(2,48) = 7.8$, $p < .001$). The RTs on valid trials were faster than on neutral trials. Averaging across the validity factor, congruent trials were faster than both local and global trials ($t(24) = 3.3$, $p = .003$, and $t(24) = 2.4$, $p = .027$, respectively), and local and global trials did not differ ($t(24) = -2.0$, $p = .061$). The cue-target validity × target level interaction was not reliable ($F(2,48) = 2.2$, $p = .119$).

2) Target-Absent Data

The error data are detailed in Table 2.2. There were no signs of a speed-accuracy trade-off. The results from the analyses on target-absent trials contrasted with the effects found on target-present trials (See Figure 2.8). As in Experiment 2.1a, a one-way ANOVA was conducted with 3 levels of validity: global cue, local cue, and neutral. There was no effect of validity (F(2,48) = .17, p = .84).

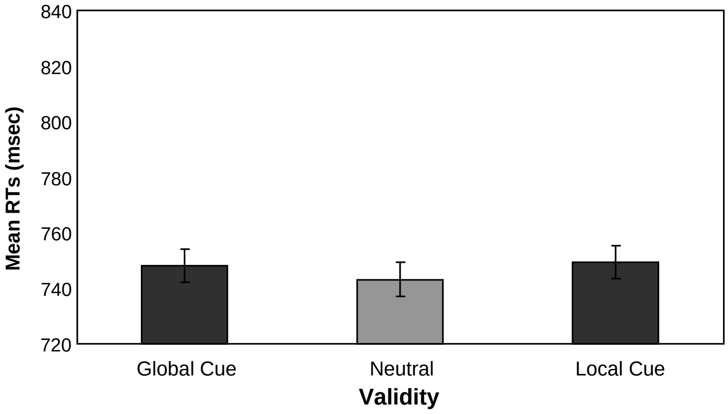


Figure 2.8. Experiment 2.1b: The effects of bottom-up priming on target-absent trials.

3) Cross-Experiment Comparisons

To assess whether having to hold a stimulus in WM influenced selection, Experiments 2.1a and 2.1b were analyzed together. For the data from target-present trials, a mixed-design ANOVA was carried out, with one between-subjects factor (experiment) and two within-subject factors (target level and cue-target validity). There was a reliable cue-target validity effect (F(2,48) = 15.6, p < .0001) but no overall effect of target level (F(2,48) = 3.55, p = .065). There were 2-way interactions between cue-target validity and experiment (F(2,48) = 3.3, p = .04) and between target level and cue-target validity (F(2,48) = 10.8, p < .0001), which were qualified by a target level × cue-target validity × experiment interaction (F(2,48) = 3.4, p = .038). Performance was analyzed by separating the data for valid trials against the neutral baseline, and invalid trials against the neutral baseline across the experiments. First a mixed-design ANOVA was conducted, with one between-subjects factor (experiment) and two within-subjects factors (levels and validity: valid vs. neutral). The same ANOVA was then repeated for invalid vs. neutral trials. For the contrast between valid and neutral trials, the results showed that there were significant main effects of cue-target validity ($F(1,48) = 34.9$, $p < .0001$) and target level ($F(2,48) = 6.2$, $p = .016$), but no effect of experiment ($F(1,48) = 1.64$, $p = .206$). However there were interactions between cue-target validity and experiment ($F(1,48) = 6.2$, $p = .017$), and between target level and cue-target validity ($F(1,48) = 14.6$, $p < .0001$). There was no target level × cue-target validity × experiment interaction ($F(1,48) = .08$, $p = .78$). The effect of cue-target validity was larger in Experiment 2.1a (WM) than Experiment 2.1b (priming) (77 msec vs. 32 msec). The cue-target validity effect overall was larger for global than for local targets (50 msec vs. 13 msec). For the contrast between invalid and neutral trials, there were no main effects (all $F < 1.0$), but there was one substantial interaction between target level and experiment ($F(1,48) = 10.1$, $p = .003$). The cost for invalid vs. neutral trials in Experiment 2.1a (52 msec, averaged across levels) became a benefit for invalid trials in Experiment 2.1b (40 msec, across levels; see contrasts reported in the individual experiments). The other interactions did not reach significance. (all $F < 1.0$).

A between-experiment analysis for target-absent trials was conducted with one between-subjects factor (experiment) and one within-subjects factor (validity: neutral, global valid, and local valid). There was no main effect of experiment ($F(1,48) = .97$, $p = .33$), but there was a reliable effect of validity ($F(2,48) = 4.4$, $p = .014$) and a validity × experiment interaction (F(2,48) = 3.1, p = .049). The effect of validity was present in Experiment 2.1a but not in Experiment 2.1b.

Discussion

In Experiment 2.1a, there were substantial effects of cue validity on responses to a hierarchical target letter, which were largest to items cued at the global level. Invalid cues also impaired performance. The effects of cueing arose on target-absent as well as -present trials. In Experiment 2.1a, participants had to memorize the cue. In Experiment 2.1b participants had to identify the cue but memorization was not required. Though there were effects of validly cueing attention to a target (relative to the neutral condition), any validity effects were smaller than in Experiment 2.1a. Perhaps even more strikingly, there was a qualitative shift in performance in the priming and memory conditions on invalid trials. Whereas previously an invalid cue disrupted target detection, in this priming experiment RTs to the target were facilitated when the cue matched the distracter at the non-target level. In studies using brain-imaging methods, neural activations are found to be reduced when stimuli are repeated (e.g., Vuilleumier, Schwartz, Duhoux, Dolan, & Driver, 2005). This repetition suppression effect may occur because stimuli are processed more efficiently when re-presented (see also Wiggs & Martin, 1998; Henson et al., 2000; Wig et al., 2009). In the present study, the repeat of the cue at the distractor level of a hierarchical letter may enable the target letter to be processed more efficiently, speeding RTs. This effect of mere repetition of the distractor contrasts with the effects when the distractor was a repeat of a cue being actively held in memory (as in Experiment 2.1a), We have proposed that the cue in WM acts as a strong attractor of attention when a matching item appears in the hierarchical form, disrupting performance when the cue is invalid. Alternatively, there is suppression of the cue in WM, which slows performance when the cue re-appears in the hierarchical form. In either case, these effects seem confined to when the cue is held in WM.

These behavioral data are particularly striking in relation to work on the neural substrates of attention capture from WM. Soto et al. (2007) used fMRI to measure neural activation during a search task when participants either merely identified a cue or held it actively in WM. When the cue was held in memory and then re-appeared in the search display, there was enhanced activation in brain areas sensitive to stimulus repetition (e.g., the parahipocampal gyrus and the superior frontal gyrus). This occurred on invalid as well as valid trials. This top-down increase in activation may serve as the neural basis for attentional capture. For example, increased activation when the cue re-appears could act to drive attention to the cue. This would be consistent with an attentional capture account of the data on invalid trials in Experiment 2.1a. In contrast, when the cue was identified but not held in memory, these same neural areas showed evidence of repetition suppression (reduced activation when the cue re-appeared in the search display compared with when it did not re-appear). This repetition suppression effect may provide the neural basis of facilitated perception of a repeated cue, found on invalid priming trials here. Bottom-up activation of cued representations may facilitate perceptual encoding without exerting a strong effect on attention.

Experiment 2.1c:
Working Memory, Hierarchical Stimuli, and Automatic Guidance

In Experiments 2.1a and 2.1b, the initial cue was valid on 33% of the trials. It is possible that this could have encouraged participants to match the cue to the target, even when the cue was equally often valid and invalid. If the tendency to match the cue deliberately was increased when the cue was also held in WM, this would account for the larger cueing effects in the WM condition (Experiment 2.1a). In experiments using spatial search rather than hierarchical letter perception, Soto et al. (2005) showed that cueing effects from WM occurred even when the cues were never valid (the cue was always invalid when it re-appeared in the search display). Soto and Humphreys (2007) reported similar results when a verbal WM cue was presented. Soto and Humphreys argued that the cue automatically directed visual attention even when it was always invalid. Experiment 2.1c here tested for a similar automatic effect from WM on attention to the level of hierarchical forms. To do this Experiment 2.1a was repeated but with only invalid and neutral trials included.

Method

Participants 25 students (aged between 19 and 28) at the School of Psychology of the University of Birmingham participated for course credit. All had normal or corrected-to-normal vision.

Apparatus and Stimuli The same apparatus for Experiment 2.1a and 2.1b were used. All stimuli (block letters and compound letters) had the same properties as the ones specified in the previous experiments.

Task and Procedure The task sequence was the same as the one in Experiment 2.1a. The letter ‘D’ remained the target, and two other alphabetical letters U and X were used to construct compound letters. For the memory cue, three letters U, X, and N were used. The important change was that valid trials, where the identity of the memory item matched that of the target, were not included in this experiment and only invalid and neutral conditions were maintained. Additionally there was a new type of trial in which the identity of the memory item was never present at either level of the compound letter (e.g., when ‘N’ was the memory item). This new control condition tested whether there was any effect of having the memory cue as a letter that could sometimes appear in the hierarchical letter display, even when it was not actually present on the trial (on neutral trials). There were in total 3 experimental conditions in the current test (invalid, neutral, and control), and 4 blocks of 72 trials were run.

Results

1) Target-Present Data

Main Effects The error rates were 5.1% and 5%, for the search and memory tasks, respectively (see Table 2.3). There was no sign of speed-accuracy trade-off no sign of any effect of validity on memory trials. These data were not analyzed further. Figure 2.9 gives the overall RT data. A 2 (target level) × 3 (cue-target validity) ANOVA showed that there was a reliable effect of target level ($F(1,24) = 22.1$, $p < .0001$), but no cue-target validity effect ($F(2,48) = .385$, $p = .698$). There was no target level × cue-target validity interaction ($F(2,48) = .02$, $p = .98$).

Table 2.3. Error data on target-present trials in Experiment 2.1c.

Experiment	Level	Validity	Search Errors (%)	Memory Errors (%)
Memory	Global	Invalid	0.3	1.0
		Neutral	0.2	0.4
		Control	1.3	0.8
	Local	Invalid	1.5	0.9
		Neutral	0.3	1.3
		Control	1.5	0.6

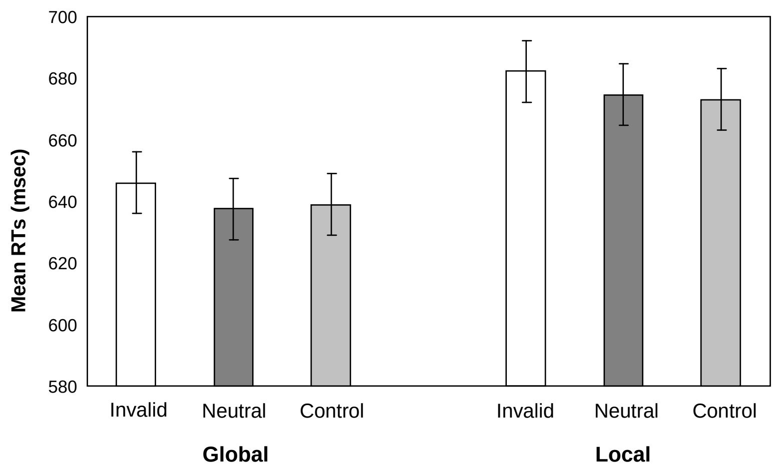


Figure 2.9. Effect of working memory on target perception at different levels of form in Experiment 2.1c (no valid trials).

Effect of Congruency The data were analyzed to assess the effect of congruency between the local and global levels (see Figure 2.10). Since there were no valid trials here, the data were based only on neutral cue trials. Averaging across the cue-target validity factor, all incongruent trials were analyzed against congruent trials by conducting a one-way ANOVA. There was a reliably significant effect of global-local congruency ($F(2,48) = 8.9$, $p < .0001$). Pair-wise t-tests showed that there were significant differences between congruent trials and incongruent trials with the target at both the global and local levels ($t(24) = 2.3$, $p = .03$, and ($t(24) = 3.4$, $p = .002$, respectively). RTs for incongruent trials with a target at a global level (WM match to the local level) were significantly faster than RTs for incongruent trials with target at local level (WM match to the global level) (t(24) = -4.7, $p < .0001$).

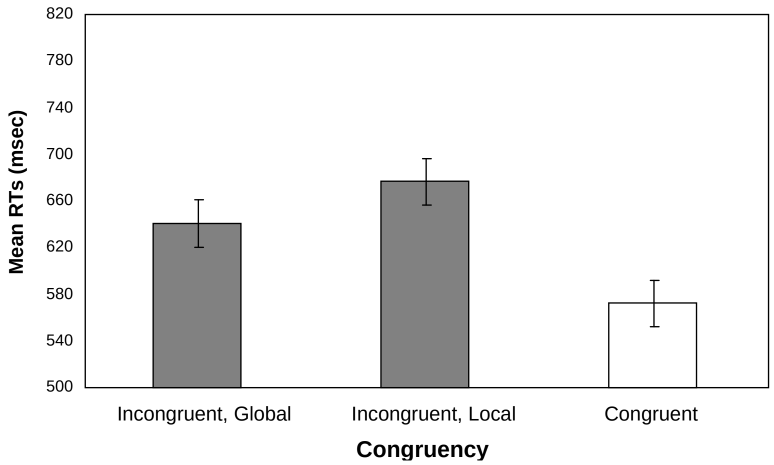


Figure 2.10. Experiment 2.1c: Effect of congruency. 'Global' and 'local' refer to the level at which the target was located.

2) Target-Absent Data

The error rates were 2.9% for the search task and 3.9% for the memory task (see Table 2.4). Again there was no effect of validity on memory. The data from target-absent trials were analyzed (see Figure 2.11) with the data separated according to whether the invalid cue matched the global or local level of the hierarchical letter by carrying out a one-way ANOVA on the 3 validity conditions. There was an effect of validity (F(2,48) = 5.9, $p = .005$). In each of the two invalid conditions RTs were significantly larger than in the neutral condition (t(24) = 3.3, $p = .003$ for global, and t(24) = 3, $p = .006$ for local matches). There was no difference between the global and local match conditions on invalid trials (t(24) = -.33, $p = .74$).

Table 2.4. The error data for target-absent trials for Experiment 2.1c.

Experiment	Validity	Level	Search Errors (%)	Memory Errors (%)
Memory	Invalid	Global	0.8	1.4
		Local	1.0	1.4
	Control		1.1	1.1

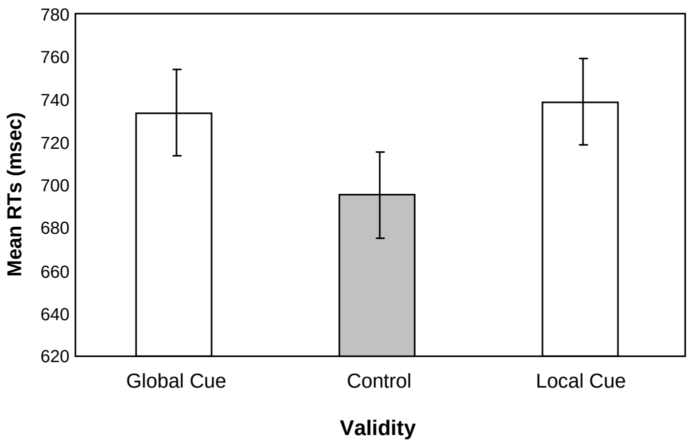


Figure 2.11. Experiment 2.1c (no valid trials): The effect of memory on target perception at different levels on target-absent trials.

Discussion

Unlike in Experiment 2.1a, there was no effect of the validity of the cue on target-present responses. However, there was an effect on target-absent responses: RTs were slowed when the cue in WM matched the identity of the letter at one level of the hierarchical form. Interestingly the magnitude of this effect on absent trials was similar to that in Experiment 2.1a (the difference between the neutral and global match conditions here was 39 msec while this difference was 36 msec in Experiment 2.1a). In addition, on trials where the cue matched one level of an incongruent distractor, RTs were faster when there was a local rather than a global match. These results are consistent with there being an automatic effect on directing attention to one level of a hierarchical form when it matched an item held in WM, affecting performance even when the WM cue is always invalid. The effect was again greater when the invalid cue matched the global level of form. An alternative is that the WM was suppressed and this slowed RTs, but there is no reason to expect such an effect to be most pronounced for cues re-appearing at the global level.

The argument that there is an automatic guidance effect on attention from items held in WM is not without controversy. For example, Woodman and Luck (2007) examined effects of a stimulus in WM on spatial search. The item in memory never matched the search target. Unlike Soto et al. (2005), they found that RTs were actually speeded when the memory cue re-appeared as a distractor in the search display. Woodman and Luck proposed that participants could bias themselves against items held in WM, so that targets were selected more easily when the WM matched a distractor rather than a target (speeding RTs on invalid relative to valid trials). Olivers (2009) has presented data suggesting that whether a bias is set against an irrelevant item in WM depends on several factors such as whether the target changes across trials (the bias against the WM item is found with varied rather consistent mapping; with consistent mapping of the search target, attention is biased to the WM cue). Han and Kim (2009) have also shown that a positive bias to an item re-presented from WM can switch to a negative bias against it when the WM item is always invalid and when there is a relatively long interval between the cue and the search display (1000 msec or more). The present study used consistent mapping (favoring a bias to the WM stimulus) but had a relatively long interval between the onset of memory cue and the onset of the hierarchical letter (1500 msec). This long interval could have enabled participants to begin to set themselves against the (always invalid) WM cue, which would reduce the strength of the positive bias to the WM item compared with when the item was sometimes valid.

One other argument can be raised against the cue in WM automatically affecting attentional guidance; this is if participants use the cue to deliberately refresh their memory by attending to the cue's re-appearance in the hierarchical form. According to this 'memory refresh' account, WM performance ought to be better when the cue re-appeared in the display (on valid and invalid trials) compared with when it did not (neutral and control trials). There was no evidence for this (Tables 1-4). Nevertheless, to test this proposal we conducted Experiment 2.3, which used conditions where it would not benefit participants to attend to the hierarchical stimulus to re-fresh their memory. These conditions make it difficult to argue that any effects reflect memory re-freshing.

Experiment 2.2a:
Working Memory, Hierarchical Stimuli, and Selective Attention

There were several interesting results in Experiment 2.1. First, in Experiment 2.1a, baseline responses with hierarchical letters did not show a global precedence effect but evidence for the effect emerged when there was a match between a cue held in WM and the hierarchical form. There were stronger positive cueing effects (on valid trials) to global targets, and a greater cost to local targets from invalid cueing trials (when the cue matched the global form). This suggests that attentional guidance from WM is globally biased. In addition, there was evidence that effects from items held in WM and from bottom-up priming from the cue may be qualitatively different (Experiments 2.1a and 2.1b). Bottom-up priming facilitated perceptual processing without biasing attention. In contrast, items in WM either bias attention to a matching form or these items are suppressed. Evidence from fMRI is more consistent with the attentional bias account (Soto et al., 2007), and this account also better explains why distractors are most disruptive when they appear at a global level, if the WM stimulus biases attention to that level.

Experiment 2.1 used a divided attention procedure, where participants had to look for the target letter at both levels. Divided attention may encourage attentional deployment at a global level. Experiment 2.2 used a selective attention format where participants were given the specific level that needed to be attended to. In this task, participants have the opportunity to filter out the letter at the task-irrelevant level. Previous studies have indicated that the selective attention procedure tends to 'weaken' differential hierarchical perception by enabling participants to focus on one specific level while ignoring the other (Yovel et al., 2001; Lux et al., 2006). We ask whether matches to a WM item biases attention to the global level even when participants attempt to attend to just the local level. A positive effect of the cue here would indicate that its effect may counter-act the focused attentional bias to the target level.

The design of Experiment 2.2 also meant that we could test for effects of response priming on performance. The effects of valid cueing in Experiment 2.1 could at least in part reflect priming of a target-present response since the valid prime had the same identity as the target. Experiment 2.2 included conditions in which the search letter had the same (congruent) letter at the global and local levels, and where the non-target level was non-response related (control stimuli; see Figure 2.12). In the congruent WM condition the prime was coded as valid (the cue had the same identity as the stimulus at the target level), neutral (the cue was not a member of the response set) or it was the response alternative to the stimulus present at the target level (we term this the invalid response condition). If there is an effect of response priming, the

RTs should be slower here in the invalid response condition compared with when the cue was neutral (response unrelated). Note that the prime is not present at either level of the target letter. In the control WM condition, the cue was coded as either valid (cued the target letter), response invalid (cued the alternative response but was not present in the hierarchical target letter), or invalid (as in Experiment 2.1). In the invalid WM condition, the cue was not a response alternative but it matched the distractor in the hierarchical target letter. Effects of response priming and invalid attention cueing can be contrasted by comparing these last two conditions. There were also incongruent stimuli, where the distractor level of the hierarchical stimulus demanded the opposite response to the target. These stimuli could be preceded by valid primes (matching the target), neutral primes (not present in the hierarchical stimulus) or invalid response & invalid primes (which both cued the alternative response to the target and also matched the stimulus at the distractor level of the hierarchical letter).

Method

Participants 25 students and staff (age range: 19-42) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The test equipment and stimuli were the same as in Experiment 2.1. Three letters D, U, and X were used to construct the compound stimuli.

Task and Procedure 14 blocks (7 global and 7 local tasks, randomized) of 18 trials were run with each participant. Figure 2.12 presents an illustration of the stimuli used in the current experiment. As a new block began one specific level was cued by the word ‘local’ or ‘global’ to indicate the level that needed to be attended to across the following trials. The trials had the same features as the ones from Experiment 2.1. Randomized within the block, each trial began with a fixation cross, which was followed by a block letter for the participants to remember. After a delay of 1000 msec and a fixation displayed for 200 msec, a compound letter was presented for response. Memory probe questions were presented, randomly at the end of trials. There were three congruency conditions, determined by the relations between the local and global levels of a single stimulus (see Figure 2.12).

The local and global levels of the hierarchical letters could be congruent (when the global and local levels were the same letter, either D or U), incongruent (when the global and local levels were different letters, D and U), and control (when one of the levels was a non-response related one, the letter X). Within each congruency condition there were three cue-target validity conditions (valid, invalid, and neutral), defined by the relation between the cue and the subsequent hierarchical stimulus. Note that for the congruent condition, there was not a non-target level and so there could be no invalid cueing trials (though there could be invalid response trials). The targets were always the letters ‘D’ and ‘U’. Participants had to decide whether the letter present at the task relevant level was D or U and to press the response keys (left arrow or right arrow keys) on the keyboard as instructed.

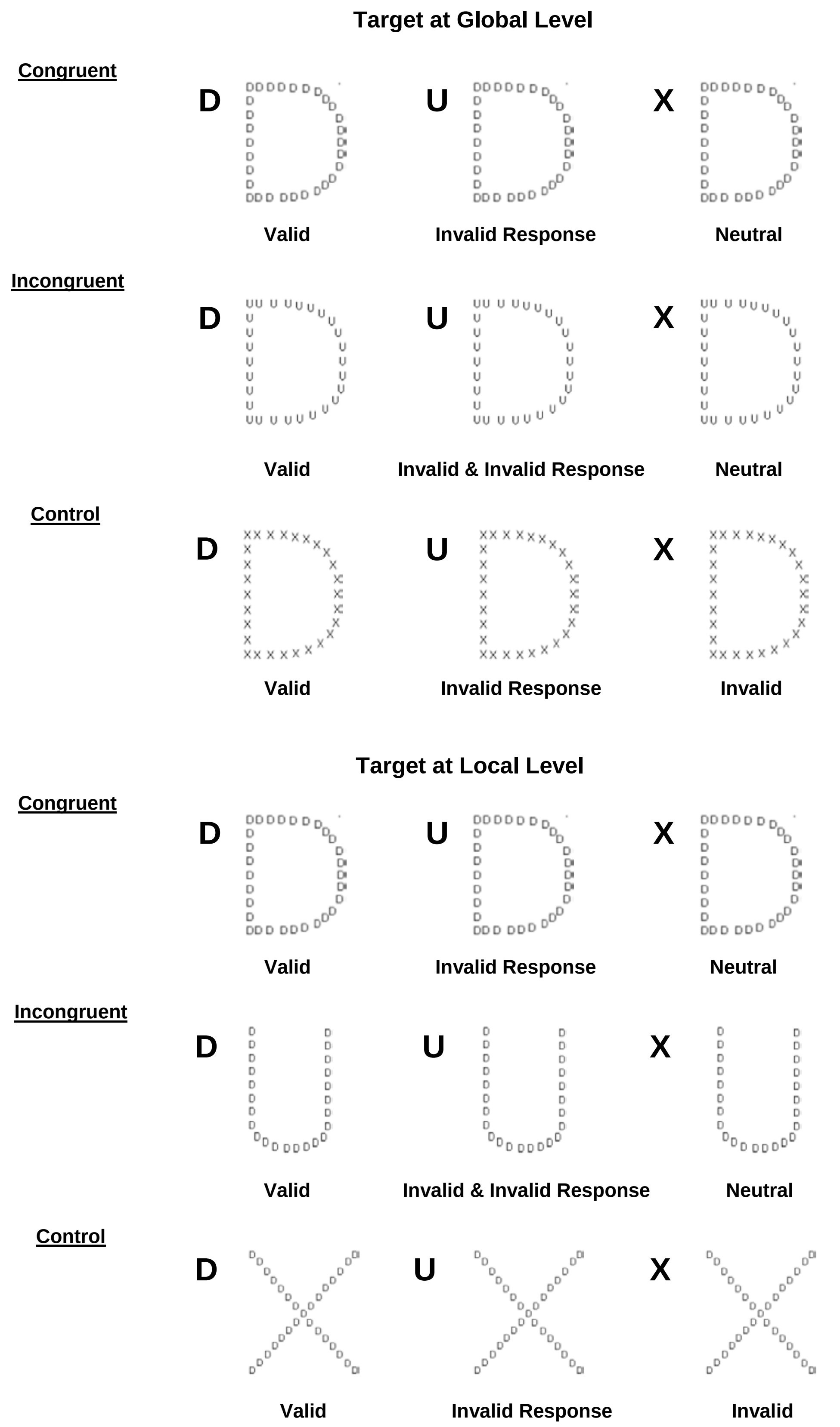


Figure 2.12. Hierarchical targets employed in Experiment 2.2, shown here to illustrate the type of target (congruent, incongruent, control) and the different WM conditions (valid, invalid, neutral, invalid response and invalid & invalid response). Targets were ‘D’ and ‘U’. The examples illustrated here are when the target is ‘D’. The small block letter illustrates the prime on that trial.

Results

The search error rate was 6.3%, and the memory error rate was 6.3% (see Table 2.5 for the data summary). 4 separate ANOVAs were conducted to test the overall congruency effect in the neutral conditions, and to test the validity effect under each congruency condition (congruent, incongruent, and control).

Congruency effect The effect of global-local congruency was assessed by taking the data when there was a neutral memory cue. The data were analyzed in a 2 (target level: global and local) × 2 (global-local congruency: congruent and incongruent) ANOVA. The results (see Figure 2.13) showed that there was a reliable global-local congruency effect ($F(1,24) = 21$, $p < .0001$). There was no effect of target level ($F(1,24) = .23$, $p = .63$) and no target level × global-local congruency interaction ($F(1,24) = .25$, $p = .62$). The magnitude of the congruency effect was the same for targets at the local and global levels.

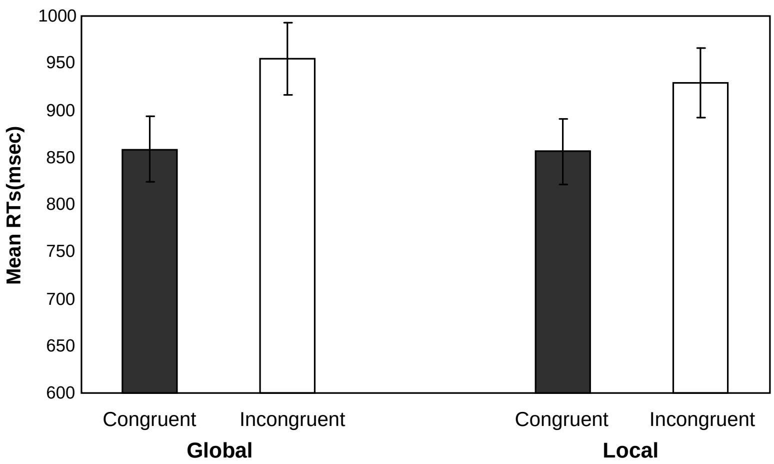


Figure 2.13. Experiment 2.2a: The overall congruency effect by level.

Validity effect under each level of congruency condition Separate 2 × 3 ANOVAs were carried out for each global-local congruency condition (for congruent, incongruent, and control stimuli), to test the relations between target level (global and local) and cue-target validity (valid, neutral, and the various invalid conditions). Figure 2.14 shows the overall data.

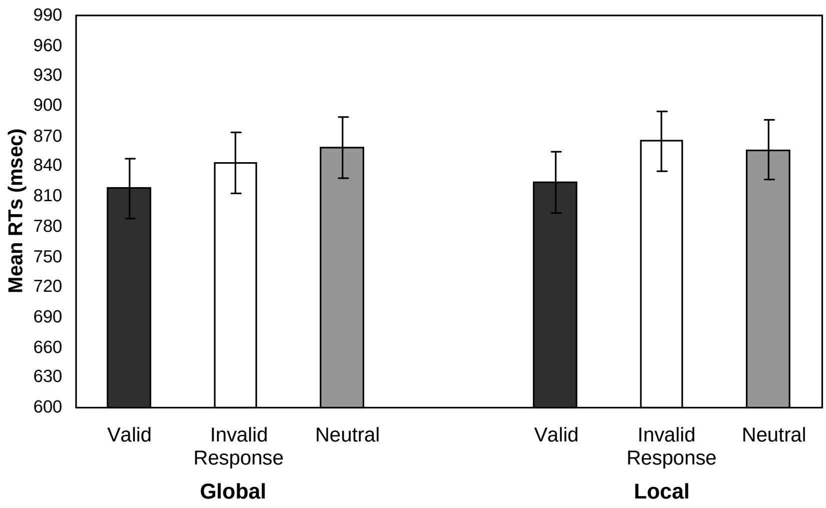
Congruent displays: There were no effects of cue-target validity or target level, and no interaction (all $F<1.0$).

Incongruent displays: There were again no reliable effects (all $F<1.0$).

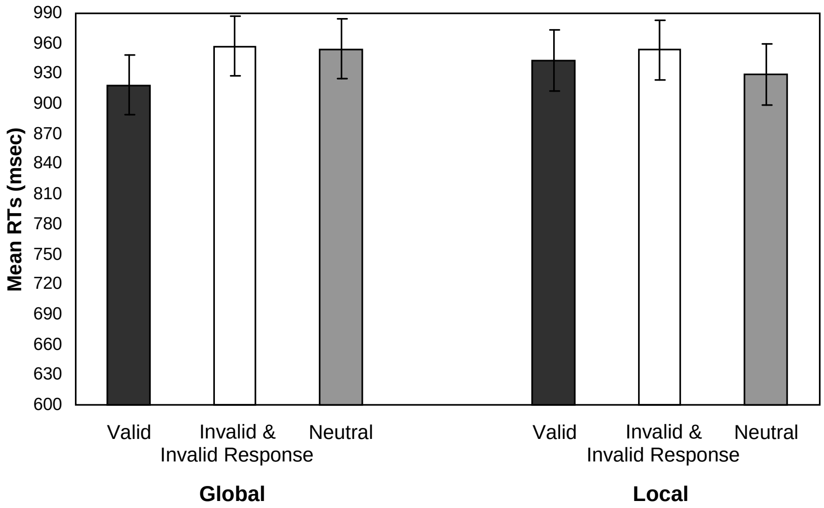
Control displays: There was a main effect of cue-target validity ($F(2,48) = 5.6$, $p = .007$). There was no effect of target level and no interaction (both $F<1.0$).

Pair-wise comparisons for control stimuli were conducted to assess the main effect of cue-target validity with the data averaged across the target level (global and local). There were significant differences between the valid and the invalid conditions ($t(24) = -2.1$, $p = .045$), and between the invalid and the invalid response conditions ($t(24) = -3.0$, $p = .007$). The valid and invalid response conditions did not differ significantly ($t(24) = .83$, $p = .41$). The absence of a difference between the valid and the invalid response condition indicates that response priming (in the invalid response condition) did not strongly modulate responses to the target. It also suggests that there was little benefit from valid priming, presumably because attention was already set to the target level. However, RTs were slowed on invalid trials. This suggests that the WM cue may still direct attention to the distractor level, even when participants are in a focused attention mode.

Congruent



Incongruent



Control

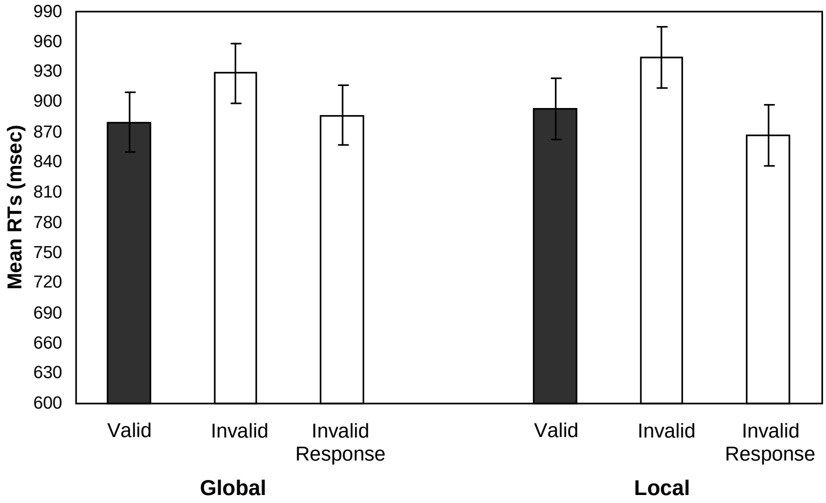


Figure 2.14. Experiment 2.2a: Effect of WM on the responses to different levels of form as a function of the congruency of the local and global forms.

Table 2.5. Error data for Experiment 2.2a.

Experiment	Level	Congruency	Validity	Search Errors(%)	Memory Errors(%)
Memory	Global	Congruent	Valid	0	0
			Invalid Response	0	1.0
			Neutral	0	0
		Incongruent	Valid	1.4	0
			Invalid	0.8	0.6
			Neutral	1.1	0.2
		Control	Valid	0.3	0.2
			Invalid Response	0	0.3
			Neutral	0	0.7
	Local	Congruent	Valid	0	0.2
			Invalid Response	0	1.0
			Neutral	0	0
		Incongruent	Valid	1.1	0.3
			Invalid	1.0	0.3
			Neutral	0.4	0.2
		Control	Valid	0.1	0.9
			Invalid Response	0	0.3
			Neutral	0.1	0.2

In order to assess how the effects of the memory cue varied across the divided and focused attention conditions, the data from the valid and invalid conditions in Experiment 2.1a were compared with those from Experiment 2.2a, with experiment as a between-subject factor.[1] There was a main effect of cue-target validity ($F(1,48) = 15.95$, $p < .0001$), which did not interact with experiment ($F<1.0$).

Discussion

In Experiment 2.2, with control stimuli, we again found a cueing effect, with RTs being slowed on invalid trials compared with the other conditions (valid and invalid response, in this case). This cost effect (relative to invalid response trials) was similar to that found in Experiment 2.1a (and the overall validity effect did not differ across

[1] For Experiment 2.2a the data were taken from the control condition. Only in that condition was the non-target level of the hierarchical letter irrelevant to the response (as was always the case in Experiment 2.1a). Also the neutral condition from Experiment 2.1a and the invalid response conditions from Experiment 2.2a were omitted, since they had no equivalent in the other experiment.

the experiments). The data suggest that the WM cue could still attract attention to a matching distractor at the non-target level, even though participants could focus attention at one level here. The alternative account is that the WM cue was suppressed and this slowed the processing of the hierarchical stimulus. However, we would expect RTs to be slowed on valid trials, too, in this case, and there was no evidence for this.

The present results appear at first sight to counter those of Hernández et al. (in press), who reported stronger effects of a WM cue on subsequent visual selection when participants adopted a broad window of attention. However, it may be that adopting a broad window of attention (as in Hernández et al., in press) is not the same as being in a distributed vs. focused mode of attention (contrasting Experiments 2.1 and 2.2 here). Even when participants could focus attention in advance here, they would still have to adopt a broad window of attention for the global form. Rather than corresponding to a narrow attentional window, focused attention here may involve tuning visual filters to a particular spatial frequency, and this tuning may operate even when a broad window of attention is adopted for a global target. The present data indicate that, even if participants focus attention on a target spatial frequency, they can still be cued to attend to the other level of the stimulus if that level matches an item in WM.

The current data also suggest that the beneficial effects of validity are reduced when participants operate in a focused mode of attention (note the lack of difference between the valid and invalid response conditions for control stimuli here). This would fit with the validity benefit occurring because attention is attracted to the appropriate level of the stimulus when the WM is valid and attention is distributed (Experiment 2.1a). Validity effects are reduced when the appropriate level of the target is already selected (in the focused attention mode). The failure to find a cost on invalid response trials, compared with valid trials (e.g., for the control stimuli), also suggests that response priming effects were not strong (given the response priming could occur on valid trials). Effects of valid and invalid cues did not appear to operate at a response level.

We failed to find effects of the cues here with congruent and incongruent hierarchical forms, though we did find that RTs were generally slower with incongruent stimuli. With these stimuli the time taken to select the response to the target could have 'washed out' any effects of the cue.

Experiment 2.2b replicated Experiment 2.2a, but used the procedure employed in Experiment 2.1b where participants identified primes but did not have to hold them in memory. This experiment then assesses effects of bottom-up priming from the cue. In Experiment 2.1b we found that RTs were speeded when the cue was present in the target letter, both when it matched target (on valid trials) and when it matched the non-target (on invalid trials). Would a similar effect emerge here in the invalid condition, even when participants can focus their attention on the target level?

Experiment 2.2b:
Priming, Hierarchical Stimuli, and Selective Attention

Method

Participants 25 students and staff (aged between 19 and 27) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal vision.

Apparatus and Stimuli The same apparatus was used as the preceding experiments. All the stimuli (block letters and compound letters) had the same properties as those used previously.

Task and Procedure Experiment 2.2b adopted the same experimental procedure as Experiment 2.2a. Trials were blocked into 14 parts, 7 blocks each for the global and local levels. Each block of trials started with an English alphabetical letter (font: Courier New, with size 32). The letter was randomly chosen among a group of 7 (A, C, E, H, M, O, S). This letter was followed by a word 'global' or 'local' (the level to be attended to at the current block). The first letter was for participants to decide whether or not to do the search task in the ensuing presentations of stimuli: if the letter was the same as the following block letter (a prime in the current experiment, equivalent to the memory cue in Experiment 2.2a), participants were instructed to perform the hierarchical letter task at the level cued. If the letter was different from the following block letter, they were not to perform the task. This ensured that participants had to encode the letter cue but not hold it in memory. The importance of accuracy and speed of response were equally emphasized.

Results

Errors in the search task were very low at 3.2% (see Table 2.6). There was no evidence of a speed-accuracy trade-off and the data were not analyzed further, as for Experiment 2.2a. 4 separate ANOVAs were conducted to test the overall global-local congruency effect following a neutral cue, and to test the effect of cue-target validity under each of the 3 congruency conditions (with congruent, incongruent, and control letters).

Congruency effect We conducted a 2 × 2 ANOVA with the factor being target level (global and local) and global-local congruency (congruent and incongruent stimuli, following a neutral cue). A strong global-local congruency effect was found when an ANOVA was conducted following neutral cues ($F(1,24) = 52$, $p < .0001$). There was also an effect of target level (global targets were detected faster than local targets; $F(1,24) = 5.4$, $p < .03$), but no target level × global-local congruency interaction ($F(1,24) = .002$, $p = .97$). Congruent trials were faster than incongruent trials but this did not differ across local and global items. Mean RTs are given in Figure 2.15.

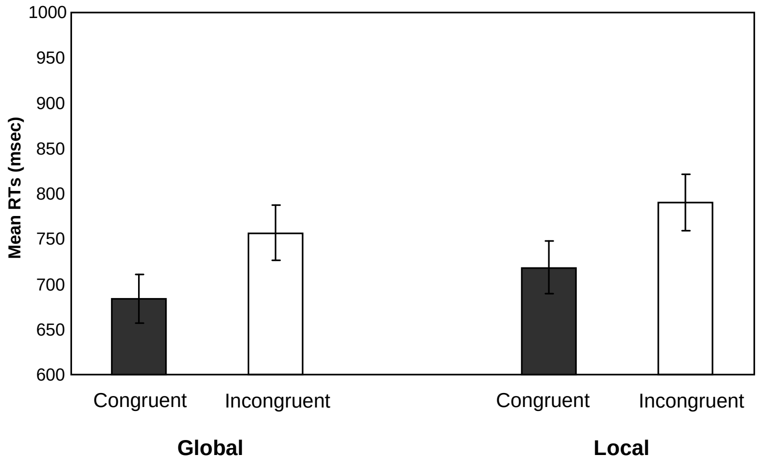


Figure 2.15. Experiment 2.2b: The overall congruency effect at each level of form.

Validity effects under each congruency condition Figure 2.16 gives the mean RTs for each condition. For each congruency condition a 2 (target level) × 3(cue-target validity) ANOVA was conducted.

Congruent displays: There was an effect of target level ($F(1,24) = 27.3$, $p < .0001$), but not of cue-target validity ($F(2,48) = 1.2$, $p = .29$), and there was no interaction ($F < 1.0$).

Incongruent displays: The effect of target level was reliable ($F(1,24) = 6.44$, $p = .018$). There was also an effect of cue-target validity ($F(2,48) = 4.5$, $p = .016$) but no interaction ($F < 1.0$).

Control displays: The effect of target level was significant ($F(1,24) = 11.5$, $p = .002$). There was a borderline effect of cue-target validity ($F(2,48) = 3.1$, $p = .053$), but no interactions between target level and cue-target validity for any of the global-local congruency conditions ($F < 1.0$).

For incongruent stimuli, pair-wise comparisons showed that there was a significant advantage for valid over neutral trials ($t(24) = -2.5$, $p = .02$) and invalid & invalid response trials over neutral trials ($t(24) = -2.8$, $p = .01$). No difference was found between the trials with valid stimuli and with invalid & invalid response stimuli ($t(24) = -.2$, $p = .83$).

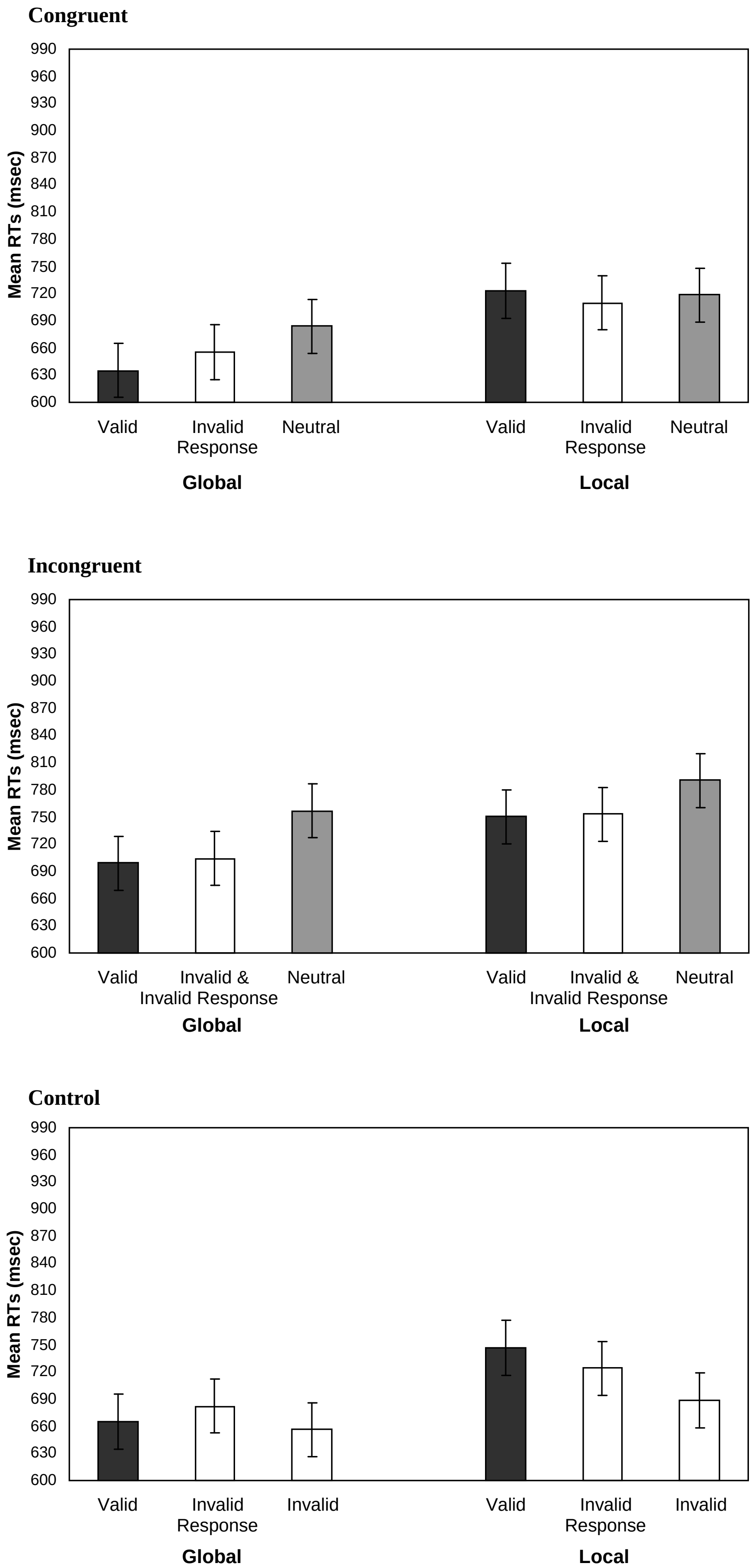


Figure 2.16. Experiment 2.2b: Effect of no-memory priming by congruency on target perception at different levels.

Table 2.6. Error rates for Experiment 2.2b

Experiment	Level	Congruency	Validity	Search Errors (%)
No-Memory	Global	Congruent	Valid Invalid Response Neutral	0 0.2 0.1
		Incongruent	Valid Invalid Neutral	0 0 0.4
		Control	Valid Invalid Response Neutral	0.1 0.7 0
	Local	Congruent	Valid Invalid Response Neutral	0.1 0 1.1
		Incongruent	Valid Invalid Neutral	0.2 0.2 0
		Control	Valid Invalid Response Neutral	0 0.1 0

Discussion

The results indicate two main points. First, the effects of the cue tended to be relatively small when participants performed the task in a focused rather than in a distributed mode of attention. For instance, in Experiment 2.1b there was a difference of around 100 msec to global targets in the valid and neutral cue conditions. Here the largest difference was around 30 msec, for stimuli with incongruent global and local forms. Second, when effects of validity occurred they reflected benefits from the re-appearance of the cue (compared with the neutral baseline), and this held irrespective of whether the cue was valid or invalid (matching the distractor rather than the target, with incongruent stimuli). This benefit, even on invalid trials, matches that found in Experiment 2.1b. Indeed, a cross-experiment comparison of trials for incongruent stimuli in Experiment 2.2a (WM) and Experiment 2.2b (priming) with invalid & invalid response stimuli and neutral stimuli indicated an interaction between validity and experiment ($F(1,48) = 5.2$, $p < .05$). There was a cost in the invalid & invalid response condition in Experiment 2.2a (mean 13 msec) but a benefit in Experiment 2.2b (mean 45 msec). These results suggest that, when the cue had to be identified but not held in memory (Experiment 2.2b), there was a priming effect which facilitated identification of a target whenever the prime re-appeared in the target letter. This occurred even though the prime in the invalid and invalid response condition could activate a response competitor to the target and could cue attention to the non-target level[2].

A final point to note here is that a robust global advantage was present in this experiment across all the priming conditions. A similar trend was present in Experiment 2.1b, when the primes were identified but not held in memory, and in Experiment 2.1c, when primes were held in memory but were never valid. On the other hand, there were no reliable differences between global and local levels in the baseline conditions of Experiments 2.1a and 2.2a. One difference between Experiments 2.1a and 2.2a and the other experiments is that participants held a cue in WM in Experiments 2.1a and 2.2a. This suggests that holding a prime in memory may weaken the global advantage.

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[2] These data from Experiment 2.2 also help to counter one alternative account of the results from Experiment 2.1. The alternative account of Experiment 2.1 suggests that the contrast between the WM and priming conditions (in Experiments 2.1a and 2.1b) was due to slower RTs in the neutral baseline in the priming conditions (though a 2 × 2 ANOVA directly contrasting the two neutral conditions in Experiments 2.1a and 2.1b failed to reveal any differences, $F(1,48) = 2.65$, $p = .11$), not to a difference between WM and priming. However, Experiment 2.2 showed a similar contrast between costs from invalid cues in WM and benefits from priming (e.g., with incongruent stimuli), but in this case baseline (neutral) RTs were faster in the priming rather than the WM condition. This is the opposite pattern in the baseline to that in Experiment 2.1. We conclude is that non-significant shifts in the baselines were not critical here.

Experiment 2.3:
Testing a Memory Refresh Account

In Experiments 2.1 and 2.2 we provided evidence for the effects of WM differing from those of perceptual priming on the identification of hierarchical forms. The data suggest that top-down cueing of attention from WM operates differently from bottom-up perceptual priming. However, as we have noted, an alternative account of the WM results is that participants deliberately attend to matching information in the hierarchical letter, and this influences their responses to the hierarchical target. This memory refresh account was tested in Experiment 2.3. In this experiment, participants were asked to remember the size of an initial stimulus, rather than its identity. Memory-test events always maintained the same letter identity, and this letter was either the same size or a different size to the initial cue. Under these conditions, there is no incentive to attend to the identity of the cue in the hierarchical stimulus (refreshing memory for the identity would not help participants decide whether the letter was the same or a different size). We ask whether responses to the hierarchical target letter are still affected by re-presenting the identity of the WM stimulus in the target display. Soto and Humphreys (2008) found that responses to a target display could be affected by irrelevant as well as relevant properties of a stimulus held in WM. We test whether task-irrelevant identity information from the WM cue affected responses based on a matching identity in the hierarchical stimulus.

Method

Participants 30 students and staff (aged between 19 and 27) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal vision.

Apparatus and Stimuli The same apparatus was used as for Experiments 2.1 and 2.2.

Task and Procedure Figure 2.17 illustrates the experimental conditions and the sequence used in the present study**.** Each trial started with a block English alphabetical letter A, N, or D, all of which were presented in equal frequency in two different sizes: the letter was either the size of the global level of the compound stimulus, or the size of the letter representing the local level. There were 6 experimental conditions: 3 validity (of identity) conditions × 2 size match conditions. The validity conditions were as follows: Valid, when the identity of the memory cue matched that of the target item; Invalid, when the identity of the memory cue was different from the target and represented the stimulus at the other non-target level; and Neutral, when the identity of the memory cue was different from the target and was not present at either of the levels. Each of these validity condition had 2 size match conditions, in which the size of the memory cue was either same as or different to the size of the target letter as represented at the level it is shown. The target was always the letter ‘D’, matching the divided attention condition used in Experiment 2.1. Participants were instructed to remember the size of the memory cue and then to look for the target letter in the compound stimulus without regard to the level it was shown at. On memory probe trials the participants were asked to decide whether the size of the item presented for probe was the same as or different to the size of the item they had held in their memory. The identity of the memory probe item was kept constant on memory test trials, in order to discourage participants from memorizing the identity of the cue. There were 4 blocks of 120 trials, half of which were target-absent. For each block there were 10 trials for each condition.

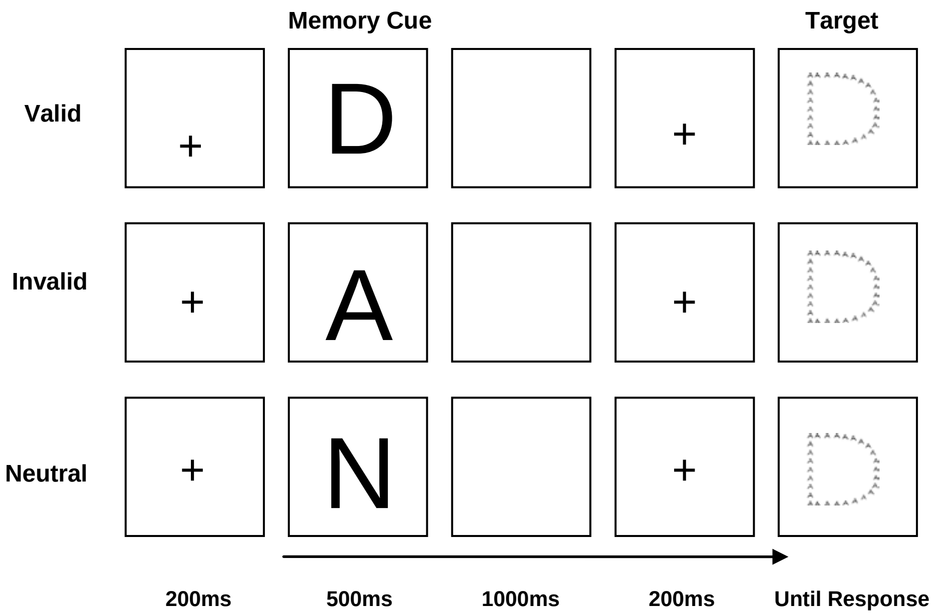


Figure 2.17. Examples of valid, invalid and neutral conditions in Experiment 2.3. In these examples the size of memory cues matched the global level of the hierarchical stimulus.

Results

1) Target-present data

The error rate for the local-global task was 4.6%, and 2.5% for the memory test (see Table 2.7 for overall data summary). There was no evidence of a speed-accuracy trade-off and the accuracy data were not analyzed further. A 2 × 2 × 3 ANOVA was carried out on the mean RT data, with the factors of Cue size (global- or local-letter size), Target level (global or local), and Validity (valid, invalid, and neutral, based on the identity of the cue). The results are shown in Figure 2.18. There was a main effect of target level ($F(1,29) = 9.5$, $p = .004$) but no effects of cue size ($F(1,29) = 1.02$, $p = .32$) or validity ($F(2,58) = 2.0$, $p = .15$). Two-way and three-way interactions were all non-significant.

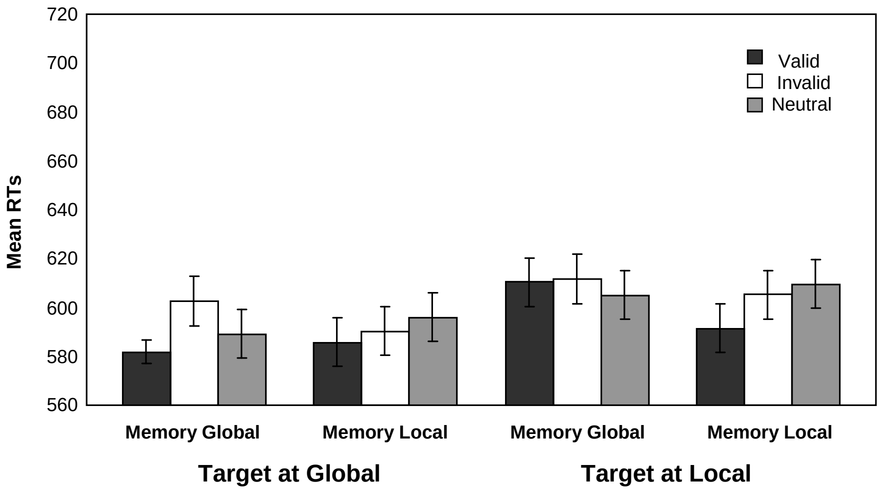


Figure 2.18. Effects of cue size and identity on the detection of targets in the hierarchical stimulus.

Table 2.7. Error data for target-present trials in Experiment 2.3.

Target Level	Memory of Size	Validity	Search Errors (%)	Memory Errors (%)
Global	Global	Valid	0	0
		Invalid	0.2	0.2
		Neutral	0.2	0.1
	Local	Valid	0.5	0.2
		Invalid	0.4	0.3
		Neutral	0.6	0.3
Local	Global	Valid	0.5	0.2
		Invalid	0.4	0.2
		Neutral	0.6	0.2
	Local	Valid	0.3	0.3
		Invalid	0.6	0.3
		Neutral	0.3	0.2

2) Target-absent data

Again, there was no indication of speed-accuracy trade-off. The error rates for the task and memory probe were 2.2% and 1.7%, respectively (See Table 2.8 for the data summary). The data from target-absent trials were sorted into 6 conditions. There were two conditions of cue size (global-letter or local-letter), each of which had 3 cue-target validity conditions (valid with the identity of the memory cue matching the target letter at the global level; valid with the identity of the cue matching the letter at the local level; and neutral with the identity of the memory cue not matching either letter of the two levels). The data were analyzed by a 2 × 3 ANOVA, with as factors size of the cue (global and local sizes) and three levels of validity (valid global, valid local, and neutral). The results are shown in Figure 2.19. There was a strong main effect of cue-target validity ($F(2,58) = 28.4$, $p < .0001$) but no effect of cue size ($F(1,29) = 2.57$, $p = .12$). Cue size and cue-target validity did not interact ($F(2,58) = 2.0$, $p = .14$). Averaged across the two cue sizes, there were reliable differences between the valid global and neutral trials ($t(29) = 5.7$, $p < .0001$), and between the valid local and neutral trials ($t(29) = 6.3$, $p < .0001$). The valid global and valid local trials did not differ ($t(29) = .06$, $p = .95$).

Table 2.8. Error data for target-absent trials in Experiment 2.3.

Memory of Size	Validity	Search Errors (%)	Memory Errors (%)
Global	Valid(G)	0.1	0.1
	Valid(L)	0.2	0.3
	Neutral	0.4	0.2
Local	Valid(G)	0.3	0.3
	Valid(L)	0.4	0.5
	Neutral	0.8	0.3

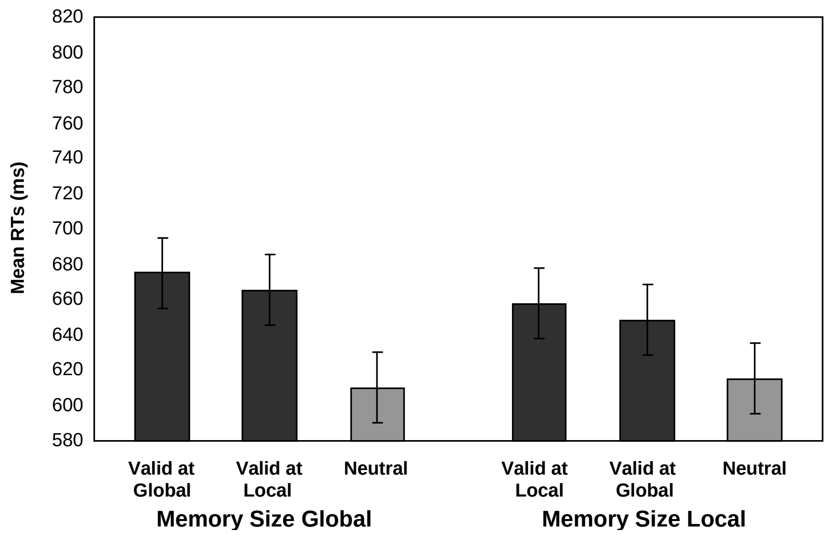


Figure 2.19. Target-absent data in Experiment 2.3: Effects of the size and identity of the memory cue.

Discussion

The data indicate that there were effects of the identity but not the size of the stimulus held in WM. As in Experiment 2.1a here, there was a cost on absent trials when the identity of the cue matched one of the letters in the hierarchical stimulus. This result is consistent with an identity match cueing attention to the congruent level of the hierarchical stimulus, making it difficult to respond that the target is absent. The result suggests that, as in Soto and Humphreys (2008), there can be effects from irrelevant as well as relevant properties of stimuli held in WM. Indeed, there were no effects of the WM cue matching the size of one level of the hierarchical stimulus, either because size information does not cue attention or because the size differences assessed on memory test trials were sufficiently large to allow size only to memorized coarsely. Irrespective of this, the important result is that participants should have voluntarily attended to the size of stimuli in the hierarchical letter, not the identity, if attention was allocated in order to boost WM. Note that the identity of the cue remained the same on memory match and mis-match trials, so refreshing the identity of the memory cue would not benefit memory performance. Despite this, there was an effect of the identity of the cue. This goes against a memory re-fresh account of the WM effects.

General Discussion

We have reported the first-ever study on the effects of irrelevant information in WM on the selection of hierarchical forms. Several critical results were established:

1) A cue held in WM strongly affected selection of hierarchical forms in a distributed attention task, when participants searched for a target that could appear at either level of the hierarchical letter (Experiments 2.1a and 2.1c). Relative to when the cue did not appear in the hierarchical letter (the neutral baseline), RTs were facilitated when the cue was valid and disrupted when the cue was invalid.
2) The WM cue had its strongest effect when it matched the global level of the hierarchical letters (positive effects of valid cueing were larger, as were costs from invalid cueing: Experiment 2.1a);
3) The costs from invalid cueing occurred even when the WM cue was never valid, indicating that the effects arose automatically (Experiment 2.1c); and the effect also arose when participants could adopt a focused mode of attention (Experiment 2.2a).
4) In contrast to the effects when the cue was held in WM, there were only benefits to performance when the cue was merely identified and it re-appeared within the hierarchical letter (Experiments 2.1b and 2.2b). This occurred not only when the cue matched the target (on valid trials) but also when the cue

matched the distractor letter (on invalid trials in Experiment 2.1b, and on trials with invalid & invalid response stimuli in Experiment 2.2b). There are opposite effects on performance from priming and from holding an item in WM.

5) The WM effects were confirmed under conditions in which it was not beneficial for participants to attend to information re-appearing in the hierarchical stimulus, contrary to a memory refresh account of the data (Experiment 2.3).

Prior studies have shown that a cue held in WM can automatically affect the guidance of spatial attention to a search display (Downing, 2000; Soto et al., 2005 & 2006; Olivers et al., 2006; Soto & Humphreys, 2007). In these studies, the search target has often been more local than the WM item, when the memory item re-appeared in the search display (e.g., a target appearing within a shape that is also held in WM). The present results indicate that this may be an important factor, since we found that WM based guidance of attention was strongly tied to selection at a global level. The present results go beyond previous studies of WM effects, then, by indicating that there is not only spatial guidance of selection (cf. Soto et al., 2005) but also guidance to select visual stimuli at different levels of hierarchical representation, even when stimuli fall at the same location (e.g., local elements falling within a global form). This guidance of attention from WM is stronger to global levels of form.

The present results showed costs to selection when the WM cue matched a distractor at the non-target level. One account of these costs is that attention is directed by an invalid cue to the wrong level of the hierarchical form, and this slows selection of the target at the other level. An alternative proposal is that the WM cue is suppressed, and this slows processing of the hierarchical target when the cue is represented in that stimulus. However, it is difficult to see why this suppression process would not affect valid as well as invalid trials, yet performance was facilitated on valid trials. This proposal also does not fit with the existing neuro-imaging data on WM effects on attention, where the WM condition increases activation for re-presented stimuli and suppression is only shown under priming conditions (Soto et al., 2007). As we discuss below, these imaging data do fit with our results in the identification conditions (Experiments 2.1b and 2.2b). We conclude that the costs on invalid trials were due to the WM cue directing attention to the wrong level of the stimulus, slowing target detection at the other level.

Distributed attention vs. a wide attentional window As noted in the Introduction, Hernández et al. (in press) have reported that effects of the WM cue were strong when participants adopted a wide attentional window (see also Belopolsky, Zwaan, Theeuwes & Kramer, 2007, for similar effects with bottom-up cueing of attention). In contrast to this the magnitude of the validity effect in the current study was the same under distributed and focused attention conditions (Experiments 2.1a and 2.2a). In Experiment 2.2 here participants could pre-select a particular spatial frequency to attend to, but cueing effects remained. This result fits with the idea that both high and low spatial frequency components of a display are extracted in parallel, and so either can be cued from WM even if participants are trying to focus attention at one level. Selective attention may influence the ‘read out’ of particular spatial frequencies, but not the coding of different frequencies in the first place. In addition, we propose that focusing on a target spatial frequency is not the same as adopting a broad attentional window, and we assume that a broad attentional window is adopted here with focused as well as distributed attention (e.g., when a global item has to be selected). When a broad attentional window is adopted the cue affects performance alike for focused as well as distributed attention conditions.

Bottom-up perceptual priming The data in the priming condition provide a striking contrast to those found under WM condition. When the cue was held in memory there were effects on attentional guidance. When the prime was merely identified, then effects on attentional guidance were minimized (e.g., there was no cost on invalid trials), but effects reflected enhanced perceptual processing when cues were repeated at both target and non-target levels. RTs were then facilitated on invalid relative to neutral trials. These results are consistent with the data on attentional guidance using functional brain-imaging – in particular the evidence for repetition suppression when participants simply identified the cue and the cue was then re-presented in the search array (Soto et al., 2007). Neural repetition suppression may reflect facilitated perceptual processing of stimuli, with less information being required for stimulus recognition when the system is primed. Here priming of one of the letters making up the hierarchical form appears to facilitate processing of the whole form, even when the prime letter re-appeared at the non-target level (on invalid trials). However, when the cue is also held in WM, the neuro-imaging results indicate top-down enhancement of cued representations when the stimulus is re-presented in the search display (Soto et al., 2007). This enhanced activity, driven by the WM representation, guides attention to the re-presented stimulus. This will disrupt responses when the cue is invalid, since the non-target letter will be selected and costs to performance result. One other result to note is that this bottom-up priming effect held both when participants were in a distributed attention mode and when they had a focused attentional set (in Experiments 2.1b and 2.2b). This contrasts with the effects of valid cueing of attention from WM, which was weakened in a focused attention mode (in Experiment 2.2.a, compared with Experiment 2.1a). The effects of bottom-up priming may arise irrespective of the perceptual set of participants.

Conclusions We have shown that attention can be biased to a level of a hierarchical form when a stimulus in WM matches the identity of the letter at that level; this disrupts performance when WM cues attention to a distractor level. The effect is not due to participants attending to matching information in the hierarchical stimulus in order to refresh their memory for the cue's identity. In contrast to the WM effects, priming a letter identity facilitates the perceptual processing of a compound letter without cueing attention. In this case matches between a prime and a distractor level of the compound facilitate identification, irrespective of whether the prime is valid or invalid in relation to the target. While matches to WM cue attention, priming facilitates perceptual processing without necessarily biasing attention.

CHAPTER 3

Size Information in Working Memory and Attentional Selection in Hierarchical Forms

Synopsis

Participants held the size of a cue in working memory and looked for target letter at local and global levels in Navon compound stimuli. There was no effect of whether the cue size matched the size of the local or global letter, even when the size memory task was made difficult. The null effect of cue size was also found under priming conditions, when size had to be identified but not held in memory. Although cue size did not affect subsequent selection in these experiments, cue identity did; RTs were faster when the cue's identity matched the target and they were slowed when the cue's identity matched the identity of a distractor letter at one level of the hierarchical form. When the identity was explicitly coded and the size implicitly primed, again effects of cue identity emerged but now the effects of cue size also emerged, with differential effects of cue identity following large and small cues. These last results suggest that cue size was processed, although the size relations between cues and targets did not modulate performance. These results are discussed in terms of the effects of overlap between the contents of WM and the attentional set for targets, and the role of focused and distributed attention on selection. Critically, however, the data run counter to the idea that local and global stimuli are selected by opening an 'attentional window' of a particular size and matching this to the target letter.

Introduction

There is ample evidence that visual attention is modulated both by the bottom-up salience of stimuli and by top-down control process (Yantis & Jonides, 1990; Theeuwas, 1991; Folk & Remington, 1998; Beck & Kastner, 2005; Reynolds & Desimone, 2003; Carrasco, Ling, & Read, 2004). To explain the interaction between bottom-up and top-down factors, researchers have argued that attentional guidance is implemented through behaviourally-relevant representations in working memory (WM), which bias attentional resources to those aspects of the incoming stimuli that best match the information currently held in memory. (Desimone & Duncan, 1995; Duncan, 1998; Duncan & Humphreys, 1989). Interestingly, the top-down effects of stimuli in WM are not limited to representations of the target – there are studies showing that there can also be effects of the contents of WM even when they are irrelevant to the current task (Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005). In Downing's study (2000), participants held one stimulus (a face) in WM and then searched for another target in a second display. Prior to the search target, the face in WM and a new face were presented, and the target then fell at the same location as one of the stimuli. RTs were faster when the target appeared where WM cue fell (on valid trials), compared with when the target appeared where the novel face fell (on invalid trials). Similar results were reported by Soto et al. (2005), who showed that irrelevant items in WM influenced the fastest RTs, and the first saccades in search, and the effect occurred even when the WM cue was always irrelevant. Soto, Wriglesworth, Balani, & Humphreys (2010) further report that these irrelevant cues affect perceptual discriminability and not just response bias. These data suggest that stimuli in WM can capture attention in an automatic manner without voluntary control when they match the subsequent display. This subsequently influences perceptual processing of targets.

In the majority of studies (e.g., Downing, 2000; Soto et al., 2005) the effects of cueing from WM have been observed on spatial selection tasks, where a target falls at a different spatial location to that of the distracter. However, the effects can also occur in non-spatial selection tasks – e.g., with hierarchical letters, when a large letter cannot be spatially selected without also selecting the local elements (Kim & Humphreys, 2010). In their study of hierarchical selection, Kim and Humphreys had participants hold the identity of a letter in memory and then they had to detect a target in a following hierarchical letter. The identity of the letter in memory could match the target or it could match a distractor letter, at the opposite level of form to the target. Although selection of the global hierarchical letter could not operate without spatial selection of the local forms, Kim and Humphreys found that RTs to the hierarchical forms were affected by whether the letter in WM matched the target or a distracter. This result occurred even if the identity of the WM cue was always invalid but it was eliminated when the cue was merely identified but not held in memory – a condition included to test for effects of bottom-up priming, from identifying the cue letter. The data indicated that identity matching from WM can take place across both local and global letters to subsequently modulate selection of the letter at one level.

Now, one way that stimuli in a hierarchical letter might be selected is by fitting an attentional window/filter that is at the appropriate size and/or resolution for the target that needs to be selected (Deco & Heinke, 2007). Evidence for spatial selection by fitting an attentional window comes from studies on object recognition, where size congruency between consecutive stimuli can modulate performance, even when it is irrelevant for the task (Jolicoeur, 1987; Ellis, Allport, Humphreys, & Collis, 1989; Larsen, 1985). Similarly in studies of hierarchical letter perception it has been shown that responses across consecutive trials are faster if selection is made from the same level of form (Ward, 1982), consistent with an attentional window being maintained from one trial to the next. In this study, we examined if an attentional window could be cued by holding a specific size representation in WM. A positive finding here would also extend prior results on cueing attention from WM to include size as well as colour, shape, and identity (Downing, 2000; Kim & Humphreys, 2010; Soto et al., 2005). Such a result would also support the idea that different levels of a hierarchical stimulus are selected by fitting an attentional window to the size of the to-be-selected element.

Experiment 3.1 examined effects of cueing size alone. Experiment 3.2 had participants remember the size of a cue but tested whether letter identity could be coded and influence selection even when it was not relevant to the memory task. This was assessed by varying whether the identity of the WM stimulus matched the local or global level of the hierarchical target. If irrelevant features of WM item are automatically coded and influence target selection (Soto & Humphreys, 2009), we should see the identity of the memory item affecting hierarchical target perception here. In Experiment 3.3 we tested if the same effects could arise from bottom-up priming with mere presentation of the cue. Participants had to identify the size of the cue but not hold it in memory. Whether or not the data match those in WM condition (Experiment 3.1 and 3.2) will provide critical evidence concerning possible bottom-up priming of size. Finally, Experiment 3.4 explored a reverse design relative to Experiment 3.2, where participants remembered the size with the identity as a task-irrelevant feature. When size was coded implicitly would it influence subsequent selection? We note that, in studies on object recognition and on responses to consecutive hierarchical forms, size consistency has typically been manipulated implicitly (Jolicoeur, 1987; Ward, 1982); it may be that implicit coding of size may be more effective than cueing directly from WM.

Experiment 3.1: Working Memory of Size and Hierarchical Perception

Method

Participants 29 students and staff (aged 19-36) at the School of Psychology of the University of Birmingham participated for course credit or cash. All reported having normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The experiment was run on a Samsung 920N colour monitor (resolution: 1280 × 1024 pixels), using E-Prime (version 2.0; PST 2002). Adobe Flash (version CS3 Professional) was adopted to produce all stimuli employed in the experiments of the current study. English alphabet letters D, U, and X were used to construct compound stimuli, with the global dimension subtending 8.5° × 7.3°, and the local 0.49° × 0.41°. Two other letters A and N were used as the memory cue, both presented as regular block letters (in Arial font) in two different sizes, made to be the same dimensions as the global and local letters in the compound stimuli. The graphic illustrations of the stimuli are given in Figure 3.1. All the stimuli were presented in the centre of the screen. Two keys (left and right arrows) on the computer keyboard were used for the responses.

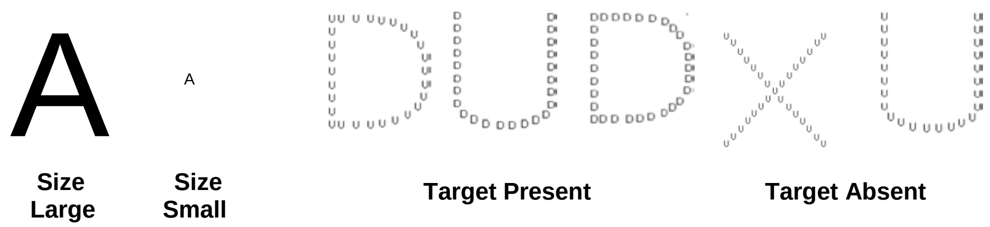


Figure 3.1. Examples of stimuli: On the left are examples of memory cue in global and local sizes; On the right are target displays when the search target is 'D'. All letters were in black displayed against white background.

Task and Procedure Figure 3.2 shows the experimental conditions and the presentation sequence used in the current study. The memory cues were either the letter A or N, in two different possible sizes: One size was equal to that of the letter shown at the global level in the search display; and the other was equal to that of the letter shown at the local level in the search display. Each block had trials in 2 conditions: Valid, when the size of the memory cue matched that of the target letter (at the global or local level); and Invalid, when the size of the memory cue did not match that of the target letter. Each trial began with a fixation cross shown for 200 ms, followed by a block letter (the memory cue) that was presented for 500 ms. Participants had to remember the size of this block letter, disregarding its identity. After a delay of 1000 ms and a fixation of 200 ms, the task was to look for the target letter 'D' in compound letter, irrespective of the level it was represented at.

Participants were asked to ignore the identity of the memory cue, focusing only on its size. Memory probe questions on the to-be-remembered sizes occurred randomly at the end of a trial, with a frequency of 25 trials out of 120 per block. The memory probe asked participants to decide if the block letter was of the same or different size to the letter held in memory. To ensure that the identity of the letter was irrelevant, and only the size was to be remembered, the identity of the letter shown in probe displays was kept the same as that of the memory cue shown in the current trial. Participants had a practice session of 16 trials at the beginning of the experiment. Each participant completed 4 blocks of 120 trials. Half of the trials were target-absent. For each block there were 12 trials for each condition, and 10 trials with a congruent hierarchical stimulus (where the target letter D was present at both levels). Participants were warned about the memory test before the start of the experiment. Instructions emphasised both accuracy and response speed for both the hierarchical letter and the memory task.

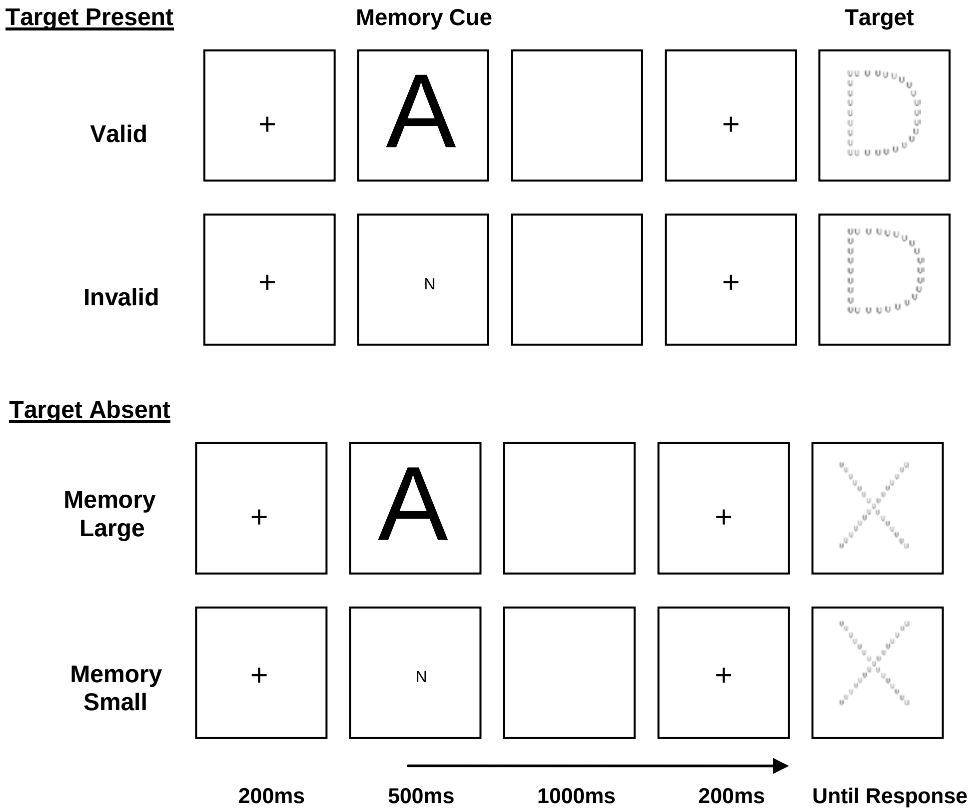


Figure 3.2. Sequence of displays on trials in an example: Top two rows show when the target was present (at the global level); Bottom two rows show when the target was absent.

Results

Data analyses were carried out on target-present and target-absent data separately, as each set of data had different conditions.

1) Target-present data

In all experiments, only RTs for correct responses in the global-local task were used. However trials with incorrect responses to memory probe questions were included to secure the largest possible amount of data. The error rates for both letter detection and memory probe performance were very low at 2.2 % and 1.5% on average, respectively (see Table 3.1 for the overall data summary). There was no indication of a speed-accuracy trade-off and the accuracy data were not analysed further. A 2 × 2 ANOVA was carried out on the mean RT data, with two factors: Target level (global and local) and Size validity (valid, when the size of the cue and that of the target were the same, and invalid, when the size of the cue and that of the target were different). The results are given in Figure 3.3. There was an effect of Target level ($F(1,28) = 4.2$, $p = .049$), but an effect of Size validity was not found ($F(1,28) = 1.74$, $p = .20$). There was no Target level × Size validity interaction ($F(1,28) = 1.25$, $p = .73$). RTs were faster to global than to local targets.

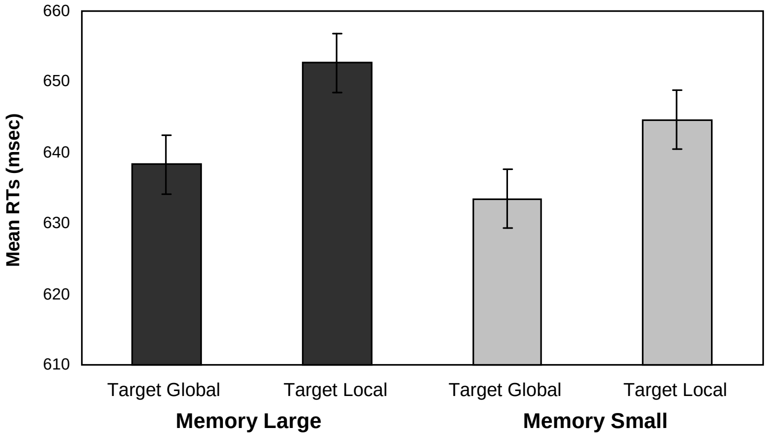


Figure 3.3. Experiment 3.1: Effect of memory of size on target perception at different levels. The error bars represent standard errors (this applies to all figures in the present paper).

Table 3.1. Error data for target-present trials in Experiment 3.1.

Level	Validity	Search Errors (%)	Memory Errors (%)
Global	Valid	0.4	0.3
	Invalid	0.5	0.4
Local	Valid	0.5	0.4
	Invalid	0.8	0.4

2) Target-absent data

The mean RTs on target-absent trials are shown in Figure 3.4. The error rates for target detection and memory probe recognition were very low at 1.5% and 0.7% on average (see Table 2 for data summary). There was no evidence of a speed-accuracy trade-off, and the accuracy data were not analysed further. The trials had 2 conditions: One where the memory cue matched the global-letter size, and the other where the cue matched the local-letter size. A *t*-test showed there was no significant difference in performance based on the cue sizes ($t(28) = -1.8$, $p = .09$).

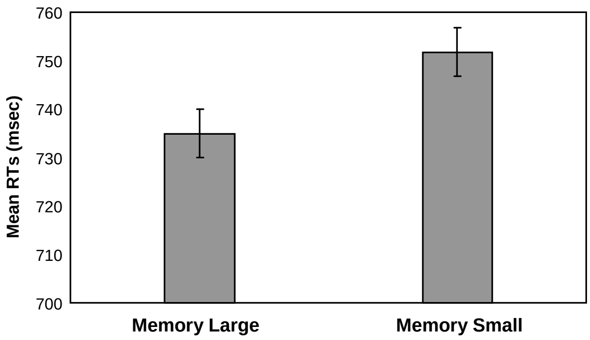


Figure 3.4. Experiment 3.1: Target-absent data. Effect of memory of different sizes.

Table 3.2. Error data for target-absent trials in Experiment 3.1.

Memory	Search Errors (%)	Memory Errors(%)
Large	0.4	0.3
Small	1.1	0.4

Discussion

There was no effect of size validity on either target-present or target-absent trials. The results suggest that holding the size of a cue in WM does not affect whether attention is allocated to a level where the stimulus matches the size of the cue.

Studies of object and hierarchical letter recognition have shown that RTs to match objects vary as a function of their size (Jolicoeur, 1987; Ward, 1982) and that size-dependent matching operates automatically during recognition (see also Ellis et al., 1989; Larsen, 1985; Kosslyn, 1987 for converging evidence). These previous studies suggest that priming the size of a stimulus might render an advantage in perceiving a target matching in size. There was no evidence for this, even though the size of the critical cue had to be explicitly maintained in WM. This null effect might arise for several reasons. One is that, contrary to Larsen & Bundesen (1978), size is not automatically extracted from the target stimulus here (i.e., the hierarchical letter), even though participants had to identify either the local or global level of such stimuli, which could be defined by size. For example, rather than targets in the hierarchical forms being defined by size, they may be defined on the basis of their identities irrespective of their relative size and position in the hierarchy. It this is the case, then it may not be critical to have consistency of size between WM and the target, as the target is not selected based on its size. According to this view, what is critical is that the effects of WM depend on there being some overlap between the information in WM and the information used to select the target (e.g., the information that may be coded in the attentional set for the target). This possibility is taken up further in the General Discussion. It is also possible that the different cue sizes used here were too easily distinguishable for size information to be strongly represented in WM, which made it conducive for the participants to code size verbally rather than visually. This last possibility was examined in more detail in Experiment 3.2 where we required participants to discriminate between four possible sizes of memory cue. This stronger test of exact memory for size may lead to size information being strongly weighted and more robust effects may then emerge on subsequent target selection.

In addition to examining effects of size information, Experiment 3.2 evaluated the effects of repeating the identity of the WM cue. Following Kim & Humphreys (2010) we presented a memory cue that could sometimes have the same identity as a letter at the level of the subsequent global stimulus. As in Experiment 3.1, participants had to hold the size of the letter in WM so that, in this case, letter identity was irrelevant to memory performance. Soto & Humphreys (2009) showed that there can be attentional guidance from an irrelevant feature of an item held in WM. In their study a coloured shape was presented as a memory cue and participants were only to remember the shape, ignoring the colour. Soto & Humphreys still found evidence of attentional capture from the colour feature: even though colour was not relevant to the memory task the participants' subsequent search performance was affected by a colour match between WM cue and the search array. Here we examined whether letter identity could still influence subsequent selection in a hierarchical display even when it was irrelevant. This would provide evidence for the coding of identity in WM even when it is not employed for the memory task.

Experiment 3.2: Size and Identity in Working Memory

Method

Unless otherwise mentioned the Method was the same as for Experiment 3.1.

Participants 25 students (aged between 19 and 28) at the School of Psychology of the University of Birmingham participated for course credit. All had normal or corrected-to-normal vision.

Task and Procedure Participants were instructed to remember the size of the first block letter given as the memory cue and to look for the target letter 'D' in the subsequent compound stimulus. The letters used for the memory item were A, N, and D. In addition to the two sizes used previously (equal to the size of the letter at the global and local level), two new intermediate sizes were included (see Figure 3.5 for illustration). The intermediate sizes were respectively 30% smaller than the global and larger than the local levels. These intermediate memory cues represented 25 % of the total number of trials.

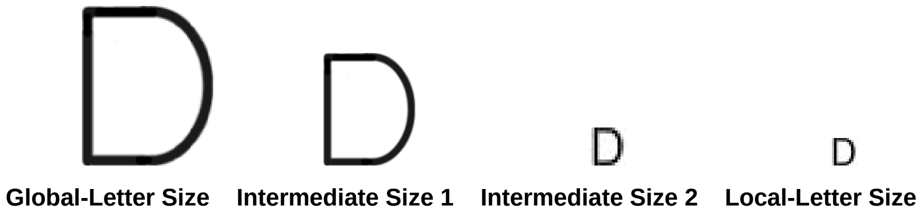


Figure 3.5. Examples of memory cue sizes employed in Experiment 3.2. There were 4 different sizes: Global-letter size, local-letter size, and two intermediate sizes.

There were 3 blocks of 180 trials before which the participants completed 30 practice trials. Participants were instructed to remember the size of the memory cue, whilst ignoring the identity of the cue. On memory match trials, the probe stimulus always had the same identity as the WM cue, so that it was not beneficial for participants to remember the cue's identity. The size of the probe matched that of the cue on half the trials and it differed on the remaining trials. In addition to this, the cue could have one of 3 identities. On valid identity trials it was a letter D (the target). On neutral identity trials it was a letter that did not subsequently appear in the hierarchical display. On invalid identity trials when the target was present, the cue's identity matched the non-target level in the hierarchical stimulus. When the target was absent, the cue matched the identity of one of the levels in the hierarchical letter on two thirds of the trials (half local match, half global match). The letters in the hierarchical stimulus were A and N.

Results

The trials with an intermediate-sized memory cue were extracted and the analyses were conducted on the remaining data. One of the participants performed poorly on the memory task (average error rate of 29 %), and her data were eliminated. The analyses were carried out on the remaining 24 participants. As discussed below, memory performance was worse in the current experiment than it was in Experiment 3.1 (this was confirmed by one-way ANOVAs on the error rates averaged over all conditions, $F(1,51) = 15.1$, $p < .0001$ and $F(1,51) = 25.9$, $p < .0001$ for target-present and for target-absent trials, respectively).

1) Target-present data

The error rates for the global-local task and memory test were 2.9% and 5.6% (see Table 3.3 for overall data summary). There was no evidence of speed-accuracy trade-off, and we did not analyse the accuracy data further. A 2 × 2 × 3 ANOVA was carried out on the mean RT data, with the factors being Cue size (large and small), Target level (global and local), and Identity validity (valid, invalid, and neutral). The results are shown in Figure 3.6. There was a main effect of Target level ($F(1,23) = 5.4$, $p = .03$) but no effects of Cue size ($F(1,23) = 2.6$, $p = .12$) or Identity validity ($F(2,46) = 1.7$, $p = .2$). There were no interactions (all $F<1.0$).

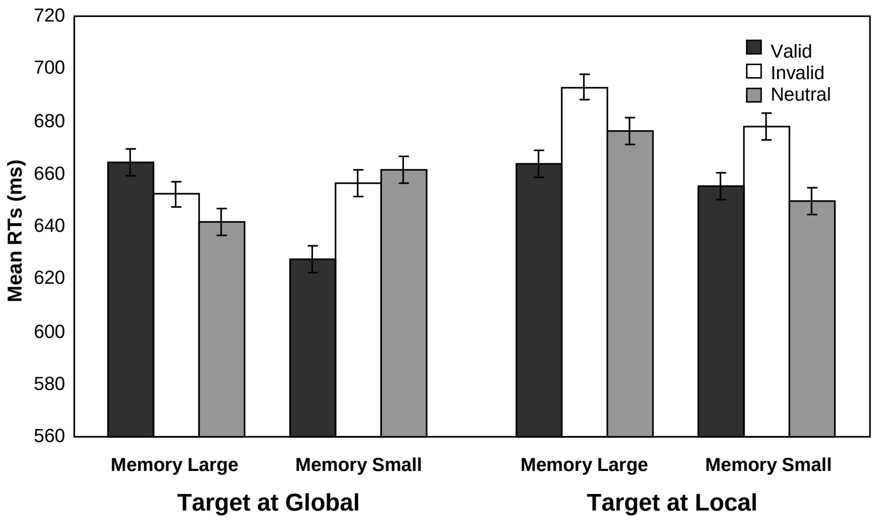


Figure 3.6. Experiment 3.2: The mean RTs (ms) to global and local targets as a function of the size of the memory cue and the validity relation between the cue's identity and the target.

Table 3.3. Error data for target-present trials in Experiment 3.2.

Target Level	Memory	Validity	Search Errors (%)	Memory Errors (%)
Global	Large	Valid	0.2	0.5
		Invalid	0.3	0.6
		Neutral	0.2	0.4
	Small	Valid	0	0.5
		Invalid	0.4	0.5
		Neutral	0.4	0.7
Local	Large	Valid	0.1	0.2
		Invalid	0.2	0.4
		Neutral	0.4	0.4
	Small	Valid	0.3	0.5
		Invalid	0.3	0.6
		Neutral	0.1	0.3

2) Target-absent data

There was no evidence of a speed-accuracy trade-off. Error rates for target detection and memory probe were 2.0% and 3.7%, respectively (see Table 3.4). The RT data from target-absent trials were analysed (see Figure 3.7 for overall data) by carrying out a two-way ANOVA with the factors Cue size and Identity validity (Invalid with the identity of the memory cue matching the letter at the global level; Invalid with the identity of the cue matching the letter at the local level; and Neutral, where the memory cue did not match either letter of the two levels of the hierarchical stimulus). There was a main effect of Identity validity ($F(2,46) = 17.5$, $p < .0001$), but no effect of Cue size ($F(1,23) = 2.2$, $p = .15$). Identity validity and Cue size did not interact ($F(2,46) = 2.0$, $p = .15$).

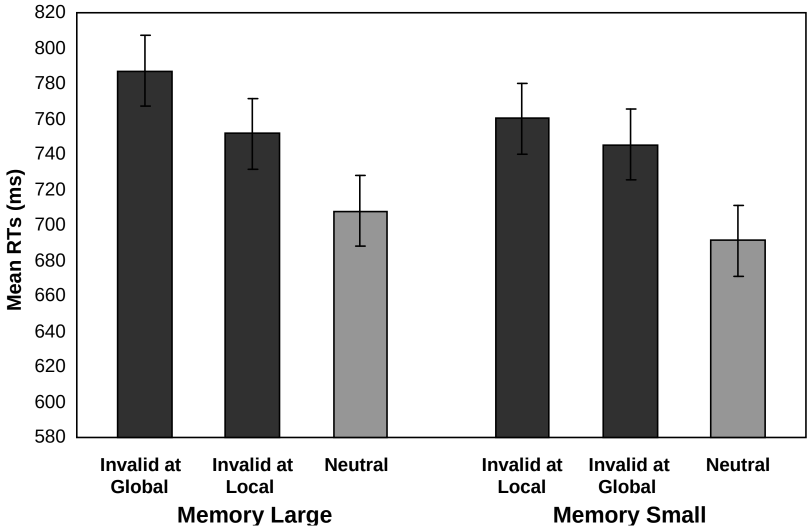


Figure 3.7. Experiment 3.2: Target-absent data. Mean RTs (ms) as a function of the size of the memory cue and the relation between cue identity and the target.

Averaged across the two cue sizes, there were reliable differences between the Invalid global and Neutral trials (t(23) = 6.7, *p* <.0001), and between the Invalid local and Neutral trials (t(23) = 4.3, *p* <.0001). The Invalid global and Invalid local trials did not differ (t(23) = .77, *p* =.45).

Table 3.4. Error data for target-absent trials in Experiment 3.2.

Memory	Validity	Search Errors (%)	Memory Errors (%)
Large	Invalid(G)	0.4	0.6
	Invalid(L)	0.2	0.7
	Neutral	0.3	0.7
Small	Invalid(G)	0.5	0.5
	Invalid(L)	0.3	0.6
	Neutral	0.3	0.6

Discussion

In this experiment we strengthened the requirement to hold the cue's size in memory by introducing additional size differences amongst the cues. Memory performance decreased here relative to Experiment 3.1, consistent with participants finding it more difficult to discriminate the size of the cue. Despite this, we still did not observe an effect of size on the selection of the hierarchical letter. Taken with the data from Experiment 3.1, the results indicate that memory representations of stimulus size do not guide visual attention towards a particular level of a hierarchical stimulus, when the size held in memory matches the dimensional feature of the global or the local level letter.

In contrast to the null effect of size, there was evidence that the identity of the WM cue did guide selective attention. There was a reliable effect of validity (of identity) on target-absent trials, with absent RTs being slowed when the identity of the cue matched the letter at one level of the hierarchical form. On target present trials there was a trend for RTs to local targets to be slowed by invalid cueing to the global level, but this was not reliable. We should note though that effects of WM cues are typically larger on absent than on present trials, because the cueing effects on present trials have to compete against the presence of the target, whereas on absent trials the target-based competition is removed. The effect on target absent trials can be conceptualised in at least two ways (see Kim & Humphreys, 2010). On one account the match of the identity of the cue to one level of the hierarchical stimulus biases attention to that level. Absent RTs are then slowed either because cueing to the letter biases a present response or because it delays the time to disengage attention to enable the other letter to be identified (and formulation of an absent response). A second possibility is that the identity of the cue in WM is inhibited and this then slows absent responses since there is delayed processing of one of the letter in the hierarchical stimulus. This last proposal seems unlikely though, in the context of other results. For example, when the identity of the cue was repeated in the hierarchical stimulus but the cue was not held in memory (a priming baseline) there can be facilitated rather than slowed responding to a target in a hierarchical form. Kim and Humphreys (2010) attributed this facilitation effect to activation of the cue's identity boosting perceptual processing of a matching letter. This perceptual effect was distinct from the effects of the cue on attentional bias, when a matching cue is held in WM. It is difficult to see why there should be perceptual priming when the cue is merely identified (in Kim & Humphreys, 2010) but then suppression of the cue when it is held in WM, as here. Consequently we favour the argument that the cue biases attention than the argument that the cue is inhibited. If an account in terms of cueing attention is adopted, then the present data indicate that there can be an effect on attentional bias from an implicit attribute (letter identity), even when another attribute must be explicitly represented (letter size). This replicates the findings of Soto & Humphreys (2009), who found effects of attentional bias from matching colour when participants had to remember the shape of a cue. The effects of letter identity in WM here were not apparent on responses to a global target, unlike Kim and Humphreys (2010), but this is perhaps not surprising given that Kim and Humphreys tested conditions when the cue's identity was explicitly held in WM and we assessed the effects of implicit coding of cue identity. Effects from implicitly coding may well be weaker.

One other aspect of Experiment 3.2 should be noted, too: the data go against an account of cueing based on participants consciously attending to the cued attribute in the search display in order to refresh their memory (see Woodman & Luck, 2007).

In Experiment 3.2, participants had to remember the cue's size and, on memory probe trials, the stimulus had the same identity irrespective of whether it was same as or different from the cue. Here there would be a disincentive to top-up their memory by attending to a level of the hierarchical letter matching the cue, since this would not aid their memory response. Instead of there being a memory top-up effect, the data are more consistent with the cue's identity biasing attention even when it was irrelevant to memory.

Given that Kim & Humphreys (2010) reported rather different results when participants merely identified the cue and when they had to hold it in memory, Experiment 3.3 tested whether there were effects of cue size under priming (mere identification) conditions, even when no effects occurred when size was held in WM. It is possible that strong facilitative perceptual priming could counteract effects of cueing attention to size, at least when invalid, so that priming and cueing effects cancel one another out. Effects of priming alone were examined here. Do effects of cue size then emerge? In addition to assessing the effects of priming based on the size of the cue, Experiment 3.3 also included conditions in which the identity of the cue matched the identity of one of the letters in the hierarchical stimulus. Kim and Humphreys found evidence for perceptual facilitation rather than evidence for attentional capture under priming conditions when they assessed the cue's identity had to be processed implicitly. In Experiment 3.3 we examined identity-based priming when identity was irrelevant to the initial judgement made to the cue (which was based on cue size).

Experiment 3.3: Bottom-up Priming of Size

Experiment 3.3 examined a perceptual priming condition in which cue size had to be identified but not held in memory. As in Experiment 3.2, the size and the identity of the cue could match one level of the hierarchical letter.

Method

Participants 24 students and staff (age range: 19-35) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli All stimuli (block letters and compound letters) had the same properties as the ones specified in Experiment 3.3. For the current experiment three letters D, U, and X were used to construct the compound stimuli.

Task and Procedure The memory cues again had four different sizes as used in Experiment 3.2 (illustrated in Figure 3.8) were employed again. The cue identities were also the same: A, N, and D, so that the cue could sometimes match the identity as well as the size of one of the hierarchical letters. The difference relative to Experiment 3.2 was that here participants performed a 'go / no-go' response to the cue but they did not have to commit it to memory: When the memory cue was large or small participants were instructed to look for the target letter 'D' in a subsequent compound letter. In contrast, presentation of a cue in other two sizes (intermediate 1 and 2) meant 'no-go' for the target detection task. On those trials, participants did not respond. The intermediate sizes were shown on 33% of total number of trials. There were 30 practice trials and 4 experimental blocks of 160 trials.

Results

1) Target-present data

The error rate was 3.6% for target detection. The overall error data are summarized in Table 3.5. No evidence of speed-accuracy trade-off was found and the accuracy data were not analysed further. The mean RTs on target-present trials are shown in Figure 3.8. A 2 × 2 × 3 ANOVA was conducted on the correct RT data with the factors Cue size (large and small), Target level (global and local), and Identity validity (valid, invalid and neutral). There were no main effects that reached significance: Cue size ($F(1,23) = 2.1$, $p = .16$); Target level ($F(1,23) = .001$, $p = .98$); or Identity validity ($F(2,46) = 1.2$, $p = .31$). None of the interactions were reliable (all $F < .1$).

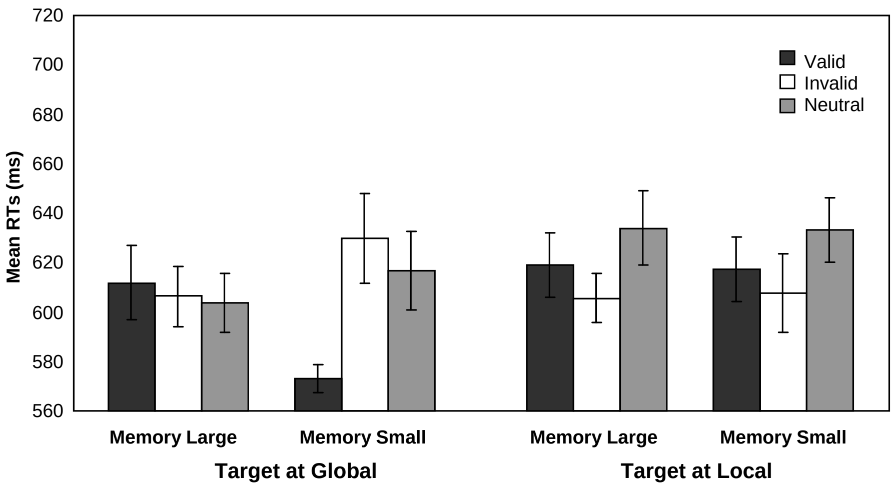


Figure 3.8. Experiment 3.3: Effect of size priming on target detection at different levels of the hierarchical stimuli.

Table 3.5. Error data for target-present trials in Experiment 3.3.

Target Level	Memory	Validity	Search Errors (%)
Global	Large	Valid	0.3
		Invalid	0.4
		Neutral	0.3
	Small	Valid	0.2
		Invalid	0.3
		Neutral	0.4
Local	Large	Valid	0.3
		Invalid	0.2
		Neutral	0.5
	Small	Valid	0.1
		Invalid	0.3
		Neutral	0.3

2) Target-absent data

The overall error data are summarized in Table 3.6. A one-way ANOVA was carried out on the data sorted according to cue size and 3 validity conditions: Invalid with the identity of the memory cue matching the letter at the global level; Invalid with the identity of the cue matching the letter at the local level; and Neutral with the memory cue not matching either letter of the two levels (see Figure 3.9). No main effect of Target level was found ($F(1,23) = 1.6$, $p = .23$). The effect of Identity validity also did not approach significance ($F(2,46) = 1.9$, $p = .16$). The Target level × Identity validity interaction was not significant ($F(2,46) = .7$, $p = .5$).

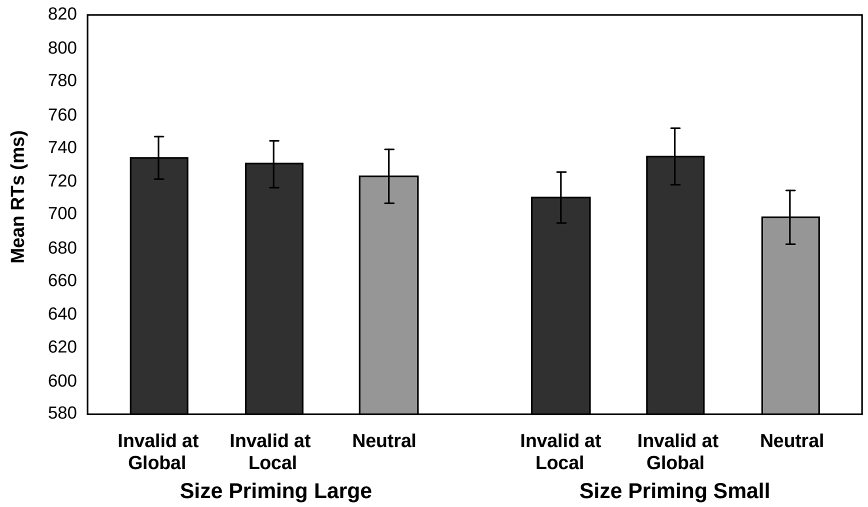


Figure 3.9: Experiment 3.3: Target-absent data. Effect of size priming on target detection at different levels of the hierarchical stimuli.

Table 3.6. Error data for target-absent trials in Experiment 3.3.

Memory	Validity	Search Errors (%)
Large	Invalid(G)	0.4
	Invalid(L)	0.4
	Neutral	0.2
Small	Invalid(G)	0.3
	Invalid(L)	0.4
	Neutral	0.4

Discussion

As in the experiments where participants had to hold the cue in WM (Experiment 3.1 and 3.2), there was no evidence for any effect of the validity of the match between the size of the cue and the size of the target in the hierarchical letter. Thus there was no indication of bottom-up priming of size affecting subsequent target selection. In contrast, there was some suggestion of priming from the cue's identity, though this was not reliable. Kim and Humphreys (2010) reported that, under priming conditions, cue identity facilitates target detection even when the cue is invalid and matches the distractor level of the forms. This facilitation effect appears to represent a type of repetition suppression effect, in which perceptual processing of the hierarchical letter is facilitated by pre-activating one level (both the target and the distractor level alike). Soto, Humphreys and Rotshtein (2007) reported neural evidence consistent with this repetition suppression effect under priming conditions in an fMRI study. In contrast to this, repetition enhancement occurred when, rather than being mere primes, cues were held in WM and matched targets. This enhancement effect was linked to the WM cue then directed attention to the matching stimulus.

In the final experiment, implicit effects of size were examined under conditions in which participants had to hold the cue's identity in memory. Could implicit size coding influence subsequent selection?

Experiment 3.4: Working Memory of Size vs. Identity

Experiment 3.4 explored a reverse design relative to Experiment 3.2 where participants remembered the size with the identity as a task-irrelevant feature. Would size priming effects emerge under these conditions?

Method

Participants 24 students and staff (age range: 19-42) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The stimuli (block letters and compound letters) and apparatus were the same as specified for Experiment 3.1-3.

Task and Procedure Each trial started with an English alphabetical letter A, N, or D, all of which were presented in equal frequency in two different sizes as in Experiment 3.1: The size of the cue either matched that of the letter representing the global level in compound stimulus, or the size of the letter representing the local level (as in Experiment 3.1). There were 6 experimental conditions: 3 validity (of identity) conditions × 2 size match conditions. The validity conditions were as follows: Valid, when the identity of the memory cue matched that of the target item; Invalid, when the identity of the memory cue was different from the target and represented the stimulus at the other non-target level; and Neutral, when the identity of the memory cue was different from the target and was not present at either of the levels. Each of these validity conditions had 2 size match conditions, in which the size of the memory cue was either same as or different to the size of the target letter. The target was always the letter ‘D’, and the task was the same as in Experiment 3.1. Participants were instructed to remember the identity of the memory cue, ignoring the size of the cue. Whilst holding the identity of the letter in memory, participants looked for the target letter in the compound stimulus without regard to the level it was shown at. On memory probe trials participants were asked to decide whether the identity of the item presented as a probe was the same as or different to the identity of the item held in memory. The size of the memory probe item was kept matched to the memory cue, in order to ensure that the size of the letter was not relevant to the task and only the identity was to be remembered. There were 4 blocks of 120 trials, half of which were target-absent. For each block there were 10 trials for each condition.

Results

1) Target-present data

The error data are summarized in Table 3.7. There was no evidence of a speed-accuracy trade-off. The mean RTs are given in Figure 3.10. The data were sorted into 12 conditions as a function of Cue size (large and small), Target level (global and local), and Identity validity (valid, invalid, and neutral). A 2 × 2 × 3 ANOVA showed that there were main effects of Target level ($F(1,23) = 5.4$, $p = .03$) and Identity validity ($F(2,46) = 11.6$, $p < .000$), but no effect of Cue size ($F(1,23) = 2.5$, $p = .13$). There was a 2-way interaction between Cue size and Identity validity ($F(2,46) = 3.7$, $p = .032$). The other interactions did not reach significance (all $F < 1.0$).

The data were averaged across target levels and analysed separately for large and small cue sizes. For large cues, there was a significant difference between Valid and Invalid trials ($t(23) = -3.1$, $p = .005$), and between Invalid and Neutral trials ($t(23) = 2.01$, $p = .05$), but Valid and Neutral trials did not differ ($t(23) = -1.1$, $p = .29$). For small cues, there were reliable differences between Valid and Invalid trials ($t(23) = -5.5$, $p < .0001$), and between Valid and Neutral trials ($t(23) = -3.7$, $p = .001$). The difference between Invalid and Neutral trials did not reach significance ($t(23) = -.14$, $p = .89$). When the cue was large, identity validity effects were due to costs on Invalid trials. When the cue was small, identity validity effects were due to benefits on Valid trials.

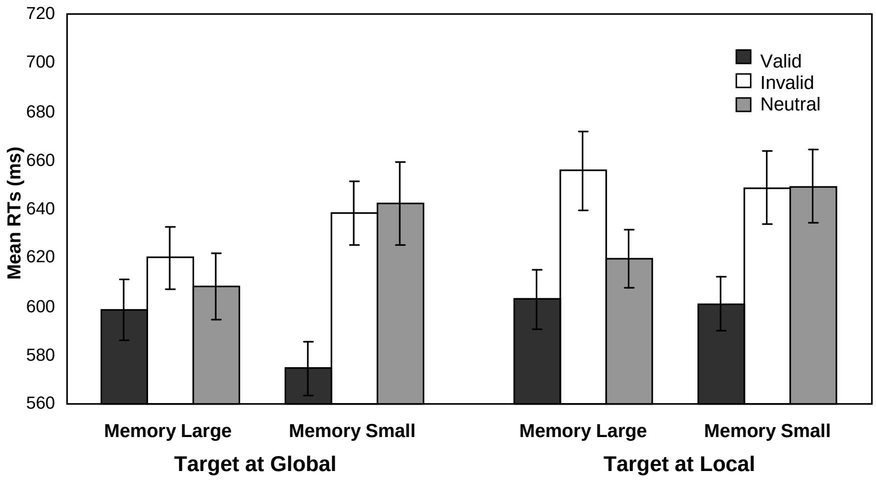


Figure 3.10. Experiment 3.4: Effect of memory of identity on target perception at different levels of hierarchical forms, as a function of the size of the memory cue.

Table 3.7. Error data for target-present trials in Experiment 3.4.

Target Level	Memory	Validity	Search Errors (%)	Memory Errors (%)
Global	Large	Valid	0.2	0.2
		Invalid	0.3	0.3
		Neutral	0.2	0.3
	Small	Valid	0.4	0.2
		Invalid	0.3	0.4
		Neutral	0.5	0.4
Local	Large	Valid	0.3	0.4
		Invalid	0.3	0.3
		Neutral	0.3	0.5
	Small	Valid	0.2	0.3
		Invalid	0.2	0.3
		Neutral	0.4	0.2

2) Target-absent data

The error data are summarized in Table 3.8. No evidence of speed-accuracy trade-off was observed (see Figure 3.11 for the mean RT data).

The RT data were sorted according to the two cue sizes, each with 3 validity conditions (global invalid, when the identity of the cue matched the letter at the global level; local invalid, when the identity of the cue matched the letter at the local level; and neutral, when the cue did not match either letter at both levels). There was a main effect of Identity validity (F(2,46) = 9.6, p < .0001) but no effect of Cue size (F(1,23) = .03, p = .9), and no Cue size × Identity validity interaction (F(2,46) = 2.1, p = .14). Pair-wise tests were conducted on the validity conditions with the data averaged across cue sizes. There was a significant difference between invalid and neutral trials for matches at a global level (t(23) = 3.4, p =.003), and between invalid and neutral trials for matches at a local level (t(23) = 3.5, p =.002). There was no reliable difference between global invalid and local invalid trials (t(23) = .06, p =.96).

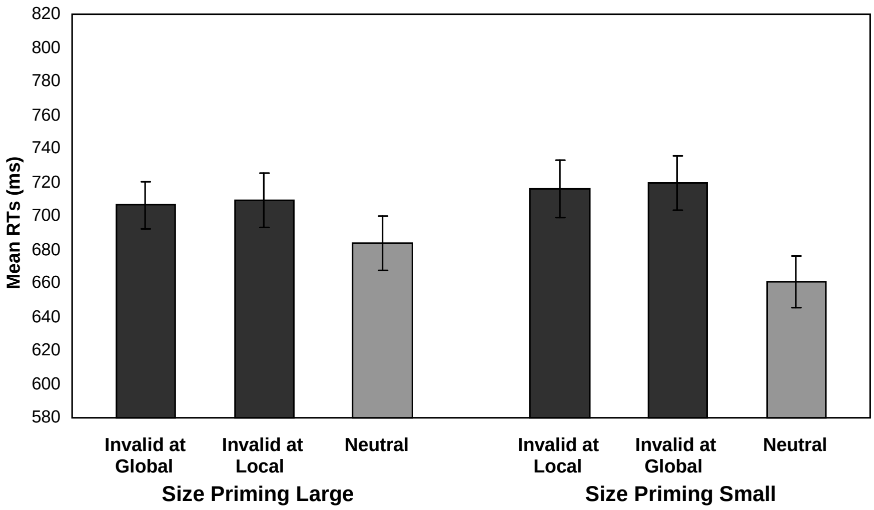


Figure 3.11. Experiment 3.4: Target-absent data. Effect of memory of identity on responses as a function of the match between the cue size and identity.

Table 3.8. Error data for target-absent trials in Experiment 3.4.

Memory	Validity	Search Errors (%)	Memory Errors (%)
Large	Invalid(G)	0.3	0.5
	Invalid(L)	0.2	0.5
	Neutral	0.3	0.7
Small	Invalid(G)	0.5	0.5
	Invalid(L)	0.3	0.4
	Neutral	0.3	0.6

Discussion

There was evidence here for an effect of the identity of the cue held in WM on the selection of stimuli on a subsequent hierarchical stimulus, but the effects varied with the size of the cue. When the cue was large, we observed mainly a cost on RTs when the identity of the cue was invalid (i.e., when the cue matched the distractor level of the hierarchical target). When the cue was small, we instead observed mainly a benefit on trials when the cue was valid (relative to the neutral identity baseline). These effects did not interact with whether the target fell at a local or global level, and so they are not the result of the relation between the cue size and the target – they reflect an effect of absolute cue size but not cue matching.

One way to account for the data is in terms of focused and distributed attention. A large cue may induce a distributed mode of attention and this may lead to two things: (i) the engagement of attention by a WM cue that does not match the search target (on trials with an invalid cue identity), and (ii) poor disengagement from a stimulus that matches the cue but is not the search target. For the hierarchical form task, participants should be set to detect a particular target, but this set may be contradicted when the cue in WM also matches a letter in the display. The likelihood of this happening may increase when the cue is large and participants are in a distributed mode of attention. A distributed attention mode may also make disengagement difficult, once a cue has attracted attention. The result would be a relatively large cost to performance when the cue is invalid. In contrast, a small cue may induce a more focused mode of attention where the cue is only effective when it also matches the set for the task – the target for the hierarchical form. There would be less guidance to an invalid cue, which does not match the set for the hierarchical letter target. The effect then is to generate larger benefits (on valid trials) than costs (on invalid trials). Evidence consistent with this proposal about differential effects of distributed and focused attention has been reported by Hernández, Costa and Humphreys (2010). These authors had participants adopt a focused or distributed mode of attention by either first identifying a small item at fixation or identifying the overall configuration of items in a display prior to searching for a target. Effects of a cue in WM were stronger on trials where a distributed mode of attention was encouraged, with cost effects in particular increasing under these conditions. We note though, that in both Hernández et al. (2010) and the present study, the putative manipulation of focused and distributed attention co-varied with the size of the cue (see also Belopolsky et al., 2007). It could be that large cue sizes per se make it more difficult to prevent attention from going to an invalid cue, perhaps because large cues impose a greater processing load.

Whichever account of the identity validity effects here, the data indicate that cue size was processed and influenced performance. This evidence for an effect of cue size is in contrasts with the null effects in Experiments 3.1-3. This result is particularly noteworthy given that cue size had to be held in memory in Experiments 3.1 and 3.2, whereas cue identity was memorized here and cue size was only coded implicitly. If *identifying* large and small cues here led to distributed and focused modes of attention, then the results suggest that *memorizing* the different cue sizes did not. We consider this further in the General Discussion.

General Discussion

We have reported 4 experiments examining the effects of size information from a cue on the selection of a subsequent target in a hierarchical letter stimulus. In Experiments 3.1 and 3.2 we had participants held the cue's size in WM for later probe recognition. There was no effect of whether the cue size matched the size of the local or global letter, even when the size memory task was made relatively difficult (Experiment 3.2). The null effect of cue size was also found under priming conditions, when size had to be identified but not held in memory (Experiment 3.3). Although cue size did not affect selection from a subsequent hierarchical stimulus in these experiments, cue identity did – even though cue identity did not have to be held in WM. RTs were faster when the cue's identity matched the target and they were slowed when the cue's identity matched the identity of a distractor letter at one level of the hierarchical form (Experiments 3.2 and 4). In this case cue identity was coded implicitly (as only size had to be memorized), but identity still modulated later selection. This effect was also eliminated under priming conditions (Experiment 3.3). In the final experiment, the cue identity had to be maintained in WM, not the cue size. Again effects of cue identity emerged on responses to the hierarchical letter but these effects of cue identity varied with cue size also emerged – large invalid cues tended to enlarge costs to from invalid cueing of identity (to a distractor rather than a target), while small cues tended to generate benefits from the valid cueing of identity (relative to the neutral baseline). These last results suggest that cue size was processed, and the size differences were sufficient to modulate performance. Nevertheless, as in Experiments 3.1-3, there was no differential effect of the size relations between the cue and the target. Size cueing was not effective here, though size differentially modulated cue identity effects.

Selection with hierarchical stimuli

In the present study we employed a divided attention task in which participants were set to detect a given target letter which could appear at either the local or global level of a hierarchical form. We hypothesized that participants may select a target letter in such forms by fitting an attentional window to the area occupied either by the global or by a local element, and then reading out the letter for identification. Across 4 experiments we found no evidence for this based on size cueing from WM – there were no effects of whether the size of the item in WM matched the size of the target in the hierarchical letter. If participants were cued to select the size held in WM, then target detection should benefit when the target is at that size rather than when it is at the other side. This did not occur.

In contrast to the lack of effect of size, there was evidence for effects of the identity of the cue held in WM, even when this information was only coded implicitly (and did not need to be explicitly coded in WM, in Experiment 3.2). These data are consistent with the view that, at least under divided attention conditions, targets in hierarchical forms are detected by the activation of identity information, and this may happen in parallel rather than after selection of first the global and then the local level (or vice versa) – given that we found cueing effects to both levels of form (e.g., in Experiment 3.4).

Overlapping attentional sets

Taking the results across the experiments, the data indicate that not all aspects of information held in WM modulate subsequent selection – here size information did not influence selection when it was explicitly represented (even though the size differences were sufficient to influence performance in other conditions; Experiment 3.4). The data cannot simply reflect the strength or weighting of the information represented in WM. We presume that size was strongly weighted in Experiments 3.1 and 3.2, as it had to be explicitly recognised, while identity would be less strongly weighted – yet identity not size affected performance (Experiment 3.2). One might also imagine that size would be critical to the selection of the hierarchical target, given prior results on both object recognition (Jolicoueur, 1987) and carry-over effects with hierarchical letter (Ward, 1982). Despite this, there was no evidence for size information in WM critically modulating selection, and we suggest instead that local and global targets are selected based on their identity, which defined a target here (see above). If this was the case, then information about the size of the cue represented in WM would not match the information being used to guide attention (target identity), and no effects of guidance would emerge with the irrelevant WM cue. In contrast, implicit effects from cue identity may still emerge if identity information is automatically extracted from the cue (even when size is memorized). Identity information from the cue, held in WM, may overlap with the identity information that defines the set for the target, and so cue identity comes to infiltrate target selection. On this view, the effects of attentional guidance from irrelevant information in WM do not reflect the representation of information in WM per se, but, critically, whether this information overlaps with the 'set' adopted for the target. When there is overlap between the contents of WM and the target set, the irrelevant WM cue can direct attention.

This argument for the overlap of the 'set' being important fits with neuropsychological data reported by Soto, Heinke & Humphreys (2006). Soto et al. examined the effects of WM on attentional guidance in patients with frontal lobe lesions. Relative to age-matched controls, the patients were not more likely to have their attention initially guided to targets matching stimuli in WM (e.g., on measures of the first eye movements), but the patients were slower to disengage on occasions when their attention was directed to a distractor matching the memory stimulus. To account for this, Soto et al. proposed that frontal patients found it more difficult than controls to keep separate the set for the target from the WM representation. Due to a failure to keep WM separate from the target set, the patients found it hard to withdraw attention from a distractor corresponding to the WM stimulus once it was selected. Applied to the current data the argument is that the size of the WM stimulus is unrelated to the set adopted to select the target in the hierarchical form, and this enables the participants to compartmentalise the WM representation of size from the (identity-based) template used to select the target, minimising guidance from the WM cue.

There are difficulties though for this proposal that the overlap in 'set' is important. A primary problem relates to earlier data on guidance from irrelevant cues in WM. In many of the earlier experiments, the stimulus held in WM (e.g., a face or a coloured shape) differed from the subsequent target (e.g., a shape or an oriented line; see Downing, 2000; Soto et al., 2005). There would appear to be little overlap in perceptual set, in such cases. However, in these studies the target was also relatively low in saliency compared to those WM stimuli that could appear in the subsequent display. It is possible that the overlap in set is less important if the WM stimuli are sufficiently salient compared with a search target. In the present case this may not have held, so that the overlap of set becomes more important. A further possibility is that, in the earlier studies, the target and WM stimulus are coded as an integral representation – shapes around a face (Downing, 2000) or a line within a shape (Soto et al., 2005). This may in turn mean that distinct attentional sets are not created for the target (oriented line in coloured shape) and the WM cue (coloured shape). Due to an overlap in the attentional sets, attention can be drawn to the cue even when search should just be for the target.

Focused and distributed attention

Experiment 3.4 demonstrated that the size of the WM cue could affect performance, when participants had to hold the cue's identity in memory. However, in this case the effect was not due to size matching but to size modulating the effects of cue identity. To account for this we propose that participants did encode letter size as well as letter identity, and that encoding large relative to small letters leads to the adoption of a more distributed attentional state. Hernández et al. (2010) have shown that costs from invalid cueing from WM increase when participants are in a distributed relative to a focused mode of attention. Consistent with this, we found large costs after participants identified and held in memory a large compared with a small letter. This result can be explained if being in a distributed mode of attention means that performance is affected by information other than the set for the target task. In this mode, an irrelevant distractor matching an item in WM may have an increased likelihood of capturing attention. In contrast, when participants are in a more focused mode any attentional set to the target may be enhanced. The result then is the WM stimulus needs to completely match the target set (on valid trials) to influence performance.

As we stress above, there were no effects of matches between the target and the cue's size, even when size information had to be explicitly represented in memory (Experiments 3.1 and 3.2). This in turn indicates that holding a large letter does not lead to more distributed attention than holding a small letter in WM. It is possible that size could be coded as a single attribute, differential demands on distributed or focused attention. Alternatively, the need to encode large letter features, rather than size, in memory may require a depth of processing that leads to the distribution of resources (in Experiment 3.4).

Memory top-up and implicit coding of identity

Experiment 3.2 demonstrated that letter identity modulated target selection even when letter size had to be held in WM. One aspect of this study was that memory probe trials always contained the same letter identity, which varied in size to match or mismatch the size of the cue. Under these conditions it would not benefit participants to deliberately attend to the WM letter identity when it re-appeared in the search display, since this would not benefit memory performance. The fact that cue identity still affected performance, though, suggests that WM guidance is not due to a deliberate top-up of the representation in WM, but rather it follows automatically once a stimulus is encoded in WM and is either very salient when it re-appears or it partially matches the attentional set to the target. Kim & Humphreys (2010) indeed showed that holding the identity of a cue in WM could guide selection to a local or global letter even when the cue was never the target, highlighting the automaticity of the effect once the WM is coded.

CHAPTER 4

Encoding Hierarchical Forms in Working Memory and How it Affects Attentional Selection of Hierarchical Forms

Synopsis

Items held in working memory can affect subsequent selection, even when they are irrelevant for the selection task. This influence is found both on spatial search and on the selection of stimuli in hierarchical forms (Kim & Humphreys, 2010). Here we assessed how memory for a hierarchical form itself influences selection of similar forms. Two experiments are reported. In Experiment 4.1 participants had to remember both levels of a hierarchical form. In Experiment 4.2 only one level of the form had to be memorized. In both cases, there were effects of cueing from letter identities in the first hierarchical form that affected target selection in the subsequent form. There were effects from both levels of the initial form, indicating that both levels were coded in memory and could generate top-down effects on later search. There was also evidence from attending to one level of the first form on selection of local and more global attributes of the second, consistent with a carry-over of the processing mode across stimuli. The implications for memory for hierarchical forms, and for understanding WM cueing, are discussed.

Introduction

Visual information processing occurs through dynamic interactions between stimulus-driven saliency and goal-directed internal control. The interplay of these two factors results in a process of attentional selection, where stimuli of lesser relevance can lose out to visual input that is more pertinent to the present behavioural goals. This competition-like mechanism is hypothesized to be implemented via representations held in working memory (Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Chelazzi, Duncan, Miller & Desimone, 1998). For example, neurophysiological studies have shown that neurons carrying relevant information in the form of a memory representation, or a 'template', are pre-activated so that the specific elements within a visual array that match the pre-activated representation, will be selected more efficiently than others (Chelazzi et al., 1998). This pre-activation provides a memory representation which biases attentional (and behavioural) selection. A large body of evidence supports this competitive account of selection modulated through the contents of WM (Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005; Soto, Humphreys, & Heinke, 2006; Soto & Humphreys, 2008; Olivers, Meijer, and Theeuwes, 2006; Kim & Humphreys, 2010; Chelazzi et al., 1998; Reynolds & Desimone, 2003).

There is also mounting work indicating that information in WM can bias selection even when it is not relevant to the task. For example, if participants are asked to hold an item in WM and then search for a different stimulus, the subsequent search task can be modulated by the re-appearance of the WM stimulus in the display. Performance is speeded if the target falls close to the re-presented cue and slowed if the cue and the target fall in different locations (Downing, 2000; Huang & Pashler, 2007; Olivers, 2009; Soto et al., 2005, 2006, 2010). The re-presentation of the memory cue affects the fastest reaction times (RTs) in the search task, the first eye movements and perceptual sensitivity to the target (Soto et al., 2005, 2010). The effects also occur even when the cue never falls at the target's location (Soto et al., 2005), in which case participants have no incentive to bias search in favour of the item in WM[3]. These last results suggest that the memory effects are both fast acting and hard to prevent.

Whilst many of the studies noted above report a top-down WM effect on spatial selection, recent work (Kim & Humphreys, 2010) has also suggested that the contents of WM can modulate non-spatial attentional selection as well. Kim and Humphreys (2010) had their participants remember the identity of a regular block letter and then search for a letter target which could appear at the local or the global level in a hierarchical compound stimulus. They found robust WM cueing effects that took the form of faster reaction times (RTs) to targets that matched the identity of the cue in WM (on valid trials), and slower RTs when the cue matched at letter at the non-target level (on invalid trials), relative to when the cue did not re-appear in the hierarchical stimulus (neutral trials). These effects were more pronounced when the stimuli matching the cue were at the global rather than the local level of the hierarchical form. These effects held both when participants looked for the target letter at both levels of the hierarchical stimulus (the distributed attention condition) and when they looked for a target at just one level (the selective attention condition). Kim and Humphreys

[3] In these studies of the effects of WM on a subsequent search task, it could be argued that participants attend to the re-appearance of the WM item in order to bolster their memory (for later testing). However, several pieces of evidence argue against this. For example, Balani, Soto and Humphreys (in press) found effects of re-presenting a different exemplar to the WM tem, even though they had to discriminate the WM item from a different exemplar in a later memory test. Here re-freshing the memory for the different exemplar would disrupt memory performance. Kim and Humphreys (2010) had participants remember stimuli of different size and tested memory for the same letters at either the same or different size. In this case topping up the identity of the WM stimulus, but attending to it in a search display, should not boost memory. However in both instances strong effects of WM were found on search.

suggested that the identities of local and global letters were extracted in parallel, and therefore either level could be cued from a letter identity maintained in WM, even if participants are trying to focus attention at one level (in the focused attention condition). Note that, using a spatial selection process, it should not be possible to select the global level of a hierarchical form without also selecting the local level; hence the biasing effect from WM here reflects a bias to one of the two computed letter identities (at the local or global level), rather than a spatial selection process[4].

In the present study, we again examined the cueing of selection in hierarchical forms, but in this case we assessed how cueing effects were modulated by the hierarchical representation of the stimulus in WM. Rather than have participants memorize block letters (as in Kim & Humphreys, 2010), we had them memorize hierarchical forms. In Experiment 4.1 both levels of the hierarchical form had to be held in memory. In Experiment 4.2 just one level of the form had to be maintained. In Experiment 4.1 we asked whether there is any differential bias on selection from one level of the form in memory – perhaps equivalent to the bias to match an item in memory to the global properties of a subsequently presented stimulus (Kim & Humphreys, 2010). In Experiment 4.2 we evaluated whether there were biasing effects from both levels of the item held in WM, even when only one level was relevant to memory performance. This last point is interesting because almost no studies have been conducted into the nature of the memory representation that may be formed to hierarchical forms – particularly under conditions in which only one level of the form has to be coded in memory. Numerous studies provide evidence that both levels of hierarchical forms may be processed together, since conflicting identities at

[4] Consistent with this, Kim and Humphreys (2010, submitted) also report that that there are no effects of holding the size of a stimulus in WM on the selection of letters in hierarchical forms. A bias to select a stimulus matching the size of the item in WM might be expected based on a spatial selection process (e.g., fitting an attentional window of a cued size to the hierarchical letter.

each level can disrupt the identification of both local (e.g., Navon, 1977) and global forms (e.g., Martin, 1978). However we simply do not know whether participants maintain the whole stimulus (representing both levels) when asked to hold only one level in WM, or whether indeed only one level is represented. By testing whether both levels can modulate subsequent selection, even under conditions where only one level is relevant, we assess this issue.

Hernández, Costa, & Humphreys (2010) have recently shown stronger effects of cueing from WM on subsequent visual selection when participants were in a distributed, relative to a focused, attentional mode. They examined two conditions. In the distributed condition, participants had to judge whether all of the elements in a search display formed a particular global shape prior to searching the display. In the focused attention mode, participants had to discriminate an item at fixation prior to searching the display. There were stronger effects from an item in WM when participants performed in the distributed attention mode (see also Belopolsky, Zwaan, Theeuwes, & Kramer, 2007, for similar evidence from singleton capture). From this result we might predict stronger effects when a global form is held in WM. Alternatively what may be important could be the relations between the level memorized and the level where the target appears. Prior studies on hierarchical letter perception indicate that the perceptual potency of the local and global levels is modulated by the particular level that has been previously attended to (a 'level-readiness' effect) (see Ward, 1982). In the current study, when the information at the level held in WM matches the following target at the same level, the cueing effect might be stronger than when the levels are different.

With the two stimulus dimensions available from a hierarchical form, we also examine whether there effects of WM-based cueing may decrease. Soto &

Humphreys (2008) reported some limitations in the effects of WM on spatial selection (also Olivers, 2009) – they found that the effects of WM reduced when two items rather than one item had to be maintained. Does a similar limitation occur when the to-be-remembered items occur within the same stimulus (e.g., the local and global levels of the forms)? If this is the case, then effects of cueing from WM may be reduced in Experiment 4.1 where both of the letter identities are held in WM, relative to when only one level of the hierarchical form has to be maintained (Experiment 4.2 here).

Experiment 4.1:
Working Memory for Two Levels of Hierarchical Forms

Method

Participants Twenty-five students and staff (age range: 19-32) at the School of Psychology of the University of Birmingham participated for course credit or cash. All reported having normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The experiment was run on a Samsung 920N colour monitor (resolution: 1280 × 1024 pixels), using E-Prime (version 2.0; PST 2002). Adobe Flash (version CS3 Professional) was used to produce all stimuli employed in the experiments of the current study. English alphabet letters A, D, N, S, U, and X in Arial font were used to construct compound stimuli, with the global dimension subtending 8.5° × 7.3°, and the local 0.49° × 0.41°. The graphic illustrations of the stimuli are given in Figure 4.1. All the stimuli were presented in the centre of the screen. Left and right arrow keys on the computer keyboard were used for responses.

Task and Procedure Figure 4.2 illustrates the presentation sequence. Each trial began with a compound letter (the memory cue) that was presented for 500 ms. Participants had to remember this letter as it was shown, holding in memory both of the letters present at the local and the global level. After a delay of 1200 ms, participants performed a second task, search for the target letter ‘D’ in a second compound letter, irrespective of the level that the target was located at. The letters making up the hierarchical stimuli were never identical. Each block had equal number of target-present and target-absent trials. For the total amount of target-present trials, there were equal numbers of trials with the target at the local and the global level, each of which had seven different validity conditions defined as follows:

1. Valid(2) Same – the memory cue had the target letter D at either the local or the global level and the second letter was identical to it (valid local and valid global).
2. Valid(2) Reversed – this was same as for the Valid(2), Same condition, except that the two letters composing the hierarchical memory cue matched the letters in the hierarchical stimulus at the opposite level.
3. Valid(1) Same – the memory cue had the target at one of its levels, which matched the target at the same level in the probe letter. The other letter in the memory cue was not present in the target display.
4. Valid(1) Reversed – the memory cue had the target at one of its levels, but this was opposite to the level where the same letter appeared in the probe.
5. Invalid, Same – the memory cue did not have a target at either of its levels but one of the letters was represented at the same level in the probe display.

6. Invalid, Reversed – the memory cue did not have a target at either of the levels but one of the cue letters was represented at the opposite level in the probe display.
7. Neutral – neither the global nor the local letters in the memory cue were present in the hierarchical letter.

For the target-absent trials, there were five conditions:

1. Invalid(2), Same – the letters representing the two levels of the memory cue were identical and matched the letters at each level of the probe stimulus.
2. Invalid(2), Reversed – same as Invalid(2), Same, but the letters representing the levels of the memory cue matched the opposite level of the probe stimulus.
3. Invalid(1), Same – a letter at the global or the local level of the memory cue was same as that of the probe stimulus.
4. Invalid(1), Reversed – a letter at the global or the local level of the memory cue matched a letter in the probe at the opposite level.
5. Neutral – none of the letters of the target matched the cue.

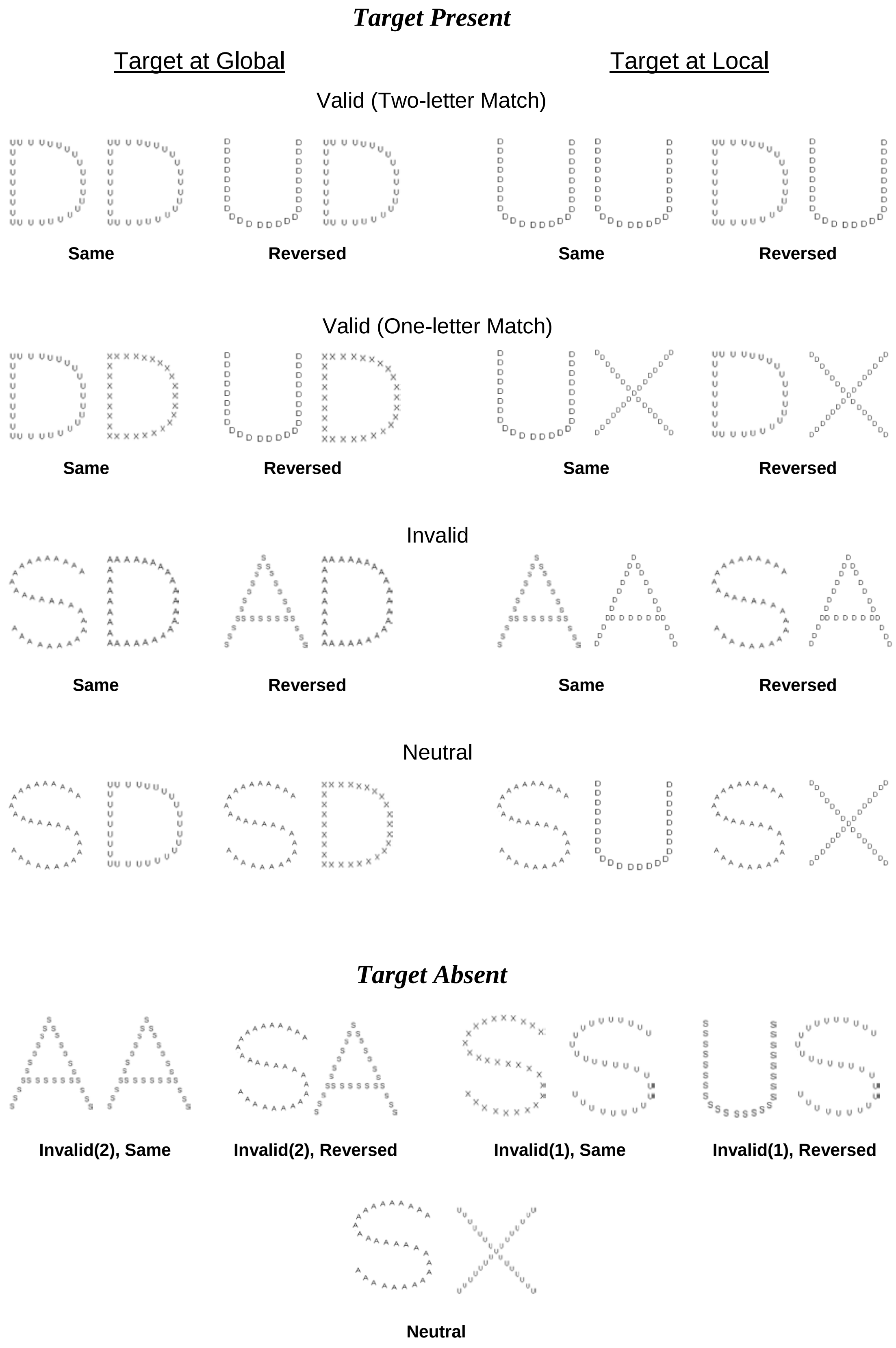


Figure 4.1. Examples of the stimuli in each condition represented in pairs with the memory item (the first in the pair) followed by the probe display (the second): All the stimuli on the left side have the target at the global level and those on the right have the target at the local level. The target was always the letter ‘D’. All the letters were in black displayed against a white background.

Memory questions occurred randomly at the end of a trial, with a frequency of 20% of all trials in a block. The memory question asked participants to decide if the compound letter shown was the same or different to the one they held in their memory (for both of the letters representing each of the two levels). When the memory item differed from the initial compound letter it had a contrasting identity at the local or global or both levels. Participants had a practice session of 20 trials at the beginning of the experiment. Each participant finished 6 blocks of 136 trials. They were warned about the memory test before the start of the experiment. The instructions emphasised both accuracy and response speed for both of the target search and memory tasks.

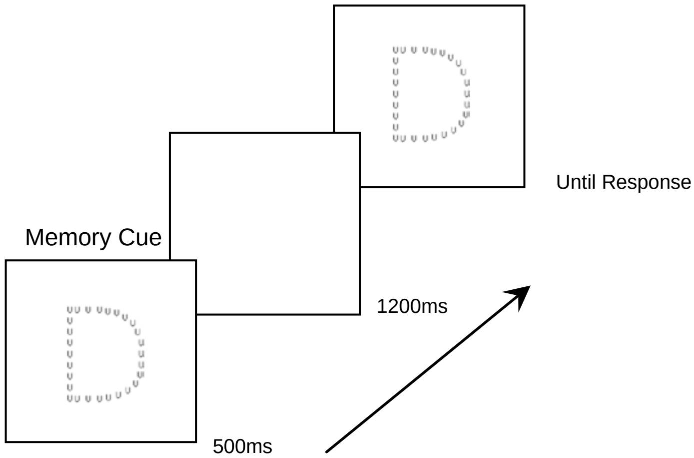


Figure 4.2. The sequence of displays on the trials in Experiment 4.1 and 4.2. In this example (Valid(2), Same), the target was present at the global level.

Results

All data analyses were carried out on target-present and target-absent data separately as each set of data had different conditions. The data for one of the 25 participants were eliminated as the error rates for target and memory tasks were very high at around 25%.

1) Target-present data

In all experiments, trials with incorrect responses to memory questions were included in the analysis to secure the largest possible amount of data. The error rates for target detection and memory performance were at 5.3% and 5.1% on average, respectively (see Table 4.1 for the overall data summary). There was no indication of a speed-accuracy trade-off and the accuracy data were not analysed further (see Figure 4.3 for the overall data). An initial 2 × 2 × 3 ANOVA was carried out on the mean RT data, with three factors: Target level (local and global), Match (cue same or reversed), and Validity (Valid(2), Valid(1), and Invalid). Neutral trials were not included here, since they did not contain levels of the Match factor. The results are shown in Figure 4.3, where the data are presented separately by level. There was a significant effect of Cue-target Validity ($F(2,23) = 7.8$, $p = .001$) and a borderline effect of Target Level ($F(1,23) = 4.1$, $p = .055$). The main effect of Match was not reliable ($F(1,23) = .46$, $p = .50$). There was a Target Level × Match interaction ($F(1,23) = 6.6$, $p = .017$), but no other interactions were reliable (largest effect: $F = 1.3$, $p = .29$). To explore how the Target Level × Match interaction was induced, the data were averaged across Validity and compared for each level by conducting pair-wise tests. At the local level, there was a significant difference between Same and Reversed ($t(23) = 2.23$, $p = .036$). No other comparisons reached significance at the local level. No effects were reliable for global targets (all $t < 1.0$).

The data were subsequently sorted by Target Level, and the Match factor was averaged for each Validity condition so that the Neutral condition could now be included in the analyses. For the global level, there was a significant difference between Valid(1) and Valid(2) ($t(23) = 2.87$, $p = .009$), Valid(1) and Invalid ($t(23) = -2.93$, $p = .007$), and Valid(1) and Neutral conditions ($t(23) = -2.51$, $p = .02$). The other conditions did not differ. For the local level, Valid(1) significantly differed from Valid(2) ($t(23) = 2.42$, $p = .024$), Invalid ($t(23) = -2.85$, $p = .009$), and Neutral ($t(23) = -1.98$, $p = .006$). Invalid and Neutral also differed ($t(23) = 2.1$, $p = .047$). Valid(2) did not differ from the Neutral condition (all $t < 1.0$).

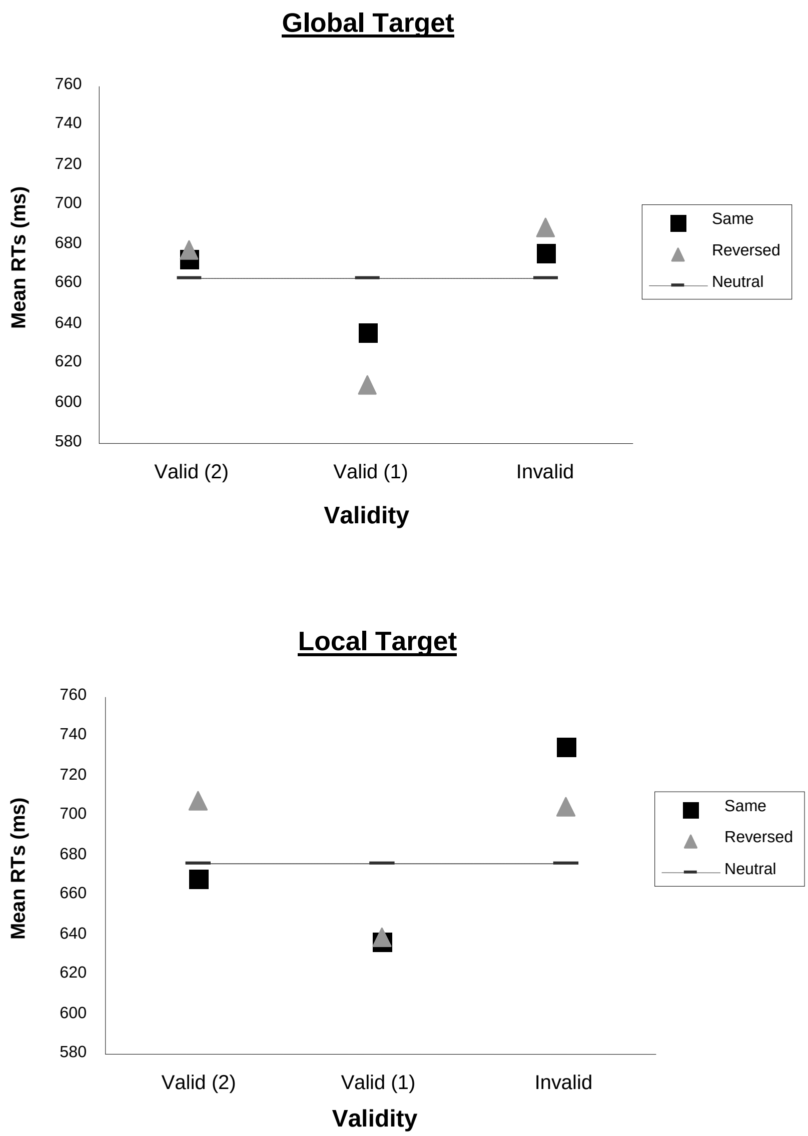


Figure 4.3. Experiment 4.1: Effect of memory of a hierarchical letter on target perception at each level, shown for each validity condition: Valid with two-letter match (Valid(2)), Valid with one-letter match (Valid(1)), and Invalid. Data for the Neutral conditions are plotted as a straight line based on the mean RT.

Table 4.1. Error data on target-present trials in Experiment 4.1.

Target Level	Reversed	Validity	Search Errors (%)	Memory Errors (%)
Global	No	Valid	0.4	0.2
		Invalid	0.3	1.0
		Neutral	0.2	1.0
	Yes	Valid	1.0	0.3
		Invalid	0.3	0.1
		Neutral	0.3	0.4
Local	No	Valid	0.1	0.3
		Invalid	0.2	0.3
		Neutral	0.1	1.1
	Yes	Valid	0.7	0.1
		Invalid	1.0	0.2
		Neutral	0.2	0.1

2) Target-absent data

The means for target-absent trials are shown in Figure 4.4. The error rates for target detection and for memory performance were low at 3.2% and 3.5% on average (see Table 4.2 for data summary). There was no evidence of speed-accuracy trade-off, and the accuracy data were not analysed further. A 2 × 2 repeated-measures ANOVA was initially conducted with the neutral trials excluded (as they did not have the Match factor). This showed an effect of Cue-target Validity ($F(1,23) = 24.4$, $p < .0001$). Match did not reach significance ($F(1,23) = .53$, $p = .48$), but there was a Cue-target Validity × Match interaction ($F(1, 23) = 4.9$, $p = .037$). *t*-tests performed to look into the interaction showed that there was a border-line difference between Invalid(2), Same and Invalid(2), Reversed ($t(23) = 2.0$, $p = .061$). The difference between Invalid(1), Same and Invalid(1), Reversed did not approach significance ($t(23) = -1.3$, $p = .21$).

A one-way ANOVA was conducted across five conditions (including the Neutral baseline), averaging over the Match factor. The effect of Cue-target Validity was significant ($F(4, 115) = 2.9$, $p = .024$). A significant difference was found between Invalid(2), Same and Neutral ($t(23) = 4.9$, $p < .0001$), and between Invalid(2), Reversed and Neutral (t(23) = 3.7, *p* =.001). The Invalid(1) conditions did not differ from the Neutral baseline (t < 1.0). There were no other differences.

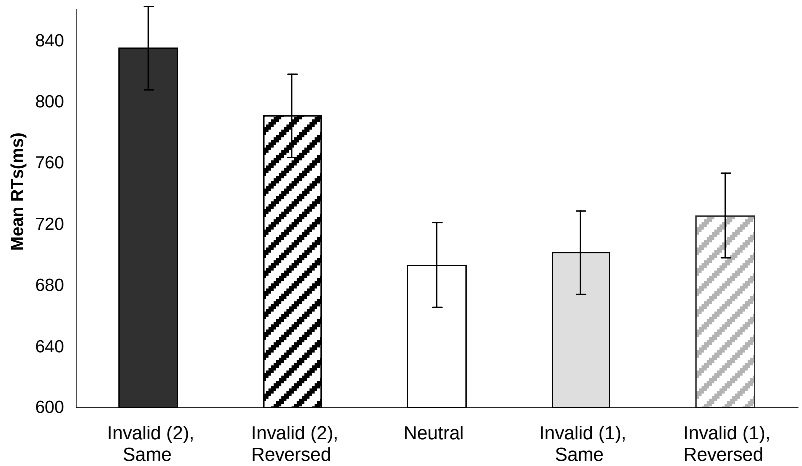


Figure 4.4. Experiment 4.1: Effect of memory of different sizes in target-absent trials. The error bars represent standard errors (this applies all relevant figures in the present paper).

Table 4.2. Error data on target-absent trials in Experiment 4.1.

Validity	Reversed	Search Errors (%)	Memory Errors (%)
Valid	No	0.8	0.9
	Yes	0.3	0.3
Invalid	No	0.7	1.1
	Yes	1.0	0.7
Neutral		0.5	0.5

Discussion

The data replicated Kim & Humphreys (2010) in showing that the identity of a cue held in WM affected subsequent selection of target letter in a hierarchical form. Here this is extended by showing effects of both letter identities present in a memorized hierarchical letter. This was shown most clearly on trials where the target was absent from the second letter display. In this case RTs were slowed when both identities present in the cue were present in the target (in the Invalid(2) conditions), compared with when only one letter was repeated. The effects of repeating the cue, on absent trials, tended to be stronger when the letters remained at the same levels, consistent with the letter being retained in their specific form, though effects still arose when the letter identities were reversed. Thus there appear to be effects based on activated letter identities (irrespective of whether the letters are local or global) and some effects based on the specific visual representation derived from the cue (on Same vs. Reversed trials).

On target present trials there was a facilitative effect when one of the letters matched the letter in the target, compared with a neutral baseline. It made little difference whether this letter was at the same level in the cue and the probe (on Same and Reversed trials) and it held both when the target was at a global and when it was at a local level. There was also a cost on invalid trials when one letter in the cue matched a global letter at the opposite level to the local target. Kim and Humphreys (2010) also observed greater costs for local targets from invalid cueing to the wrong level, and this was attributed to the WM cue tending to direct attention to the global level. When the matching item at the global level is invalid, the detection of a local target is slowed.

At least two accounts of the costs of invalid cueing from WM can be proposed. One account attributes the effect to participants engaging attention on the letter that matches the identity of one of the cue letters; on present trials this disrupts selection of the target, on absent trials there is a delay in attention to the other level of the search letter and this slows responses. An alternative is that there is suppression of the letter in the cue, and this delays the processing of search letter containing the same letter (Woodman & Luck, 2007). There are various reasons to discount this last proposal, however. One is that it is difficult to see why there should be a benefit to target responses when the cue matches the target (on target present trials in the Valid(1) condition). If there is suppression of the target, then RTs to the target should be delayed. Also, in conditions examining priming from the first item (e.g., when participants identify the cue but do not hold it in memory), Kim and Humphreys (2010) found facilitation from repeating the cue's identity in the search letter – even when the cue was invalid (e.g., matching the level opposite to that containing the target). It is difficult to see why mere identification should facilitate processing but WM should inhibit processing, when the initial item has to be more strongly maintained in the WM condition.

Interestingly, although target present responses were facilitated when one of the letters in the cue matched the target (and the other differed, the Valid(1) condition), performance returned to neutral when both of the letters in the cue matched the letters in the search letter (in the Valid(2) condition, where one letter matched the target, the other the distractor level). This result suggests that the benefits of valid matching to the target traded-off against the cost from invalid matching (to the distractor level). This could come about in either of two ways. One possibility is that the two levels of the cue match to the two levels of the search letter and each compete in parallel for selection – the result being that performance does not differ from the neutral baseline. The second possibility is that, across trials, either the valid or the invalid cue wins the competition. There is then a benefit from valid cueing on some the trials and a cost from invalid cueing on the remaining trials. If the competition is resolved roughly equal for valid and invalid cues, then overall performance would match the baseline. To assess this last possibility, the variance for each participant in each Valid(2) condition was compared with that in the neutral baseline. This analysis showed that, when the target was at the global level, the variances for both Same (311 ms) and Reversed (289 ms) trials were significantly different from the Neutral (180 ms) trials ($t(23) = 4.2$, $p < .0001$ and $t(23) = 5.6$, $p < .0001$, respectively), whilst the difference between Same and Reversed conditions did not reach significance ($t(23) = .95$, $p = .35$). When the target was at the local level, the variances for both the Same (290 ms) and the Reversed (289 ms) trials were also significantly different from Neutral (234 ms) trials ($t(23) = 2.0$, $p = .055$ and $t(23) = 2.5$, $p = .02$, respectively). No significant difference was found between the Same and the Reversed conditions ($t(23) = .06$, $p = .95$). The data support the account that one level of the probe stimulus is selected at a time, with cueing in the Valid(2) condition leading to alternations in which level is selected.

Experiment 4.1 demonstrated effects from each level of an item memorised in WM. In Experiment 4.2 we assessed whether similar effects would emerge in conditions in which participants are asked only to hold one level of the initial hierarchical letter in memory. Studies on the processing of hierarchical letters, from Navon (1977) onwards, have provided evidence that both levels of hierarchical form can be processed together even when participants have to select one level – as evidenced by response congruency effects from a non-target level of the form.

However, it is not clear that both levels will be equally effective in directing attention, when only one level has to be represented in memory. Nevertheless, there is precedence that irrelevant properties of stimuli coded in WM can still modulate subsequent selection. Soto and Humphreys (2009) showed that the irrelevant colour of a shape in WM affect a later search task, and Kim and Humphreys (2010) demonstrated similar attentional effects from the identity of a letter when participants had only to remember its size. These studies show that irrelevant as well as relevant information in WM can modulate subsequent selection. Was this the case for an irrelevant level of form in a hierarchical letter?

Experiment 4.2: Working Memory of One Level of Hierarchical Forms

Method

Participants Twenty five students and staff (aged between 19 and 25) at the School of Psychology of the University of Birmingham participated for course credit or cash. All had normal or corrected-to-normal vision.

Apparatus and Stimuli The same apparatus was used as for Experiment 4.1. All stimuli had the same properties as the ones specified in Experiment 4.1.

Task and Procedure Overall the task and procedure were the same as for Experiment 4.1. Each trial started with a compound letter (the memory cue) that was presented for 500 ms. In the current test, however, participants were instructed to remember only the letter represented at a given level in the compound letter. Before the beginning of a block, the level to attend to was shown in written words (as in 'global' or 'local'). For all the trials in the following block participants had to remember the letter placed at that given level. For each trial, the search task was to look for the target letter 'D' in the presentation of the second compound letter, irrespective of the level it was located at. All blocks had equal numbers of trials with the target at the global or at the local level, each of which had the same validity conditions as in Experiment 4.1. On target-present trials there were three Validity conditions (Valid(2), Valid(1), and Invalid), two Match conditions (the letters in the memory cue and the target were the Same or Reversed), and two Target Levels (local vs. global). There were also Neutral trials where the letters in the cue and the target were completely different. On target-absent trials, there were five conditions: Invalid(2), Same; Invalid(2), Reversed; Invalid(1), Same; Invalid(1), Reversed; and Neutral (as in Experiment 4.1). Memory questions referred to the given level of the to-be-remembered cue. The probe occurred randomly at the end of a trial, with a frequency of 20% across all trials in the block. The memory question asked participants to decide if the probe was the same as or different to the relevant level of the cue.

Results

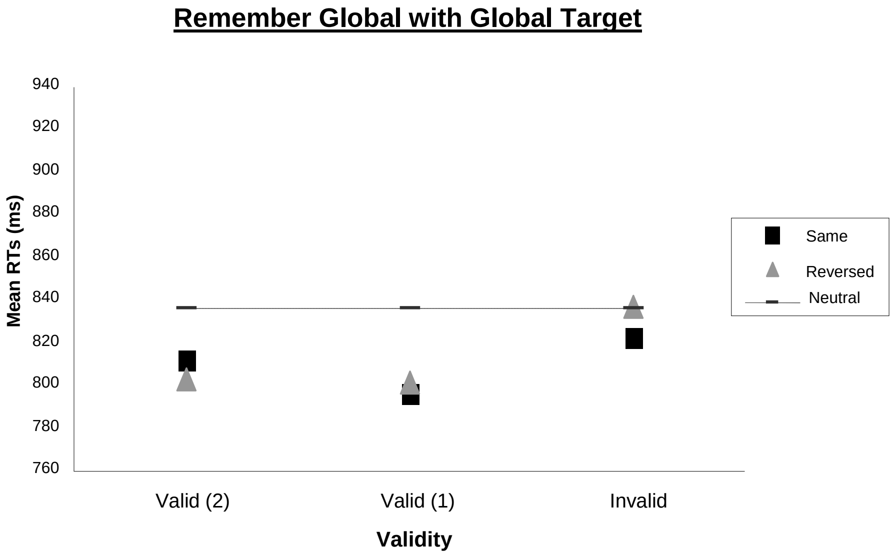
Data from 3 participants were discarded because they had error rates of over 30% in the memory test. The rest of the data were divided into two sets, according to whether the global or the local cue was memorised.

Remember Letter at a Global Level

1) Target-present data

The error rates for target detection and memory tasks were 4.6% and 5.6%, respectively (see Table 4.3 for overall data summary). There was no evidence of a speed-accuracy trade-off and the accuracy data were not analysed further. A 2 × 2 × 3 ANOVA was carried out on the mean RT data, with the factors being: Target level (local and global), Match (cue same or reversed), and Cue-target Validity (Valid(2), Valid(1), and Invalid). The neutral trials were not included here since they did not fit in the nested design. The results are shown in Figure 4.5. There was a significant effect of Target level ($F(1,21) = 17.1$, $p < .0001$). RTs were faster to global than local targets. There was no main effect of Cue-target Validity ($F(2,42) = 2.35$, $p = .11$), and no effect of Match ($F(1,21) = .5$, $p = .49$). All 2-way and 3-way interactions were non-significant ($F < 1.0$).

The data were sorted by Target Level, and the Match factor was averaged for each Cue-target Validity condition so that the Neutral condition could now be included in the analyses. For both the global and local levels, no contrasts reached significance (all $t < 1.0$).



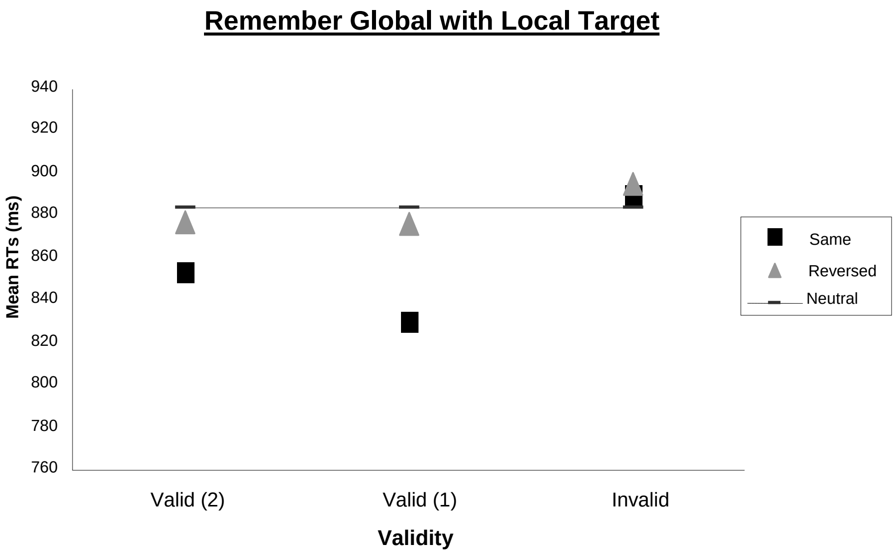


Figure 4.5. Experiment 4.1: Effect of memory of the hierarchical letter on target perception at different levels, shown for each validity condition. The mean RT in the Neutral condition is shown as a straight line.

Table 4.3. Error data on target-present trials in Experiment 4.2.

Target Level	Reversed	Validity	Search Errors (%)	Memory Errors (%)
Global	No	Valid	1.0	1.1
		Invalid	0.8	1.0
		Neutral	0.2	0.3
	Yes	Valid	0.1	0.2
		Invalid	0.3	0.2
		Neutral	0.3	0.1
Local	No	Valid	0.2	1.0
		Invalid	0.3	0.8
		Neutral	0.1	0.3
	Yes	Valid	0.9	0.1
		Invalid	0.2	0.2
		Neutral	0.2	0.1

2) Target-absent data

The means for target-absent trials are shown in Figure 4.6. The error rates for target detection and memory performance were 3.5% and 3.8% on average (see Table 4.4 for data summary). There was no evidence of speed-accuracy trade-off, and the accuracy data were not analysed further. Excluding the Neutral trials, a 2 × 2 ANOVA was conducted with the factors being Cue-target Validity and Match. Neither of the main effects were significant (Cue-target Validity ($F(1,21) = 1.4$, $p = .25$), and Match ($F(1,21) = .24$, $p = .63$)). The Validity × Match interaction was also not reliable ($F(1, 21) = .40$, $p = .54$).

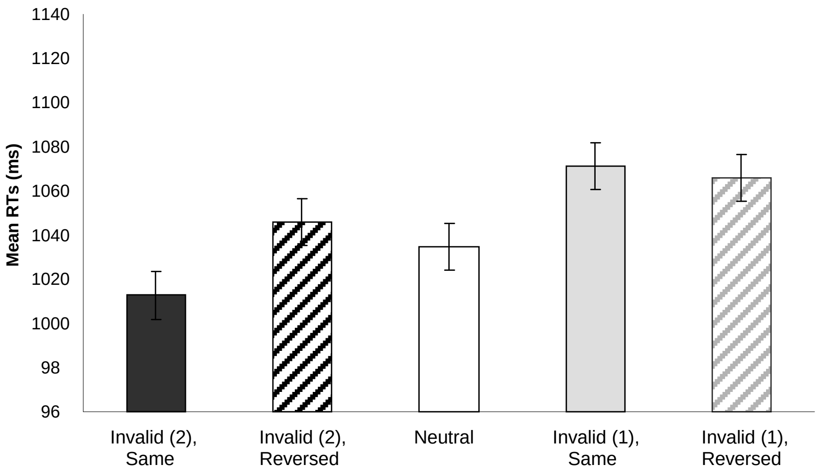


Figure 4.6. Target-absent data in Experiment 4.2: Effect of memory of letter at global level on target perception.

Table 4.4. Error data on target-present trials in Experiment 4.2.

Validity	Reversed	Search Errors (%)	Memory Errors (%)
Valid	No	0.7	0.9
	Yes	0.5	0.5
Invalid	No	0.9	1.1
	Yes	1.0	0.7
Neutral		0.4	0.6

Remember Letter at Local Level

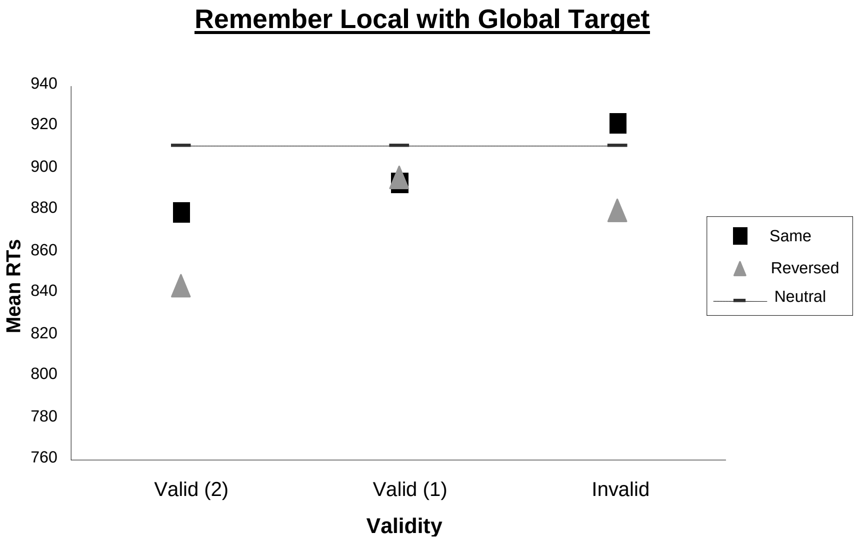
1) Target-present data

There was no evidence of a speed-accuracy trade-off and the accuracy data were not analysed further. The error rates for target detection and for the memory probe response were 4.8% and 5.5% on average (see Table 4.5 for data summary). As in the analyses on the trials with a global-level letter cue, an initial repeated-measures ANOVA was carried out on the mean RT data with the factors being: Target level (local and global), Match (cue reversed or not), and Validity (Valid(2); Valid(1); and Invalid), The results are shown in Figure 4.7. There were no main effects of Target level ($F(1,21) = 2.14$, $p = .16$) or Cue-target Validity ($F(1,42) = .96$, $p = .39$), but there was a border-line effect of Match ($F(1,21) = 4.2$, $p = .055$). There were reliable 2-way interactions of Target Level × Match ($F(1,21) = 4.9$, $p = .038$) and Cue-target Validity × Match ($F(2,42) = 4.1$, $p = .025$). No other interactions were reliable.

To assess the Target Level × Match interaction, the data were first averaged across Cue-target Validity, and the effect of Match (Same vs. Reversed) condition was evaluated for both the global and local target trials. For global target trials, there was no difference between the Same and Reversed conditions ($t(21) = -1.3$, $p = .20$). For local target trials, there was a significant difference between the two Match conditions ($t(21) = -2.7$, $p = .013$). RTs were faster on Same trials.

The Cue-target Validity × Match interaction reflects that, for both Valid(2) and Valid(1) trials, Same stimuli tended to generate faster RTs than Reversed stimuli whereas this was not the case for Invalid trials. However, individual comparisons between the conditions were not reliable.

The data were also averaged across the Match conditions to enable the Valid and Invalid conditions to be compared with the neutral baseline. A 2 (Target Level) × 4 (Cue-target Validity) ANOVA showed that there was a main effect of Target Level ($F(1,21) = 6.0$, $p = .023$), but no effect of Cue-target Validity ($F(3,63) = .72$, $p = .55$). The 2-way interaction did not reach significance ($F(3,63) = .64$, $p = .59$).



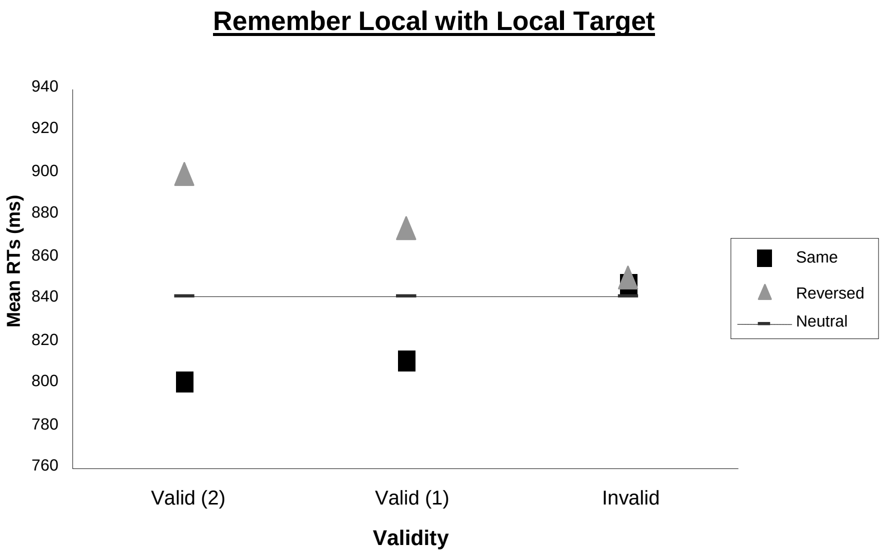


Figure 4.7. Experiment 4.2: Effect of memory of hierarchical letter on target perception at different levels, shown per each validity condition

Table 4.5. Error data on target-present trials in Experiment 4.2.

Target Level	Reversed	Validity	Search Errors (%)	Memory Errors (%)
Global	No	Valid	0.9	1.0
		Invalid	0.8	1.0
		Neutral	0.1	0.3
	Yes	Valid	0.1	0.2
		Invalid	0.3	0.1
		Neutral	0.5	0.3
Local	No	Valid	0.3	1.0
		Invalid	0.3	0.8
		Neutral	0.1	0.2
	Yes	Valid	1.0	0.2
		Invalid	0.2	0.2
		Neutral	0.2	0.2

2) Target-absent data

Again, there was no indication of a speed-accuracy trade-off. The error rates for the search and memory probe task were 4.0% and 4.1%, respectively (see Table 4.6 for the data summary). The overall data are presented in Figure 4.8. A repeated-measures ANOVA showed that the effects of Cue-target Validity and Match did not reach significance (F(1,21) = 2.6, *p* = .13 and F(1,21) = .22, *p* = .65, respectively). However there was a significant interaction between Cue-target Validity and Match (F(1,21) = 6.8, *p* = .02). This interaction reflected the opposite effects of Match (Same vs. Reversed) on Invalid(2) and Invalid(1) trials. On Invalid(2) trials, although non-significant, RTs tended to be faster on Same than Reversed trials (by 66 ms, t(21) = -1.4, *p* = .18), whereas on Invalid(1) trials RTs were faster on Reversed than Same trials (by 80 ms, t(21) = -2.4, *p* = .028). Comparisons were also conducted relative to the Neutral baseline. The only difference was between the Neutral trials and the Invalid(1), Reversed (t(21) = -2.7, *p* = .012).

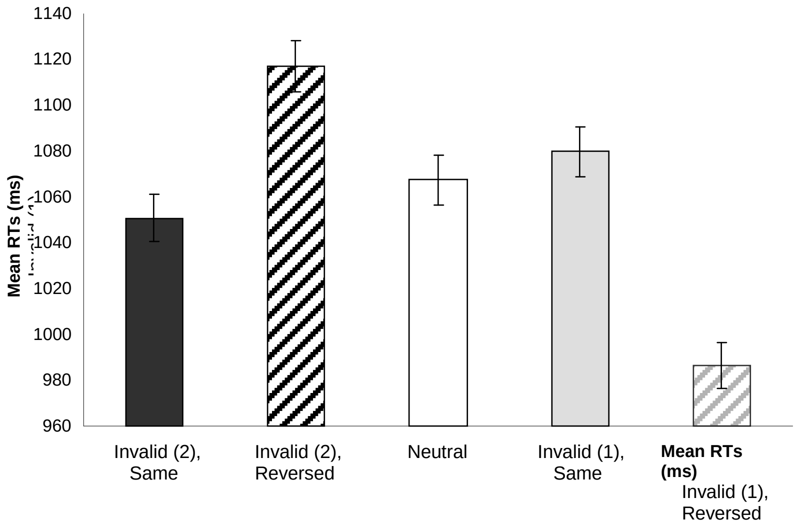


Figure 4.8. Target-absent data in Experiment 4.2: Effect of memory of letter at local level on target perception.

3) Cross-experiment analyses

To assess whether holding only one level of a hierarchical stimulus was different from holding both of the levels in influencing attentional selection, the data from Experiment 4.1 and 4.2 were taken together for cross-experimental comparisons.

Experiment 4.2 was divided into two groups (global-memory vs. local-memory trials) and each group was respectively analysed together with all the data from Experiment 4.1. For present trials in Experiment 4.1 vs. Experiment 4.2 with global memory cue, a mixed-design ANOVA was carried out, with one between-subjects factor (experiment) and three within-subjects factors (Target level, Match, and Cue-target Validity). There were main effects of Target level ($F(1,44) = 20.7$, $p < .0001$), Validity ($F(2,88) = 9.2$, $p < .0001$), and Experiment ($F(1,44) = 12.4$, $p < .0001$), but no effect of Match ($F(1,44) = .97$, $p = .33$). Target level × Experiment and Target level × Match interactions were significant ($F(1,44) = 4.3$, $p = .044$ and $F(1,44) = 4.2$, $p = .044$, respectively). No other 2-way interactions, and none of the 3-

way and 4-way interactions were significant ($F < 1.0$). The difference between RTs to global and local targets were greater in Experiment 4.2 (with a global memory, global < local RTs).

For Experiment 4.1 vs. Experiment 4.2 with local memory cue, the same mixed-design ANOVA was conducted. The main effects of Validity ($F(2,88) = 5.3$, $p = .007$), Match ($F(1,44) = 4.3$, $p = .044$), and Experiment ($F(1,44) = 16.5$, $p < .0001$) were found, but the effect of Target level did not approach significance ($F(1,44) = .4$, $p = .55$). There were 2-way interactions for Target level × Experiment ($F(1,44) = 4.8$, $p = .034$), Target level × Match ($F(1,44) = 10.6$, $p = .002$), Validity × Experiment ($F(2,88) = 4.9$, $p = .009$), and Validity × Match ($F(2,88) = 3.9$, $p = .023$). No other 2-way interactions were reliable, and so were none of the 3-way and 4-way interactions ($F < 1.0$). The Target level x Experiment interaction was due to the RTs to local and global target differing more in Experiment 4.2 (local < global in this local memory condition) compared with Experiment 4.1.

Across both sets of comparisons with Experiment 4.1, there were reliable interactions between Validity and Match which were not qualified by the Experiment. Taking Same letter trials, the mean RTs across the experiments were 748 ms for Valid (2), 745 ms for Valid (1) and 770 ms for Invalid trials. For Reversed letter trials the mean RTs were 784 ms for Valid (2), 747 ms for Valid (1) and 788 ms for Invalid trials. The Valid(2) condition tended to show a stronger effect of Same vs. reversed displays relative to the other conditions.

Table 4.6. Error data on target-absent trials in Experiment 4.2.

Validity	Reversed	Search Errors (%)	Memory Errors (%)
Valid	No	1.1	0.9
	Yes	0.3	0.6
Invalid	No	0.9	1.2
	Yes	0.9	0.8
Neutral		0.8	0.6

Discussion

When only one level of the hierarchical form had to be held in WM, there remained effects of the cue's identity on search. The effects varied according to whether the global or local letter was coded in memory. When the global letter was coded, the effects of cue validity were relatively small, though RTs to local targets were faster on valid trials when the matching level was same (especially in the Valid(1) condition). When the local letter was held in memory, there were effects of cue validity on detecting local targets. Relative to the neutral baseline, RTs were speeded when the letter remained at the same level and the target was validly cued (Valid, Same trials). In contrast, RTs tended to be slowed when the letters in the memory cue reversed (Valid, Reversed trials). This last result arose on trials when the target was at the global level of the cue and then at the local level in the probe. It may be that, even though only the local level of the cue had to be memorized, there was also coding of the global target, and this may then have cued attention to the global level of the probe, slowing RTs to the local target. This would be consistent with the identity of the global letter being coded even though only the local letter was relevant for memory. There were also effects of the memorized letter on absent trials. Absent RTs tended to be slowed when the local and global letters in the memory cue reversed in the probe and there was a clear difference in performance on Invalid(2) than Invalid(1) trials, which again points to both letters of the hierarchical form being coded in memory. Absent RTs were speeded when one letter repeated from the memory cue to the probe and it reversed levels. It is not clear why this result occurred but it suggests that a partial match (on Invalid(1) trials) allowed fast rejection of the irrelevant dimension. There was no other evidence for benefits from invalid cueing in this study, so we do not give strong weight to this one result.

Over and above the effects of the validity of the memory cue, the data indicate that RTs were faster to a global target when the global level of the memory cue had to be maintained (an overall global advantage) while they were faster to a local target when the local level of the memory cue was held in memory (an overall local advantage). This striking reversal indicates effects of holding a particular level of form in memory, which biases attention to the same level of form in a subsequent search task. Effects of having targets identified at the same level of form in local-global tasks have been noted before (Ward, 1984), but effects due to WM representation have not been reported. These data also stand in stark contrast to the results of Kim and Humphreys (submitted). In Kim and Humphreys (submitted), there were no effects of holding a particular size stimulus in memory on the subsequent selection of a local or global target; that is, there was no evidence for an effect based on memory for size. The contrast with the present results suggests that memory for stimulus level is more critical than for size. We elaborate on this point in the General Discussion.

General Discussion

Identity cueing

In the present study, we explored for the first time the effects on attention of different levels of hierarchical form maintained in WM. The identity of letters in WM that comprised a hierarchical memory cue influenced the deployment of attention toward either the global or the local level of a subsequent hierarchical probe. The effect of letter identity in WM replicates previous studies where letter identity coded in WM strongly modulated attentional selection (Kim & Humphreys, 2010), even when the identity was not a relevant element to the target detection task (e.g., when letter size rather than memory had to be maintained; Kim & Humphreys, submitted). Here, the data are extended by showing effects of both letter identities present in a memorized hierarchical letter. This was demonstrated most clearly on trials where the target was absent from the target letter display: RTs were slowed when a letter in a hierarchical form in memory was re-presented in the hierarchical probe and the target letter was absent, and this effect was greatest when both letters in the cue were repeated in the probe. We attribute this to the letter identity in WM cueing attention to the matching level in the probe stimulus, which slows RTs to then select both letters in the probe and/or which primes a ‘target present’ response.

In Experiment 4.1 (remember both letters of the hierarchical cue), there was evidence for facilitation on target present trials when only one of the letters matched the letter in the target (Valid(1)), relative to a neutral baseline. This held both when the target was at a global and when it was at a local level. In contrast, when both parts of the hierarchical cue were memorized and repeated (Valid(2) trials in Experiment 4.1), RTs were similar to neutral trials, when letters in the hierarchical cue did not repeat. There was also increased variance on Valid(2) trials relative to the neutral condition. Note that, on Valid(2) trials there was a match not only between a target in the cue and the probe, but also between the non-target letters in each hierarchical stimulus. To account for the data, we suggest that attention was drawn either to the matching target or to the matching non-target on different trials, with RTs benefitting in the former case but being slowed in the latter. The net results will be that RTs are similar to the neutral baseline, while the variance will increase. On Valid(1) trials, the non-target levels of the hierarchical cue and probe will not match and hence there will be less competition against the matching target. Benefits to target detection can then emerge. In Experiment 4.1 there was also a cost on invalid trials when one letter in the cue matched a global letter (with the target at the local level). A similar trend had been observed by Kim and Humphreys (2010), who found greater costs for local targets from invalid cueing to the wrong level, and they attributed this to the WM cue tending to direct attention to the global level. When the matching item at the global level is invalid, the detection of a local target is slowed.

Maintaining multiple levels of cues: Binding identities to level

When only 1 level of the cue had to be memorized (in Experiment 4.2), there were again effects of the identity of that memorized cue, but also of the other letter present in the memorised stimulus. Responses to local targets were affected by whether the letters in the cue remained at the same level or reversed in the probe, with faster RTs when they remained the same. This effect was strongest when both letter identities in the cue remained in the probe. On absent trials too performance was affected by whether identity information in the cue reversed in the probe, and there was a substantial RT slowing when both letters reversed (Invalid(2) Reverse) compared with when only one of the letters in the cue was present at a reversed level (Invalid(1) Reverse). These results provide evidence that, even when instructed to hold only one level of the stimulus in WM, participants represented both. Though there is substantial evidence from tasks requiring the immediate identification of hierarchical stimuli that the identities of stimuli at both local and global levels can be activated together (Navon, 1977), there is little prior work on the encoding of hierarchical stimuli in memory. The current data indicate that, when encoded in memory, both local and global levels of forms remain capable of influencing subsequent attentional selection, and this holds even when participants are instructed to selectively encode only one level (Experiment 4.2). In addition, across both experiments, the cueing effects tended to be stronger when the letter identities remained at the same level in the cue and the probe, compared with when they reversed levels. This provides evidence that participants did not simply maintained two letter identities but also coded the letters at the levels they originally appeared in. There was maintenance of letter binding to the level of form,

Interestingly, the magnitude of the cueing effects here were at least as large as those reported by Kim and Humphreys (2010) in their study of WM cueing from block forms, even though participants here maintained two identities in working memory. In Experiment 4.1 here (remember both levels of the forms) the cost on absent trials from re-presenting cued letters at both letters of the probe were 142 ms (Invalid(2) Same), whereas costs on absent trials from presenting the cue in WM at the global level of a subsequent probe (the strongest effect in Kim & Humphreys) was 39 ms. The costs on Invalid(2) Same trials in Experiment 4.2 (when only 1 level of the cue had to be maintained) were 22 ms (for remember global trials) and 16 ms (for remember local trials). Thus even when using similar stimuli we found no evidence of a diminution of cueing from having to hold two rather than one form in memory. In contrast to this, Soto and Humphreys (2008) reported that the effects of cueing from WM decreased when participants had to maintain two rather than one shape. In Soto and Humphreys, the shapes were presented as separate stimuli and so may have occupied two ‘slots’ in WM (Zhang & Luck, 2003).

Here the letter identities were presented within a single hierarchical stimulus, and there was evidence of binding of letter identities to their level in the cue. Such a hierarchical stimulus may only occupy a single slot in WM, and so may not be subject to the load effects reported by Soto and Humphreys (2008). Clearly the question of capacity constraints on the encoding of hierarchical forms in WM is a question worthy of further exploration.

Effects of matching the level of coding

Alongside the effects of cueing letter identities we found evidence of cueing from the memorized *level* of the hierarchical form to the matching *level* of the target. In Experiment 4.2, RTs were faster to global than local targets when participants had to memorize the global form of the memory cue. In contrast, RTs to local targets were faster than to global targets when participants memorized the local level of the memory cue. These results differ from prior studies where participants had to memorize the size of a memory cue that could match the size of the local and global forms. When stimulus size had to be memorized, there were no benefits for targets that matched the memorized size (though evidence for identity priming indicated that the memorized items still influenced search; Kim & Humphreys, 2010, submitted). The different pattern of results observed here suggests that the *level* of form being held in working memory is more critical than the absolute *size* of the stimulus. One way to think about this result is to suggest that working memory holds a control setting about the level of stimulus being represented, and the processing of the subsequent display is affected by this control setting. When the control setting is 'global', then the identification of a target coded at that level in a subsequent stimulus is facilitated (and vice versa for coding at a local level). The notion that a control setting may be represented in working memory, and this influences ongoing processes, fits with the literature on task switching. Effects of task switching can reflect the time taken to reconfigure the control setting that may be required for the new task, and this time can be modulated by 'task-set inertia', the tendency to maintain control-state settings across time (Monsell, 2003). In the current study, maintenance of the control-setting for the local or global level of the stimulus is carried over to influence target selection in the subsequent hierarchical stimulus.

Working memory and priming

The present effects are unlikely to stem from 'mere priming' from processing the memory cue. Kim and Humphreys (2010) tested for priming using blocks letters as cues and hierarchical stimuli as probes. Rather than having participants hold items in WM they had them identity the initial cues. They found a qualitatively different pattern of performance under priming conditions. On invalid trials (when the cue matched a non-target letter in the probe), RTs were facilitated rather than costs occurring (relative to when the cue was not re-presented in the probe). They attributed this benefit to a form of repetition suppression, in which perceptual processing was facilitated when the cue re-appeared in the subsequent display. In contrast to this, when the cue is held in WM it modulates where attention is directed, so that an invalid cue biases attention to a non-target form. Having cues identified, but not held in memory, does not have this potent effect on attention. In the present study we found clear evidence for invalid cues disrupting performance[5]. Our conclusion is that this pattern matched the WM rather than the priming conditions reported in Kim and Humphreys (2010), and they reflect top-down cueing from representations of the hierarchical forms in WM.

Memory top-up

It has been argued that effects of WM on subsequent selection can occur because participants attempt to 'top-up' their memory of the to-be-remembered form by attending to its re-appearance in a probe display (Woodman & Luck, 2007). The results found in the present study suggest that this is unlikely. As elaborated already, we found effects even when the identities of the letters in the memory stimulus reversed in the hierarchical probe, even though the memory test required the exact representation of the stimulus to be maintained. Deliberate attendance to such reversed figures would disrupt rather than boost memory, yes strong effects still emerged. Similar to other recent findings reported by Balani et al. (in press) and Kim and Humphreys (2010), the current results indicate that cueing from WM can occur even under conditions that are detrimental to memory representation, consistent with their being a genuine cueing of attention from WM representations.

[5] The one exception being the fast absent responses in Experiment 4.1 when one letter identity in the cue re-appeared at a reversed level in the probe. However, as we have noted this finding is anomalous in the context of the overall results and it is not clear why it arose.

Conclusions

The present study has shown that there can be cueing of attention from WM representations of hierarchical forms. These cueing effects are stronger when both levels of the form re-appear in a probe stimulus, when both letter identities are maintained at the same level, and they occur even when only one level of the initial hierarchical form has to be maintained. There was no evidence for these effects of cueing diminishing when two rather than one level of the initial form had to be maintained. There are in addition effects of carrying over the same control setting, when participants selective attend to one level of the initial form. The results highlight that multiple levels of stimuli in WM can modulate subsequent visual selection.

CHAPTER 5

The Lingering Trace of Working Memory on Visual Selection: Effects of Directed Forgetting

Synopsis

Previous studies show that visual selection can be affected by stimuli held in working memory (WM), even when the stimuli are irrelevant to a subsequent selection task. Here we examined whether the effect of an item in WM could be eliminated when participants were directed to forget it. Effects of holding the item in WM on subsequent selection were found for items that participants were directed to forget, even with relatively long cue-target intervals. The influence of directed forgetting on subsequent attention only decreased when there were multiple items initially in WM, and when other stimuli had to be maintained in WM while cued items had to be forgotten. We discuss the results in relation to the literature on directed forgetting and to the factors determining the interaction between WM and attention.

Introduction

Previous research has suggested that visual attention can be guided in a top-down manner from previously activated representations (Downing, 2000; Soto, Heinke, Humphreys, & Blanco, 2005; Soto, Humphreys, & Heinke, 2006; Kim & Humphreys, 2010), even when the representations are not relevant to current behavioural goals (Soto et al., 2005; Soto & Humphreys, 2009; Kim & Humphreys, 2010). For example, attention can be drawn to a stimulus that matches an item being held in WM, and this occurs under conditions where the WM stimulus never matches the search target (Soto et al., 2005). Similarly attention can be captured by a stimulus that is semantically related to a search target (Belke, Humphreys, Watson, Meyer, & Telling, 2008; Moores, Laiti, & Chelazzi, 2003; Telling, Kumar, Meyer, & Humphreys, 2010). These data have been modelled in a 'biased competition' framework (Duncan & Humphreys, 1989; Desimone & Duncan, 1995; Duncan, 1998), which suggests that when there is a match between a preceding cue and a following stimulus, attention is influenced by the match and selectively drawn to the matching part. This account is supported by considerable evidence from single-neuron and functional imaging studies (Cheazzi, Duncan, Miller, & Desimone, 1998; Brefczynski & De Yoe, 1999; Fockert, Rees, Frith, & Lavie, 2001; Reynolds & Desimone, 2003; Beck & Kastner, 2005), as well as behavioural data (e.g., Soto et al., 2005).

But what would happen if one discards the cued representations as irrelevant? Would the effect of a cue on attentional guidance be reduced or even disappear? How quickly might the effects dissipate? The ability to inhibit irrelevant information has been investigated through a paradigm called directed forgetting (DF) (Bjork, 1989; Bjork & Bjork, 1996, Basden & Basden, 1998). Typically in a DF task, items are given to participants to remember either as individual stimuli or in a unitized list, and then following a cue, participants are instructed to either remember or forget some of the initial memory stimuli. When tested for recall and recognition of the stimuli later, participants normally show reliably better performance with to-be-remembered than with to-be-forgotten items or lists (a DF effect). However, when the test is re-formatted with a list task, as opposed to the initial item task, the to-be-forgotten stimuli are recognised just as well as to-be-remembered ones, suggesting that the critical lists were temporarily suppressed, rather than entirely eradicated from memory. It has been also argued that a critical condition for the DF effect to occur is whether or not there are new items to learn after the forget instruction (Bjork, 1989; Conway, Harries, Noyes, Racsmany, & Frankish, 2000): the presence of new items to learn provides an opportunity for participants to focus attention on items to be remembered and away from the to-be-forgotten items, and this facilitates DF.

The data on DF suggest that the instruction to forget a stimulus leads to at least temporary suppression, blocking an item's later recall. In the present study we set out to test if an instruction to forget an item currently held in WM will suppress the effect of that item on the subsequent guidance of visual attention. Perhaps if the item remains available, then it will continue to have as strong an effect as a stimulus maintained in WM. In this case, a subsequent search task should be affected when the item originally held in WM re-appears in the search display. In contrast, if participants can discard an item from WM, then it should lose its influence on subsequent search. Performance should then be unaffected by whether the item re-appears in the search display.

To assess how selective visual attention is modulated by each WM and forgetting state, we used geometrical stimuli (coloured shapes and slanted lines, following Soto et al., 2005) as respectively the memory cue and search target, and gave instructions to remember or to forget the cue, as in typical DF studies (Experiment 5.1-4). Experiment 5.1 was conducted to set maintenance in WM against forgetting, with one memory item: we had participants hold a coloured shape in memory, and then gave them a ‘remember’ or a ‘forget’ cue before they looked for a slanted line contained in a shape. The memory cue could match a coloured shape surrounding either the target (valid) or a distractor (invalid), which should induce benefits or costs in search RT, respectively. If a forgetting effect occurs, any validity effect should be reduced in the ‘forget’ condition. In Experiment 5.2 we explored whether or not cueing from the WM item would still emerge even when there was no incentive to hold the cue to perform the search task. In this case we did not include valid trials so that the cue, when it re-appeared, never matched the target. In Experiment 5.3 and 5.4 we investigated whether the presence of additional memory items were necessary for a DF effect to occur. Here we used two memory cues, one of which was instructed to be forgotten (Experiment 5.3). This enabled us to see if the WM effect reduced when multiple items were held in WM (Soto & Humphreys, 2008), and whether a DF effect would then emerge (Experiment 3). In Experiment 5.4 we eliminated valid cueing trials under conditions with multiple initial items, to assess whether DF effects were most apparent under these conditions.

Experiment 5.1: One memory item, 30% cue-target validity

Method

Participants Fourteen students and staff (aged 18-35) at the School of Psychology of the University of Birmingham participated for course credit or cash. All reported having normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The experiment was run on a Samsung 920N colour monitor (resolution: 1280 × 1024 pixels), using E-Prime (version 2.0; PST 2002). Paint.NET was used to produce all the stimuli. Seven different line-drawn forms (circle, triangle, reversed triangle, square, diamond, hexagon, and star) and seven different colours (red, yellow, blue, green, orange, pink, and purple) were adopted to construct the stimuli. Each form was drawn in one of the colours and had an unfilled inside area. The dimensions of each shape in visual angle were as follows: 1.7 × 1.7° for the circle, 2.4 × 2.0° for the triangle, 2.0 × 2.4° for the reversed triangle, 2.0 × 2.0° for the square, 2.1°× 2.1° for the diamond, 2.2 × 2.2° for the star, and 2.4 × 2.0° for the hexagon. Two keys (left and right arrows) on the computer keyboard were used for the responses.

Task and Procedure Figure 5.1 shows the experimental conditions and the presentation sequence used in the current study. Each trial started with a 500 ms display of a shape in a colour randomly taken from the stimulus pool (7×7 combinations), which was presented as a memory item. Participants were instructed to hold both the shape and the colour in memory. This was followed by an auditory cue comprising one of two distinguishable tones of different lengths (600 ms vs. 170 ms, each with the same frequency of 44 kHz). The longer tone indicated that participants should keep holding the cue in memory and the shorter tone indicated that they should forget the cue. Participants were instructed to start each trial by remembering the memory cue as it was presented and then to keep remembering it or to forget it based on the subsequent auditory cue. After the auditory cue there was an interval (150 ms, 700 ms, or 1400 ms) until the search display appeared. The interval was kept constant within a block, and there were 2 blocks for each interval (6 blocks in total). The search display had five different shapes in five different colours that were drawn from the stimulus pool described above. The shapes were positioned at each point of an imaginary pentagon form (14.3 × 14.7°). Placed within each of these shapes was a black line (0.8°). All the lines were upright except for one that was slanted (7.5°) toward either right or left. The task was to look for this tilted line which could fall in one of the shapes on any the five angle points, before deciding on the direction of the slant. Left-arrow and right-arrow keys were used to respond to the left or right orientations, respectively. There were three experimental conditions in all trial sequences: Valid, Invalid, and Neutral. Valid trials were when the memory cue matched the search target based on the conjunction of the shape and the colour; Invalid trials were when the memory cue reappeared in the search display but contained a distractor; and Neutral trials were when the memory cue did not reappear in the search display. When the memory cue re-appeared it was as the original conjunction, and it never re-appeared as just the shape or the colour - there was never another stimulus present with either the shape or colour of the cue. Immediately after the response to the search display a memory probe was presented on trials where the memory had to be maintained. Participants had to decide whether or not the given item was the same or different to the one they were holding in their memory. For a ‘same’ response the probe had to match the memory cue in both shape and colour.

The memory probe appeared on 33 % of all trials, and 50 % of the probes were conjunction matches, with the rest equally representing a shape match, a colour match, or no match (all 'no' memory responses). Participants had a practice session of 20 trials at the beginning of the experiment. Each participant finished 6 blocks of 60 trials. The instructions emphasised both accuracy and response speed for both of the target search and memory tasks.

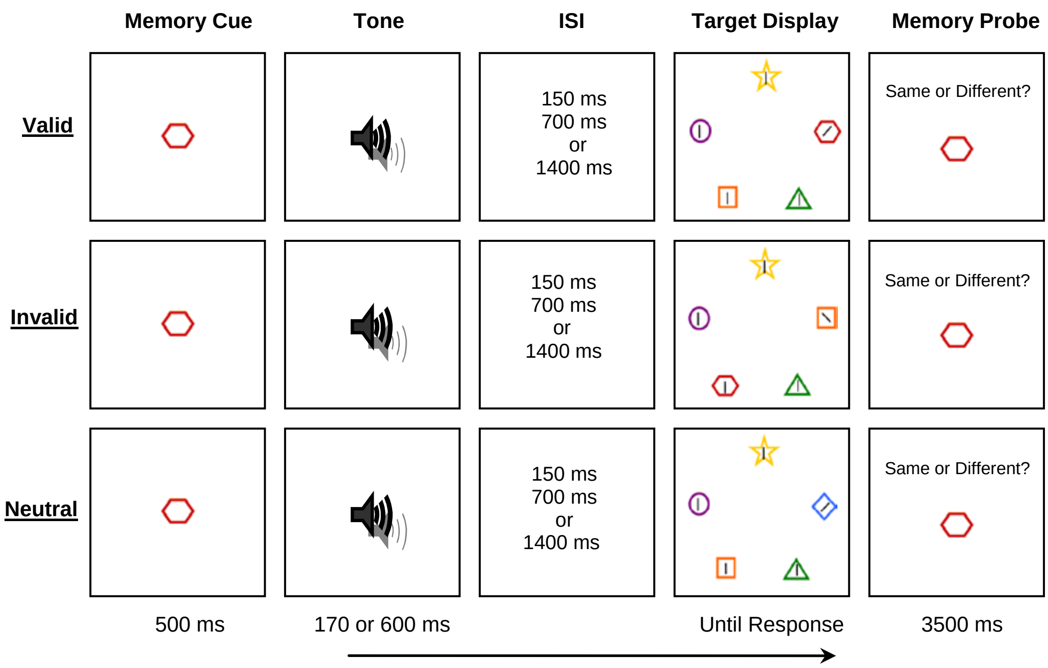


Figure 5.1. Experiment 5.1: Sequence of displays showing examples of experimental trials in three different conditions.

Results

In all experiments, only RTs for correct responses in the target search task were used. However trials with incorrect responses to memory probe questions were included in the analysis to secure the largest possible number of data (see Figure 5.2 for mean

RTs). The error rates for both target letter detection and memory probe were very low at 0.7 % and 2.7% on average, respectively (see Table 5.1 for overall data summary). There was no indication of a speed-accuracy trade-off and the accuracy data were not analysed further. A 2 × 3 × 3 ANOVA was carried out on the mean RT data, with three factors: Memory (remember vs. forget), Interval (150 ms, 700 ms, and 1400 ms) and Cue-target Validity (valid, invalid, and neutral). There was a main effect of Cue-target Validity ($F(2,26) = 96.6$, $p < .0001$), but no other main effects were found (all $F < 1.0$).

No 2-way interactions reached significance (all $F < 1.0$), but the 3-way interaction between Memory, Cue-target Validity, and Interval was reliable ($F(4,52) = 3.5$, $p = .014$).

To look into how the interaction was induced, the data from each memory condition (remember vs. forget) were analysed separately. For ‘remember’ trials, there was a significant main effect of Cue-target Validity ($F(2,26) = 66.4$, $p < .0001$), but no effect of Interval ($F(2,26) = 2.1$, $p = .14$). There was a trend for a Cue-target Validity × Interval interaction ($F(4,52) = 2.1$, $p = .099$). The validity effect tended to be larger at the shortest cue-target interval compared with the other intervals (298 ms, 236 ms, and 234 ms, respectively for the difference between Valid and Invalid trials). For ‘forget’ trials, there also was a main effect of Cue-target Validity ($F(2,26) = 71.6$, $p < .0001$), but no effect of Interval ($F(2,26) = .21$, $p = .81$), and the Cue-target Validity × Interval did not approach significance ($F(4,52) = 1.4$, $p = .26$). If anything, the validity effect tended to be smaller at the shortest cue-target interval (193 ms, 247 ms, and 210 ms for the difference between Valid and Invalid trials across the three intervals).

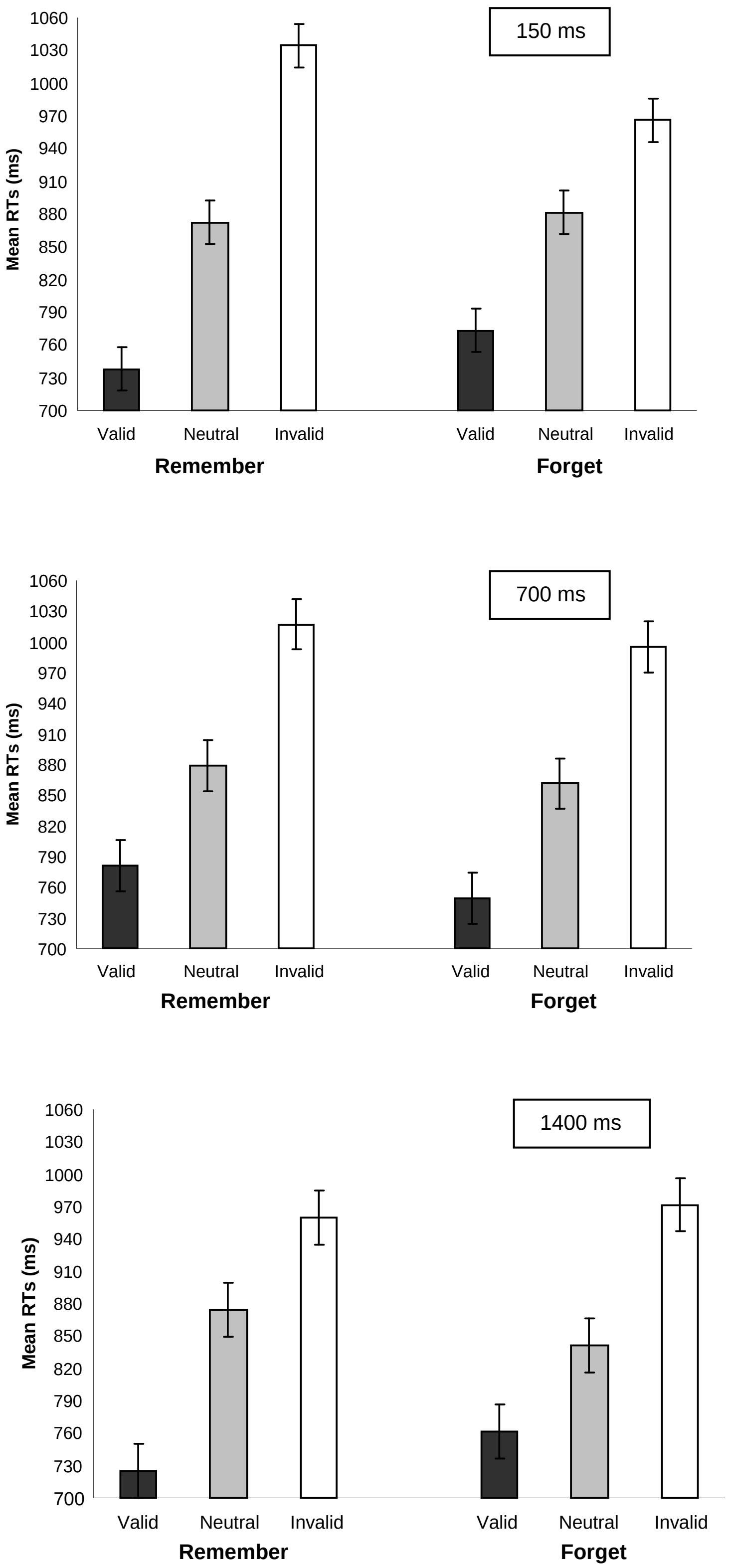


Figure 5.2. Experiment 5.1: Effect of remembering and forgetting an object on target search for trials with different inter-stimulus interval (150 ms, 700 ms, and 1400 ms from top to bottom). The error bars represent standard error (this applies to all figures in the present paper).

Table 5.1. Error data for Experiment 5.1.

Memory	Inter-stimulus Intervals (ms)	Validity	Search Errors (%)	Memory Errors (%)
Remember	150	Valid	0	0.2
		Invalid	0	0.3
		Neutral	0.1	0.3
	700	Valid	0	0.1
		Invalid	0.1	0.3
		Neutral	0	0.2
	1400	Valid	0	0.1
		Invalid	0.1	0.1
		Neutral	0.1	0.2
Forget	150	Valid	0	0.1
		Invalid	0	0.1
		Neutral	0	0.1
	700	Valid	0.1	0.2
		Invalid	0.1	0.1
		Neutral	0	0.1
	1400	Valid	0	0.1
		Invalid	0	0
		Neutral	0.1	0.1

Discussion

There were strong effects of cue validity irrespective of whether participants were instructed to maintain the WM cue or whether they were asked to forget it. In the 'forget' condition, performance did not vary across the three cue-target intervals here, so there was no sign that participants were able to remove the cue from WM, given sufficient time. In the WM condition, however, there was a trend for stronger cueing at the shortest cue-target interval, perhaps because there was an initial 'refreshing' of the memory representation when participants were told to maintain the stimulus.

In Experiment 5.1, the memory cue was valid on 30% of the trials. With search displays of 5 items, this means that the cue carried some information about the target's location in display, as the target was 4 times more likely to occur in the location of the memory cue than in one of the other four shapes present, when the memory cue reappeared in the search display. This might have meant that participants continued to maintain the cue even in the forget condition, and they might have been reinforced by the valid trials to use the cue deliberately to bias search. In Experiment 5.2 we eliminated this possibility by never having the cue contain the target, when the cue re-appeared. Prior work shows that when participants are instructed to maintain the cue in memory, reliable effects of attentional guidance are found even when the cue is never valid (Soto et al., 2005). Does that hold for the forget condition?

One other point to note is that evidence for an effect of the memory cue on forget trials goes against the argument that memory effects on search are due to participants using the search display to 'top up' their memory. It has been argued that effects on search can arise if participants deliberately attend to the reappearance of the memory cue in order to refresh their memory (see Woodman & Luck, 2007). On forget trials here, participants were told they did not have to remember the cue and so any strategy to attend to the cue's reappearance should be abandoned. There was no evidence that this occurred, however, even though participants had up to 1400 ms to stop the deliberate allocation of attention. This 'stop time' is long outside the length of time required to inhibit a response, based on evidence from the stop signal paradigm (Logan, 1984).

Experiment 5.2: One memory item, Cue never valid

Method

Participants Seventeen students and staff (aged 19-35) at the School of Psychology of the University of Birmingham participated for course credits or cash. All reported having normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The same apparatus as for Experiment 5.1 was used. All the stimuli had the same properties as the ones specified in the previous experiments.

Task and Procedure The trial sequence and the task were the same as in Experiment 5.1. The only change made in the current experiment was that valid trials, where the memory item matched that of the target, were not included in this experiment; only invalid and neutral conditions were run.

Results

The error rates for target search and memory tasks were 0.7% and 2.1% (see Table 5.2 for overall data summary). There was no evidence of a speed-accuracy trade-off, and we did not analyse the accuracy data further. A 2 × 2 × 3 ANOVA was carried out on the mean RT data, and the factors were Memory (remember vs. forget), Cue-target Validity (invalid and neutral), and Interval (150 ms, 700 ms, and 1400 ms). The results are shown in Figure 5.3. There was a main effect of Cue-target Validity ($F(1,16) = 68.1$, $p < .0001$) and a borderline main effect of Interval ($F(2,32) = 2.8$, $p = .077$), but the effect of Memory did not reach significance ($F(1,16) = 2.3$, $p = .16$). The Memory × Cue-target Validity and Memory × Interval interactions were significant ($F(1,16) = 15.4$, $p = .001$ and $F(2,32) = 6.1$, $p = .006$, respectively) but the Cue-target Validity × Interval interaction did not reach significance ($F(2,32) = .07$, $p = .93$). There was a reliable 3-way interaction ($F(2,32) = 9.9$, $p < .0001$). Separate analyses were conducted contrasting the two memory conditions.

On 'remember' trials, a 2 (Validity) × 3 (Interval) ANOVA showed that there were significant main effects of Cue-target Validity ($F(1,16) = 56.1$, $p < .0001$) and Interval ($F(2,32) = 5.1$, $p = .012$). The Validity × Interval interaction was also significant (F(2,32) = 4.8, p = .016). The validity effect at the short interval (Invalid – Neutral = 184 ms) was greater than at the long interval (96 m, t(16) = 3.1, p = .007) but not at the intermediate interval (130 ms, t(16)= 2.0, p = 0.64). The Validity effects at the longer intervals did not differ (t(16) = -1.1, p = .28).

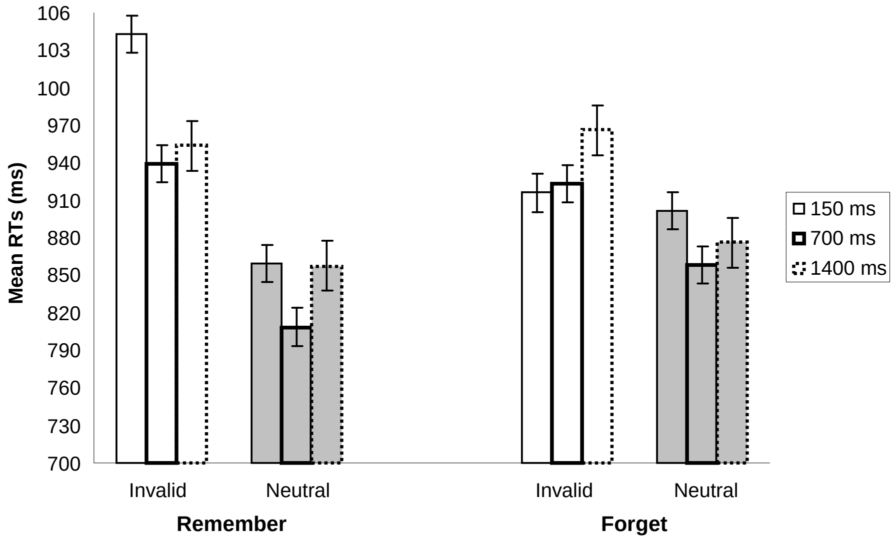


Figure 5.3. Experiment 5.2: Effects of WM and forgetting on Invalid and Neutral trials.

The same ANOVA on 'forget' trials revealed that there was a main effect of Validity (F(1,16) = 21.1, p < .0001) but no effect of Interval (F(2,32) = 1.1, p = .36). The Cue-target Validity × Interval interaction did reach significance, however (F(2,32) = 6.7, p = .004). The effect of validity was larger at the longest and intermediate intervals (90 ms and 65 ms) than at the shortest interval (14 ms; t(16)= -3.3, p = .004 and t(16)= -2.6, p = .02, respectively). At the shortest interval the Cue-target Validity effect was not reliable (t(16)= .99, p = .33).

Cross-experimental analyses were conducted extracting data from trials with a 1400 ms interval between the cue and target from Experiment 5.1. A mixed-design

ANOVA showed that there was a reliable effect of Cue-target Validity ($F(2,62) = 68.0$, $p < .0001$), but no effect of Memory ($F(1,31) = .0001$, $p = .99$). There was a borderline effect of Experiment ($F(1,31) = 4.0$, $p = .054$). No 2-way interactions reached significance (all $F<1.0$), but the Cue-target Validity × Memory × Experiment 3-way interaction did reach significance ($F(2,62) = 4.3$, $p = .017$). The effects of cue validity were stronger in Experiment 5.1 than Experiment 5.2, especially for the forget condition. However, effects of validity remained reliable in the longer intervals of Experiment 5.2.

Table 5.2. Error data for Experiment 5.2.

Memory	Inter-stimulus Intervals (ms)	Validity	Search Errors (%)	Memory Errors (%)
Remember	150	Invalid	0	0.3
		Neutral	0	0.3
	700	Invalid	0.1	0.2
		Neutral	0	0.1
	1400	Invalid	0.1	0.1
		Neutral	0	0.3
Forget	150	Invalid	0.1	0.2
		Neutral	0.1	0.2
	700	Invalid	0	0
		Neutral	0.1	0.2
	1400	Invalid	0.1	0.1
		Neutral	0.1	0.1

Discussion

As in Experiment 5.1, there were reliable effects of cueing in both the remember and the forget conditions, even though the cue was never valid here. This suggests that the cueing effects arose automatically. This held on forget as well as remember trials.

Nevertheless, across the cue-target intervals cueing tended to be stronger on remember than forget trials, generating an interaction between the memory condition and cue-target validity. This was not apparent in Experiment 1. This suggests that reducing the cue's validity did tend to weaken its effect in the forget condition, though the effect remained significant.

There were also some variations in performance in the remember and forget conditions across the cue-target intervals. As in Experiment 1, cueing in the remember condition tended to be strongest at the short cue-target interval, consistent with the cue representation being temporarily re-freshed when participants were instructed to maintain it in memory. Interestingly the opposite result arose in the forget condition, where cueing tended to increase at the longer intervals. One possible reason why this result would occur is that there is a temporary inhibition of the cue's representation in the forget condition, reducing its effect at the shorter intervals. There is some evidence to support this. The difference between invalid and neutral trials at the shortest interval here (a non-significant 14 ms) tended to be smaller than in Experiment 5.1 (85 ms). No similar trends were present in the remember condition (the equivalent values were 184 ms vs. 163 ms). These data fit with there being greater temporary suppression of the cue's re-presentation in Experiment 5.2, when the cue was never valid. If this suppression is short-lived, though, then cueing effects could increase as the cue-target interval lengthens.

Experiments 5.1 and 5.2 demonstrate that participants found it difficult to eliminate effects of the cue, even when it was never valid and even when they were instructed to forget it. However these results occurred under conditions in which there was only a single item that was initially represented in memory. It may be that it is easier to eliminate an item from memory, and to prevent it from influencing search, if there are several stimuli competing for selection. Soto and Humphreys (2008) examined cueing effects from WM when multiple items had to be maintained. They found that cueing effects reduced when two rather than one item was held in WM, and they reduced again when participants were engaged in articulatory suppression and so had an increased processing load. They suggested that there was weaker top-down guidance from WM under these conditions. Given this, we may expect that effects of reducing the memory's potency, by instructions to forget the cue, might be particularly effective when multiple stimuli are initially maintained – and this may be especially the case when other stimuli remain held in WM. That is, even if the 'forget' instruction does not lead to the eradication of the memory representation, it may lead participants to prioritise a to-be-remembered item and place to-be-forgotten item into the background. Holding a stimulus in the 'foreground' of WM may be critical to the item subsequently influencing attention (see Olivers, 2009). This was tested in Experiment 3, where we presented two stimuli to be held in WM, and then, in the critical condition, instructed participants to forget one. Work on directed forgetting suggests that forgetting effects might be maximised under condition where multiple items need to be represented and other stimuli maintained when a stimulus has to be forgotten (e.g., Bjork, 1989; Conway et al., 2000). Would DF under these conditions still lead to the initial stimuli modulating subsequent visual selection?

Experiment 5.3: Multiple memory items, cue 30% valid

Method

Unless otherwise mentioned the Method was the same as for Experiments 5.1 and 5.2.

Participants Nineteen students (aged between 19 and 31) at the School of Psychology of the University of Birmingham participated for course credit. All had normal or corrected-to-normal vision.

Task and Procedure The overall sequence of trial was same as Experiment 5.1 and 5.2, except that in the current experiment there were two memory cues presented consecutively with an interval of 1000 ms between them (see Figure 5.4). Participants were instructed to remember both of the cues in the order they were presented, so that they could identify each cue (both the shape and the colour) as well as the order of the two items later on at the time of the memory probe. While holding both items in memory, participants heard an auditory cue (the long or the short tone, as in Experiment 5.1 and 5.2), which instructed them either to keep remembering both items, or to forget the first and only remember the second one. A search display followed after an interval of 1400 ms, which was identical to the display in the previous experiments.

There were three cue-target validity conditions: valid where the cue contained the target; invalid where the cue was re-presented but contained a distractor; and neutral where the cue was not re-presented in the displays). Critically, only the first memory cue was presented in the search display, and the second cue (nor any of its properties) was never presented in the search display. A memory probe was presented after the search display on forget and remember trials. However on forget trials, memory was only tested for the to-be-remembered second item.

Results

The error rates for the target search and memory tasks were 1.0% and 4.6% (see Table 5.3 for an overall summary of the data). There was no evidence of a speed-accuracy trade-off, and we did not analyse the accuracy data further. A 2 × 3 ANOVA was carried out on the mean RT data for the search task, with Memory (remember vs. forget) and Cue-target Validity (valid, invalid, and neutral) as factors. The results are shown in Figure 5.5.

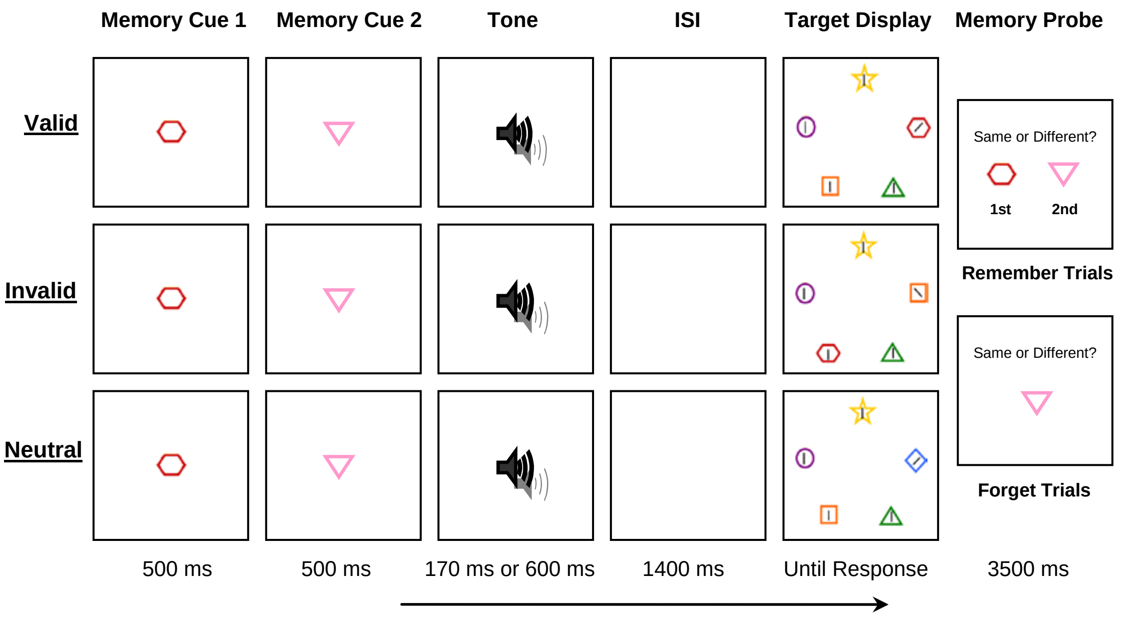


Figure 5.4. Experiment 5.3: Sequence of displays showing examples of experimental trials in three different conditions.

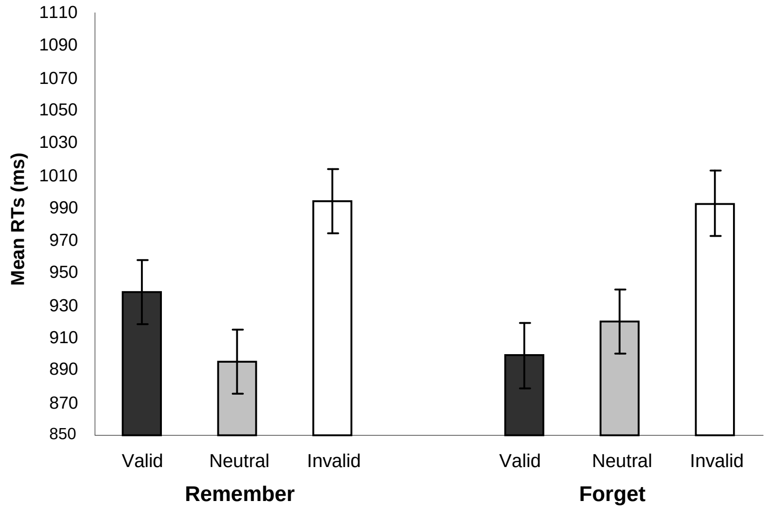


Figure 5.5. Experiment 5.3: Effects of WM and forgetting on Valid, Invalid and Neutral trials.

There was a main effect of Cue-target Validity ($F(2,36) = 26.4$, $p < .0001$) but no effect of Memory ($F(1,18) = .16$, $p = .69$). The 2-way interaction did not reach significance ($F(2,36) = 2.2$, $p = .13$). The data were averaged across Memory conditions to decompose the significant effect of the Cue-target Validity. Pair-wise tests showed that there was a reliable difference between Invalid and Neutral conditions ($t(18) = 6.4$, $p < .0001$), and between Valid and Invalid ($t(18) = - 6.2$, $p < .0001$). Valid and Neutral conditions did not differ from each other ($t(18) = .83$, $p = .42$)

A cross-experiment comparison was carried out with Experiment 5.1 to test if cueing effects were overall greater in Experiment 5.1, where there was one memory cue, compared to when there were two as in the current experiment. Taking the data with a 1400 ms interval from Experiment 5.1, a mixed-design ANOVA was performed. There was a reliable main effect of Cue-target Validity ($F(2,62) = 67.8$, $p < .0001$), and a borderline effect of Experiment ($F(1,31) = 4.0$, $p = .054$), but no effect of Memory ($F(1,31) = .00$, $p = .99$). The Cue-target Validity × Experiment interaction reached significance ($F(2, 62) = 18.8$, $p <.0001$), as did the Cue-target Validity ×

Memory × Experiment interaction ($F(2,62) = 4.3$, $p = .017$). The effect of validity was larger in Experiment 5.1 than Experiment 5.3, and the change in the magnitude was larger on remember trials (Invalid – Valid = 56 ms in Experiment 5.3 vs. 234 ms in Experiment 5.1) than on forget trials (Invalid – Valid = 94 ms in Experiment 5.3 vs. 210 ms in Experiment 5.1).

Table 5.3. Error data from Experiment 5.3.

Memory	Validity	Search Errors (%)	Memory Errors (%)
Remember	Valid	0.2	0.7
	Invalid	0.1	1.1
	Neutral	0.2	0.8
Forget	Valid	0.3	0.7
	Invalid	0.2	0.7
	Neutral	0	0.6

Discussion

The data from Experiment 5.3 confirm that, even when instructed to discard one of two items from WM, the discarded items can still influence the allocation of attention in a subsequent search display. The results occurred despite the memory load being increased here (initially 2 rather than 1 item had to be maintained) and despite one item always being held in WM. Replicating Soto and Humphreys (2008), there was evidence that the effects of cue validity reduced relative to when only one item was held in WM (in Experiment 5.1), but this effect of load was if anything greater for stimuli maintained in WM (on remember trials) and for those that had to be discarded (on forget trials). The result emphasises the difficulty of nullifying the effect of the memory trace of items initially placed into WM. Effects on remember trials here might reflect a reduced initial 'refreshing' of memory under greater load; this refreshing was evident at the shortest cue – search interval in Experiment 5.1.

To provide an even stronger test of the effects of load, Experiment 5.4 was conducted. In Experiment 5.4, we replicated Experiment 5.3 but removed trials where the cue sometimes validly indexed the target. When the cue re-appeared it was now always invalid. Does this eradicate attentional cueing from WM in the forget condition?

Experiment 5.4: Multiple memory items, cue never valid

Method

Participants For Experiment 5.4a, fifteen students and staff (aged 19-35) at the School of Psychology of the University of Birmingham participated for course credit or cash. A new different pool of twenty-one students and staff (aged 18-28) took part in Experiment 5.4b. All reported having normal or corrected-to-normal visual acuity.

Apparatus and Stimuli The apparatus and all stimuli had the same properties as the ones specified in the previous experiments.

Task and Procedure The trial sequence and the task were the same as in Experiment 5.3. The important change was that valid trials, where the memory item matched that of the target, were not included in this experiment and only invalid and neutral conditions were run. With these two conditions, two sets of experiment each with two different ISIs (150 ms vs. 700 ms, Experiment 5.4a, and 1400 ms vs. 2700 ms, Experiment 5.4b) were carried out.

Results

Experiment 5.4a

Figure 5.6 gives the mean RT data. The error rates for target and memory tasks were 0.5% and 5.0% (see Table 5.4 for an overall data summary). There was no evidence of a speed-accuracy trade-off, and we did not analyse the accuracy data further. A 2 × 2 × 2 ANOVA was carried out on the mean RT data, with Memory (remember vs. forget), Interval (150 ms and 700 ms), and Cue-target Validity (invalid and neutral) as factors.

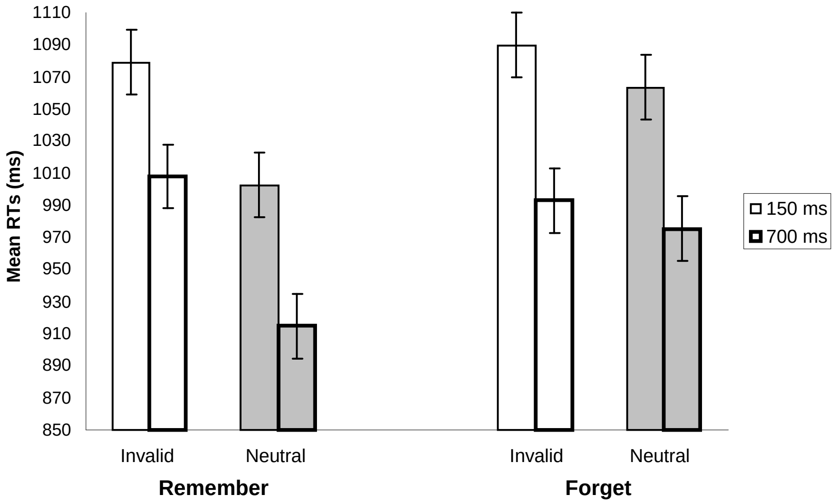


Figure 5.6. Experiment 5.4a: Effects of WM and forgetting on Invalid and Neutral trials with two different inter-stimulus intervals, 150 ms and 700 ms.

There were main effects of Cue-target Validity ($F(1,20) = 14.6$, $p = .001$) and Interval ($F(1,20) = 37.8$, $p < .0001$), and a borderline main effect of Memory ($F(1,20) = 4.2$, $p = .055$). The Memory × Cue-target Validity interaction reached significance ($F(1,20) = 4.7$, $p = .04$). The other 2-way and 3-way interactions were not significant (all $F<1.0$).

The Memory × Cue-target Validity interaction was further explored by analysing each memory condition separately. On 'remember' trials, a 2 (Validity) × 2 (Interval) ANOVA showed that there were significant main effects of Cue-target Validity ($F(1,20) = 37.7$, $p < .0001$) and Interval ($F(1,20) = 21.4$, $p < .0001$). The Cue-target Validity × Interval interaction was not significant ($F(1,20) = .54$, $p = .47$). Cue-target Validity effects (Invalid – Neutral trials) tended to be larger at the 700 ms than the 150 ms interval (93 ms vs. 76 ms), although the difference was not reliable ($t(20) = -.7$, $p = .47$). Cue-target Validity effects were reliable at both intervals ($t(20) = 3.7$, $p = .001$ and $t(20) = 6.2$, $p = .0001$ for the 150 ms and 700 ms intervals, respectively). The same ANOVA on 'forget' trials revealed that there was a main effect of Cue-target Validity ($F(1,20) = 26.1$, $p < .0001$) but no effect of Interval ($F(1,20) = .78$, $p = .40$). Cue-target Validity × Interval interaction did not reach significance ($F(1,20) = .07$, $p = .81$). Averaging across the intervals, the Cue-target Validity effect (Invalid – Neutral trials) was larger on remember than forget trials (84 ms vs. 22 ms; ($t(20) = 2.2$, $p = .043$).

Table 5.4. Error data from Experiment 5.4a.

Memory	Inter-stimulus Intervals (ms)	Validity	Search Errors (%)	Memory Errors (%)
Remember	150	Invalid	0	0.4
		Neutral	0	0.5
	700	Invalid	0.1	0.5
		Neutral	0	0.8
Forget	150	Invalid	0.1	0.9
		Neutral	0.2	0.6
	700	Invalid	0	0.6
		Neutral	0.1	0.7

Experiment 5.4b

The mean RT data are given in Figure 5.7. The error rates for target search and memory tasks were 0.4% and 4.7% (see Table 5.5 for overall data summary). There was no evidence of speed-accuracy trade-off, and the accuracy data were not analysed further. A 2 × 2 × 2 ANOVA was carried out on the mean RT data, with as factors Memory (remember and forget), Interval (1400 ms and 2700 ms), and Cue-target Validity (invalid and neutral). There was a main effect of Cue-target Validity (F(1,14) = 5.4, p = .036) but no effects of Memory (F(1,14) = 1.6, p = .23) or Interval (F(1,14) = 2.3, p = .16). The Memory × Cue-target Validity interaction was significant (F(1,14) = 9.3, p = .009) but the other 2-way and 3-way interactions did not reach significance (all F<1.0).

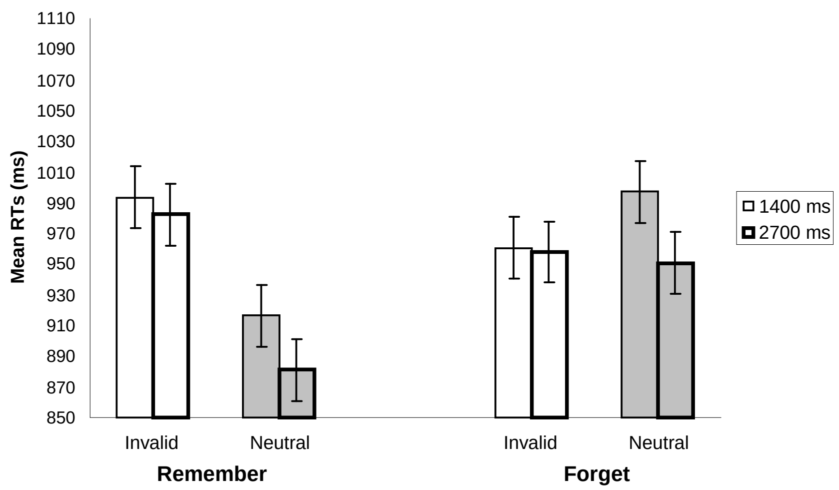


Figure 5.7. Experiment 5.4b: Effects of WM and forgetting on Invalid and Neutral trials with two different inter-stimulus intervals, 1400 ms and 2700 ms.

Separate analyses contrasted the conditions under each memory condition. On 'remember' trials, a 2 (Cue-target Validity) × 2 (Interval) ANOVA showed that there was a significant main effect of Cue-target Validity (F(1,14) = 14.8, p = .002), but no effect of Interval (F(1,14) = 2.5, p = .14). Invalid trials were slower than Neutral trials, and this held across the Intervals. The Cue-target Validity × Interval interaction did not reach significance (F(1,14) = .78, p = .39). For ‘forget’ trials there was a main effect of Cue-target Validity (F(1,14) = 5.2, p = .04), but no effect of Interval (F(1,14) = 1.8, p = .20). The Cue-target Validity × Interval interaction was significant, however (F(1,14) = 5.6, p = .033). At the 1400 ms interval, Invalid trials tended to be faster than Neutral trials (960 ms vs. 996 ms), although the difference did not reach significance (t(14) = -1.2, p = .25). There was no difference between Invalid and Neutral trials at the longer cue-target interval (958 ms vs. 951 ms, t(14) = .27, p = .79). The overall interaction between Memory and Cue-target Validity arose because the effect of Cue-target Validity was stronger on remember than on forget trials, and the effects reversed in direction (an overall cost for invalid trials in the remember condition, 89 ms vs. an overall benefit in the forget condition, 15 ms).

Table 5.5. Error data for Experiment 5.4b.

Memory	Inter-stimulus Intervals (ms)	Validity	Search Errors (%)	Memory Errors (%)
Remember	1400	Invalid	0	0.8
		Neutral	0	0.4
	2700	Invalid	0.1	0.4
		Neutral	0	0.6
Forget	1400	Invalid	0.1	0.6
		Neutral	0.1	0.7
	2700	Invalid	0	0.5
		Neutral	0.1	0.7

Discussion

Under conditions of a greater memory load and when the cue was never valid, clear differences emerged between the remember and forget conditions. In the remember condition, the effects of the cue were generally stronger than in the forget condition. Furthermore, while the remember condition generated costs from invalid cues on search across the cue-target intervals, the forget condition generated a trend for benefit at shorter cue-target interval. How real this benefit is may be questioned, given that there was no consistent evidence for it at the other (longer and shorter) cue-search intervals (Experiment 5.4a and 5.4b). Nevertheless, facilitation from the cue could occur if the cue's representation is suppressed. In this case, the re-presented cue will be less likely to attract attention than the other stimuli, facilitating search for the target. Benefits from invalid cueing from WM have been reported before under conditions where the cues are always invalid (Han & Kim, 2009; Woodman & Luck, 2007). In our study, suppression occurred in the forget rather than the remember condition. It is interesting to note that these results arose when there was an increased memory load (in Experiment 5.4b) but not Experiment 5.2, when there was a single cue that was always invalid, revealing some consistency with overall findings on directed forgetting, that directed forgetting is most evident when there are additional stimuli to maintain in memory (Bjork, 1989; Coway et al., 2000). It also suggests that cue suppression is easier when there is not a single item at the forefront of WM (cf. Olivers, 2009; Soto & Humphreys, 2008). The suppression effect may arise at the intermediate interval if suppression takes some time to effect (see also Han & Kim, 2009), and it may not be evident at longer intervals if the item is then actually eliminated from memory.

General Discussion

We have reported four experiments where we investigated effects on attentional selection from cues that participants were instructed to either hold or discard from WM. In Experiment 5.1 we had participants remember or forget one item. There were strong cue-target validity effects across the memory conditions, with no evidence of the forget condition having cue-suppressing effect. When the same test was carried out in a stronger format without including valid trials (Experiment 5.2), the cueing effect tended to reduce with the effect being stronger in the forget condition. Increasing the WM load decreased cueing generally, but if anything effects were stronger on remember trials (Experiment 5.3). However, when increased WM load was imposed without valid trials (Experiment 5.4), clear disparity emerged between the remember and forget conditions. In this case, cueing was either eliminated or reversed for the forget condition.

As in other studies of attentional capture from WM, cues actively maintained in WM affected subsequent search performance – search benefitted when the cue was re-presented and contained the target (on valid trials) and it was disrupted when the re-presented cue contained a distractor (on invalid trials). This held across a range of cue-target intervals, and it occurred even when the cues were always invalid (e.g., Experiment 5.2). The effect decreased but was still apparent when the memory load increased (Experiments 5.3 and 5.4). These results replicate data reported by Downing (2000), Olivers (2009), Olivers, Meijer, and Theeuwes, (2006), Soto and Humphreys (2007, 2009), and Soto et al. (2005).

The novel results arose in the conditions where participants were instructed to forget the WM cue. When a single cue was present it had a strong effect on search, even when it was always invalid (Experiments 5.1 and 5.2). In the latter case, cueing effects were generally reduced relative to when the cues were sometimes valid, but, if anything they increased as the cue-target interval increased. This fits with participants temporarily inhibiting the cue (reducing its activation level); however if such inhibition is temporary, then the cue representation may regain its activation level over time, to re-exert its influence on selection. When the memory load increased (with 2 rather than 1 item initially being held), there was again a decrease in cueing on forget trials, and when the cue was always invalid and there was a longer cue-target interval, then search was facilitated when an invalid cue was present. This last result would follow if there was active suppression of the cue's representation over time.

The present results fit with the larger literature on directed forgetting in showing that it is difficult for participants to eliminate the effect of a stimulus currently being in WM. When there was a single stimulus the evidence suggests that it could be temporarily suppressed, but this was not effective over time (Experiment 5.2). The findings from directed forgetting studies suggest that the potency in memory of to-be-forgotten information is not largely affected by the instruction to forget: recognition performance for to-be-forgotten items have not been found to be depressed (Elmes, Adams, & Roediger, 1970; Geiselman, Bjork, & Fishman, 1983; Gross, Barresi, & Smith, 1970), and effects from 'forgotten' items can be restored at full strength under appropriate conditions (Bjork & Bjork, 1996).

Any evidence for longer-term suppression here was only evident when there was an increased memory load and another item was held at the forefront of WM (Experiment 5.4b). The data are consistent with the view that stimuli held at the forefront of WM exert a strong influence over subsequent selection, even when participants are instructed to forget them and even when they are never valid. It also appears to be difficult to eliminate such stimuli from WM, especially if only a single item is maintained in memory. However, the representation of the item to-be-forgotten is less effective when other items must be maintained in WM. The data also suggest that items held in WM do not simply decay when participants are asked to forget them, but rather there is a process of active suppression in which a representation of the stimulus is maintained but suppressed from positively guiding attention.

One last point to note is that evidence for an effect of the memory cue we found here on forget trials goes against the ‘memory refresh’ argument that memory effects on search arise because participants deliberately attend to the re-appearance of memory cue in the search display in order to aid their memory (see Woodman & Luck, 2007). On forget trials in the current experiments, participants were not just told that they did not have to remember the cue but they were instructed to forget it, and therefore there should have been little attempt to refresh their memory, intentionally or otherwise.

CHAPTER 6

General Discussion

Synopsis

As indicated throughout the thesis, selective visual attention and its interaction with WM is still a moot issue. The present thesis explored this open question, focusing on how WM might affect attentional selection in hierarchical forms. When an item is held in WM, would it affect the selection of global and local forms, and would this effect be different from effects of merely identifying the initial stimulus? If the memorised item is a size that corresponds to the dimension of target at global or local level, would it facilitate the process of target selection? Also what if the memory item is itself hierarchical? I also looked at inhibitory mechanisms linked to forgetting from WM (Bjork & Bjork, 1996): would intentionally forgetting an already memorised item suppress or perhaps eliminate the effect of WM? In the following sections key findings from each chapter are noted, and a few main issues are discussed.

Summary of Chapters

Chapter 2: The effects of WM and perceptual priming on hierarchical perception in divided and focused attentional modes

The experiments in the first empirical chapter were carried out to explore how WM and mere priming might differentially affect selective attention in hierarchical forms. Replicating previous findings (Downing, 2000; Soto et al., 2005; Olivers et al., 2006; Soto & Humphreys, 2009), there was a strong effect of validity from holding a letter identity in WM: when the identity of a cue was held in memory, there was benefit on valid trials (when the cue matched the target), and cost on invalid trials (when the cue matched the distracter). Furthermore the cost was bigger when the target was at local level (with the cue matched the distracter at the global level) than when it was at global level (with the cue matched the distracter at the local level). In addition to demonstrating cueing effects from WM, these results also suggest that a global bias emerges when stimuli in WM match a target at the global dimension. Intriguingly, all these effects occurred in an opposite manner in a no-memory condition where the cue was merely identified. Under this priming condition, there was a benefit on valid trials (as in the WM condition) but invalid trials also induced benefit, rather than a cost to target detection. Here, when the cue matched distracter, it facilitated rather than disrupted target detection. The different pattern of effects from WM and priming conditions suggests that there might be qualitatively dissimilar processes involved: WM facilitates target detection by biasing attention to a stimulus that matches the memory content, whilst priming helps target detection by facilitating the encoding of a repeated stimulus.

These data on the contrast between the effects of WM and of priming converge with functional imaging data reported by Soto et al. (2007). As noted in the Introductory Chapter, Soto et al. found opposite activation patterns under conditions of WM and priming. Under WM conditions, re-appearance of a cue in a display resulted in increased activity in a number of areas often associated with memory including the superior frontal gyrus, and the parahippocampal gyrus and the lateral occipital complex. In contrast, under priming conditions these areas showed reduced activity. Soto et al. proposed that the last result reflected a form of repetition suppression, when perceptual encoding is facilitated by repetition. The increased activity under WM conditions, then, may stem from matching an incoming repeated stimulus to memory, which then provides an enhanced signal to drive attention to the location of the matching stimulus. Whatever the case, the results fit with the pattern reported here and indicate that a qualitatively different pattern of processing emerges under WM compared with priming conditions.

The data reported in Chapter 2 also replicated prior results in showing an effect of WM on cueing attention even when the memory cue was never valid, leaving little incentive for participants to attend to the memory item in the search display (see also Soto et al., 2005). This finding provides support to the notion that information in WM can automatically cue attention to matching stimuli, even when this is never beneficial to target selection. Lastly, when participants were tested in a focused mode of attention where the level of the target was preselected, the WM effect still arose as did the contrasting priming effect. The overall effects, however, were less potent as they were under divided attention.

Chapter 3: Size information in WM and its attentional effect on the perception of hierarchical forms

Chapter 3 examined the effects of the size information of a memory cue on the selection of a subsequent target in a hierarchical letter stimulus, by having participants hold the cue's size in WM for later recognition. Across four experiments there was no evidence for an effect of whether the cue size matched the size of the local or global target letter. This goes against the idea that local and global letters may be selected by opening an attentional window to a size matching that of the to-be-selected letter. However, although remembering the cue size did not affect subsequent selection, performance was affected by the identity of the cue (RTs were faster when the identity of the cue matched the target and they were slowed when the cue's identity matched the non-target level of the hierarchical stimulus, compared with the neutral baseline when the cue did not re-appear). This indicates that cue identity was coded implicitly, even when only the size had to be memorised, and it replicated the effects found in the first set of experiments from Chapter 2. When the cue identity had to be maintained in WM, not the cue size, the effects of cue identity again emerged but now effects of cue size were apparent – though again there was no effect of a match between the size of the cue and the size of the letter that had to be discriminated. In this case there were differential effects of identity-cueing following large and small cues – large invalid cues tended to enlarge costs to targets, while small cues tended to generate benefits without costs. To account for these results, I propose that large cues tend to induce a distributed mode of attention. When this distributed mode is adopted, attention is likely to be cued to distracter information that matches stimuli in WM even if the distracter does not match the 'template' for the target. As a consequence, costs from invalid cueing increase. In contrast, small letter induce a more focused mode of attention in which irrelevant information in WM only guides attention when it coincides with attentional guidance from the template for the target. This will enhance effects of valid cueing. These last results confirm that the sizes of the stimuli used in this chapter were sufficient to influence performance, but there remained no evidence for size-based cueing of attention.

One other aspect of the data reported in Chapter 3 to note is that, on memory test trials, the identity of the letter remained the same as that initially present in the cue, and only memory for size was tested. This means that there was no incentive for participants to attend to the identity of a matching letter in the hierarchical stimulus in order to 'top-up' their memory. Despite this, effects of identity cueing still emerged. This goes against the argument that the effects of the WM cue arise because participants deliberately attend to the re-appearance of the cue in order to top-up their memory (see Woodman & Luck, 2007, for this argument).

Chapter 4: WM for hierarchical stimuli and selective attention

Chapter 4 explored the effects of holding in WM visual stimuli that have separate local and global representations. In one case, both dimensions of the hierarchical stimulus had to be maintained, in another only one level had to be held in memory. In both cases, repeating the identity of letters present in the initial cue in the subsequent hierarchical letter probe affected responses to the probe. With one exception these effects were stronger when both levels of the probe were repeated than when only one level was repeated, and this occurred even when participants only had to memorise one level of the cue. The effects were also stronger when the letters in the cue maintained their positions in the probe. The results indicate that participants represent in memory both levels of the hierarchical stimulus, even when selective encoding instructions are given, that the letter identities are bound to their levels in the hierarchical form, and that both levels of the cue in memory can modulate subsequent attentional selection. The exception to this was the effects of valid cueing, which reduced when both levels of the cue repeated compared with when only one level repeated. This reduction also coincided with an increase in variance on trials when both levels of the cue repeated. I interpreted this increase in variance to participants sometimes being cued to attend to the target (speeding RTs) but also sometimes being cued to attend to the non-target level of the probe, which also matched the cue (when both letter identities repeated). If there is cueing to the target and non-target levels on around 50% of the trials, the benefits from valid cueing will be eliminated. One noteworthy point about this is that the biasing effects of the WM cue seem somewhat 'unintelligent' in that biasing to non-targets seems as potent as biasing to targets. This is consistent with the cueing from WM being reflexive rather than purposeful here.

Although participants had to maintain two letter identities in Experiment 4.1 of Chapter 4, there was no evidence that cueing effects were reduced (either compared with the data reported in Kim & Humphreys, 2010, Chapter 2, or with the data from Experiment 4.2, Chapter 4, when only one level of the form had to be memorized). Previously Soto and Humphreys (2008) reported that cueing from WM decreased as the WM load increased. The present data suggest that load effects may be weaker (or even eliminated) when stimuli are bound together in a single hierarchical representation, relative to when stimuli are coded as separate items (as in Soto & Humphreys, 2008). In terms of a 'slot' version of WM (Zhang & Luck, 2008), it can be argued that the letters in a hierarchical form only take up one slot in WM whereas separate stimuli take up two slots. Load effects are apparent only in the last instance.

There was also evidence of carry-over effects from the memorised level of the hierarchical form to the matching level of the target (Chapter 4, Experiment 4.2). When participants memorized the global level of the cue, RTs to global targets were generally facilitated (even on neutral trials). When participants memorized the local level of the cue, RTs to local targets were boosted. This differs from the data reported in Chapter 3, when participants had to memorise the size of a memory cue that could match the size of the local and global forms. When stimulus size had to be memorised, there were no benefits for targets that matched the memorised size. The different pattern of results observed here suggests that the *level* of form being held in working memory is more critical than the absolute *size* of the stimulus coded there. One way this can be conceptualised is in terms of attentional control settings. I propose that the attentional control setting is set to particular level of the hierarchical form, when only one level of the form has to be memorised. On the immediately following event (detect a target in a probe display), the same control setting may be applied, which facilitated selection of stimuli matching the setting. This links to studies of task switching where it has been argued that at least task switching costs can be conceptualized in terms of the time required to re-configure attentional control settings across tasks (Monsell, 2003).

Chapter 5: WM and forgetting

The data presented in Chapter 5 deviated from the study of hierarchical forms to consider the effects of forgetting rather than remembering information in WM. A directed forgetting paradigm was adopted for this, varying the memory load and the cue-target intervals. Participants held a coloured shape in memory and were then subsequently asked to maintain the memory content or abandon it. The shape could then be re-presented in a search display, with the search task being to discriminate the orientation of a bar that could appear within irrelevant shapes (following Soto et al., 2005). Here, when a single cue was present it had a strong effect on search not only for remember condition and also for forget condition, and this held even when the cue was always invalid to the target display. Varying the time interval between the cue and the target did not make notable differences for either condition, suggesting that participants were not able to really ‘forget’ the cue even when given prolonged time to do so. When the memory load increased to two items from one item, and when the cue was never valid, some clearer differences between the remember and forget cues did appear – now the cueing effect was stronger in the remember than the forget condition. Indeed, there was even some evidence that, in the forget condition, RTs were facilitated by the re-appearance of the cue even when it invalidly cued the target. This last result is consistent with participants inhibiting the cue, so that it is no longer a strong competitor with the target – enabling attention then to be drawn more easily to the target. The idea that stimuli may be initially be inhibited when participants are told to forget them matches with the directed forgetting literature (Bjork, 1989; Bjork & Bjork, 1996, Basden & Basden, 1998). Inhibition may be applied in order then to reduce the activation of the item in WM. This application of inhibition may also be helped by having participants also keep in memory a second item (under the increased load condition). Direct forgetting literature suggests that forgetting is most evident when there are additional stimuli to maintain in memory, indicating that whether or not there are new items to learn after the forget instruction is critical for the DF effect to occur (Bjork, 1989; Conway et al., 2000).

General Discussion

From the above results, several general conclusions can be made:

WM vs. Perceptual Priming in Hierarchical Perception

As laid out in the Introduction, WM has been found to tightly interact with attentional selection. WM content, in a top-down manner, influences the selection of task-relevant targets amongst multiple bottom-up 'candidates', much as biased competition model suggests (Downing, 2000; Soto et al., 2005; Soto & Humphreys, 2008, 2009; Olivers et al., 2006). The overall findings from the present thesis broadly, and those from Chapter 2 categorically, support this proposal. There was a benefit when memory cue matched target and there was a cost when the memory cue matched a distracter. This held across the levels at which the target was coded in Chapter 2 and also in Chapter 4, although, notably, the cost was bigger when the distracter matching the target was at the global level, relative to the local level. The global advantage that emerged specifically under WM load is an interesting finding which may provide explanations for some of the results in related previous studies (e.g., Soto el al., 2005) – top-down effects from WM might be more effective when a WM-target match occurs at a global level of representation of a display, relative to when it occurs at a local level. Attentional guidance perhaps might be globally biased.

Another notable finding is the contrast between the WM and perceptual priming conditions. The behavioural data obtained in the present studies confirm neurophysiological evidence that shows the neural basis of facilitation and suppression induced by WM and mere identification differ (Soto et al., 2007).

WM Effects on Irrelevant Features

As further evidenced in the present thesis, information held in WM seemed to exert automatic guidance on attentional allocation, making participants involuntarily attend to matching visual data. The WM effect also extended to irrelevant features of a memory item, as shown in Chapter 4. When a stimulus at one level of a hierarchical form was held in memory, letters from the irrelevant level still modulated attention. Unlike effects with separate forms (Soto & Humphreys, 2007), there also appeared to be few capacity limitations on cueing from hierarchical forms (effects were as strong when both levels of a form had to be memorized as when only one level was memorized). These results provide supporting evidence not only to the notion that WM has powerful influence on selection. They also indicate that WM and selective attention operate in an object-based as well as a space-based way, and that it can occur across multiple levels of form of automatic guidance of WM contents.

Hierarchical Targets, Focused and Distributed Attention

Although there was no evidence for effects of holding a specific size in memory, there were effects of the absolute size of the letter that was maintained. The cueing of identity from a large letter led to increased costs on invalid trials, and the cueing of identity from a small letter led to increased benefits without costs. From this last result I propose that attentional selection in hierarchical forms might be modulated by whether participants adopt a focused or distributed mode of attention, rather than having a narrow or wide attentional window. Other authors (Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Hernández, Costa and Humphreys, 2010) have also argued that, when participants adopt a distributed mode of attention, they are more likely to be captured by irrelevant distractors, and this effect can be enhanced when the distractors also match the context of WM (Hernández et al., 2010).

Rather than suggesting that local and global forms are selected by setting an attentional window of a given size, the current results indicate that the letter identities at both levels of form can be derived in parallel. Which level is first selected can then be determined by various factors including the saliency of the items and whether they match information in WM. In the current study, matching to WM biased selection. Although the letter identities seemed to be processed in parallel, there was also evidence of an attentional control setting being applied, once a given level was selected (Chapter 4). This might reflect a post-selection process adopted under conditions of selective attention, when only a particular level of form has to be identified and/or held in memory.

Memory Top-up

One of lingering issues in the discussions of WM as a top-down guide of visual attention concerns whether or not WM content has been deliberately 'topped up' by participants while carrying out the task, and this might give rise to the cue-target validity effect. Throughout the present thesis, however, a good deal of evidence has been presented to counter the argument. For example, there was an effect of irrelevant identity when the task was to remember the size but not the identity of the cue (Chapter 3, Experiment 3.2); there was a WM cueing effect from a level of a hierarchical cue that was reversed in the hierarchical target display, even though the memory task asked for memory for an exact match to the cue (Chapter 4); and there was a strong cueing effect from items once held in WM but later forgotten, even though the instruction was explicitly to forget the cue and there was little incentive for participants to attend to the memory (Chapter 5). These results add convincing weight to the view that the process of attentional allocation can be automatically biased when there is a match between WM content and a target.

Suppression and Forgetting

In confirmation of the larger literature on directed forgetting, the results reported in the present thesis showed that it was difficult for participants to eliminate the effect of a stimulus currently being held in WM. Removal of the influence of an item in WM was possible only when there was an increased memory load and another item held at the forefront of WM, and the WM stimulus never cued a target. The data are consistent with the view that stimuli held at the forefront of WM exert a strong influence over subsequent selection, even when participants are instructed to forget them and even when they are never valid.

The data seem to suggest that it takes active intentional suppression to effectively ‘forget’ items that are already held in WM, because it was not easy to observe DF effect here. This matches with evidence for temporary suppression of the WM cue (Chapter 5, Experiment 5.4), although this only arose under load conditions. This in turn suggests that suppression from WM might not reflect a deliberate effort to forget, but rather it may be a by-product of having to concentrate on other items in memory. This view indicates that there might be some limitations in adopting ‘forgetting’ in its everyday sense – and deliberate forgetting may not work as well as occupying the mind with another stimulus/task. As a further exploration, focusing on the last result where there was a significant effect of forgetting, it might be worthwhile to have a closer look at the diversion of attention. There is evidence that WM can guide attention to targets that are semantically associated to the WM content, not just to those that are matching (Moores et al., 2003). Would it be relatively easier to direct attention away (or "forget") from the memory item to another one that is unrelated than to one that is related?

Concluding remarks

The findings in the current thesis provide novel additions to the existing data for WM-attention mechanisms, consistent with the biased competition framework: I set out to explore how WM could guide visual attention non-spatially, contrasting performance with a no-memory priming condition. With their 'local' and 'global' dimensions, the 'hierarchical' stimuli that I employed were suitably structured for looking at the non-spatial deployment of attention. The top-down WM effect found here appeared to be automatic, occurring even when the memory cue was always invalid, just as in studies where spatial attention is biased by WM (e.g., Soto et al, 2005), and there was also evidence for effects of visual information at an task-irrelevant level (when the attribute of the memory cue did not have to be memorised). Interestingly, the WM effect was more pronounced when the memorised item was present at global level than at local level. In addition, when the information held in WM was itself hierarchical, there was a consistent effect of the level of the stimulus held in WM, which influenced attentional selection in the subsequent hierarchical stimuli. Also remembering both of the levels or only one of the levels brought about similar WM carry-over effects in compound stimuli. The equally potent effects of selection from attended and unattended attributes supports the important notion that the cueing effect from WM is reflexive and involuntary, rather than purposeful and under voluntarily control.

As is noted previously, a considerable amount of evidence shows that attentional influences are present in early visual areas including the primary visual cortex and even the LGN, which is often considered a ‘messenger’ organ to pass on visual data incoming through the retina (See Kastner & Pinsk, 2004, for a review). This indicates that there may not be ‘pure’ bottom-up sensory representations of visual information in a strict sense, and further, that top-down mechanisms might play a more important role than sometimes thought in attentional selection. The influential framework of biased competition emphasises the role of WM as a top-down control process, and the present thesis reconfirms this mechanism, whilst expanding our understanding by showing how the effects of WM influence the selection of non-spatial properties in hierarchical perception

Visual attention can select a particular region of the space so as to increase the efficiency of processing visual data occurring in that region. Visual attention can also select visual stimuli at different levels of hierarchical representation, even when stimuli fall at the same location both forms of selection are influences in an involuntary manner, by stimuli held in WM.

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