University of Cyprus

DEPARTMENT OF PSYCHOLOGY

ATTENTIONAL CAPTURE BY VISUAL OBJECT- REPRESENTATIONS

DOCTOR OF PHILOSOPHY DISSERTATION

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2018

DEPARTMENT OF PSYCHOLOGY

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A Dissertation Submitted to the University of Cyprus in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

April, 2018

VALIDATION PAGE

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Doctoral Thesis Title: Attentional Capture by Visual Object-Representations

The present Doctoral Dissertation was submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy at the ***Department of Psychology*** *and was approved on the 03/04/2018 by the members of the* ***Examination Committee****.*

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DECLARATION OF DOCTORAL CANDIDATE

The present doctoral dissertation was submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy of the University of Cyprus. It is a product of original work of my own unless otherwise mentioned through references, notes, or any other statements.

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…………………………………….. [Signature]

Περίληψη

Η σύλληψη της προσοχής από ένα αντικείμενο συμβαίνει όταν αυτό ταιριάζει με τα περιεχόμενα της μνήμης εργασίας. Η τρέχουσα μελέτη ερεύνησε ένα αντίστοιχο αποτέλεσμα στις αναπαραστάσεις των οπτικών περιοχών: Όταν υπάρχει αναζήτηση σε μια σειρά αναπαραστάσεων οπτικών αντικειμένων, τότε ένα αντικείμενο που κρατιέται στη μνήμη εργασίας οδηγεί αυτόματα την προσοχή σε μια αντίστοιχη αναπαράσταση. Η επίδειξη του φαινομένου βασίστηκε στην ανάλογη επιχειρηματολογία για την αυτοματοποίηση της σύλληψης της προσοχής. Ως εκ τούτου, για την επικύρωση της αυτόματης λειτουργίας χρησιμοποιήθηκαν τρεις προϋποθέσεις για αυτόματη σύλληψη: α) Η στρατηγική εμπλοκή της προσοχής αποτρέπεται όταν ο προσανατολισμός της προσοχής σε μια οπτική αναπαράσταση είναι αρκετά γρήγορος, β) Η προσοχή σε μια οπτική αναπαράσταση που είναι σχετική με ένα αντικείμενο στην μνήμη εργασίας δεν θα πρέπει να αποτελεί μέρος του έργου στη διάταξη των αναπαραστάσεων των οπτικών περιοχών γ) Η αντιληπτική και γνωστική απαίτηση για τη σύγκριση ενός αντικειμένου και μιας οπτικής αναπαράστασης πρέπει να είναι χαμηλή. Στο Πείραμα 1 χρησιμοποιήθηκαν οι τρεις συνθήκες αυτοματισμού και παράχθηκαν οφέλη στους χρόνους απόκρισης, τα οποία ήταν ισοδύναμα με εκείνα της επιλεκτικής αναδρομικής προσοχής στις οπτικές παραστάσεις. Τα αποτελέσματα έδειξαν ότι η προσοχή καθοδηγείται από τα περιεχόμενα της μνήμης εργασίας και διευκολύνει την ανάκληση υπό τις τρεις συνθήκες αυτόματης λειτουργίας. Στο Πείραμα 2, τα οφέλη του χρόνου απόκρισης δείχθηκαν να είναι σταθερά με την αυξημένη εγκυρότητα του αναδρομικού δείκτη, γεγονός που έδειξε ότι ο προσανατολισμός της προσοχής στην αντίστοιχη αναπαράσταση προς το αντικείμενο στη μνήμης εργασίας ήταν αυτόματος. Το Πείραμα 2 έδειξε περαιτέρω ότι οι τρεις συνθήκες αυτοματισμού ήταν επαρκείς για την αυτοματοποίηση της καθοδηγούμενης προσοχής στις οπτικές περιοχές. Στο Πείραμα 3, η τρίτη συνθήκη για την αυτοματοποίηση αφαιρέθηκε με την αύξηση της ομοιότητας μεταξύ των αντικειμένων και απαιτώντας μια νοητική περιστροφή πριν από τη σύγκρισή τους. Η ακρίβεια της ανάκλησης ήταν πάνω από το επίπεδο των τυχαίων αποκρίσεων, αλλά τα οφέλη του χρόνου απόκρισης εξαλείφθηκαν. Το Πείραμα 3 επιβεβαίωσε το Πείραμα 2 ότι τα οφέλη του χρόνου απόκρισης παρήχθησαν από την αυτόματα καθοδηγούμενη προσοχή στις οπτικές αναπαραστάσεις. Η αυτόματα καθοδηγούμενη προσοχή στις αναπαραστάσεις των οπτικών περιοχών ολοκληρώνει ένα πρότυπο αλληλεπίδρασης μεταξύ της μνήμης εργασίας και της προσοχής. Όταν η στρατηγική προσοχή κατευθύνεται στο οπτικό πεδίο διευκολύνεται από την προσοχή που καθοδηγείται αυτόματα από τη μνήμη εργασίας όταν ο στόχος αναζήτησης

και το περιεχόμενο της μνήμης εργασίας είναι συμβατά. Στην παρούσα μελέτη, δείχθηκε μια αντίστοιχη αλληλεπίδραση μεταξύ της μνήμης εργασίας και της προσοχής στις οπτικές αναπαραστάσεις. Η αρχικά αυτόματα καθοδηγούμενη προσοχή από το περιεχόμενο της μνήμης εργασίας συνιστά τη σύλληψη της προσοχής στις αναπαραστάσεις των οπτικών περιοχών και διευκολύνει τη στρατηγική προσοχή και την αναζήτηση σε αυτές.

Abstract

Attentional capture by an object occurs when the object matches the contents of working memory. The current study investigated a corresponding effect in the visual areas representations: When there is a search in an array of visual object-representations, then an object which is held in working memory automatically guides attention to a matching representation. The demonstration of the effect was based on the analogous argumentation for the automaticity of attentional capture. Hence, three conditions for automaticity for attentional capture were employed to validate the automaticity of the effect: (a) Strategic attention is prevented when focusing on a visual representation is fast enough; (b) Attention to a visual representation relative to an object in the working memory should not be part of the task in the array of the representations of the visual areas c) The perceptual and cognitive requirement for comparing an object and a visual representation must be low. In Experiment 1 the three conditions of automaticity were employed and benefits on response times were produced, which were equivalent to those of selective retrospective attention in the visual representations. The results demonstrated that attention was guided by the working memory contents and facilitated recall under the three automaticity conditions. In Experiment 2, the benefits of the response time were shown to be constant with the increased validity of the retrospective cue, which showed that the orientation of attention to the representation relevant to the object in working memory was automatic. Experiment 2 further demonstrated that the three conditions for automaticity were sufficient for the automaticity of the guided attention in the visual areas. In Experiment 3, the third condition for automaticity was removed by increasing the similarity between the objects and requiring a mental rotation before their comparison. The accuracy of recall was above the chance level but response time benefits were eliminated. Experiment 3 confirmed Experiment's 2 results that the response time benefits were produced by the automatically guided attention in the visual representations. The automatically guided attention in the visual areas representations completes a pattern of interaction between working memory and attention. When strategic attention is directed in the visual field it is facilitated by the working memory-guided attention when the search goal and the working memory contents match. In the current study, a corresponding interaction between working memory and attention to visual representations was established. The initially automatically-guided attention from the working memory contents constitutes attentional capture in the visual representations and facilitates strategic attention and search for them.

ΕΥΧΑΡΙΣΤΙΕΣ

Ευχαριστώ ιδιαίτερα τον επόπτη της διατριβής μου κ. Γεώργιο Σπανούδη, για την ουσιαστική συμβολή του στην ανάπτυξη και στην διεκπεραίωση του τρέχοντος έργου. Οι δημιουργικές συζητήσεις που είχα μαζί του, η πρακτική συμβολή του στην διεκπεραίωση των πειραματικών έργων, η βοήθεια του για την εμπλοκή των μελών μιας αξιόλογης συμβουλευτικής και εξωτερικής επιτροπής με βοήθησαν στην ανάπτυξη των απαιτητικών ιδεών και εννοιών της διατριβής μου.

Ευχαριστώ επίσης τα μέλη της συμβουλευτικής επιτροπής μου κ. Τίμο Παπαδόπουλο και κ. Μάριο Αβρααμίδη για τη δημιουργική κριτική τους που με βοήθησε στην αποσαφήνιση των επιστημονικών εννοιών που αναδύθηκαν από τη διατριβή μου, την ερμηνεία των πειραματικών αποτελεσμάτων κ.ά.

ΑΦΙΕΡΩΣΗ

Αφιερώνω τη διατριβή μου σε όσους συμπορεύτηκαν μαζί μου στη δύσκολη αυτή περιήγηση στη γνώση της ανθρώπινης νόησης.

Στη σύζυγό μου Άντρη,

Στους γιους μου Νικόλα και Ευαγόρα,

Στον αδελφό μου Χάρη,

Στους γονείς μου Νίκο και Παναγιώτα,

Στους συναδέλφους μου.

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The limited processing capabilities of the mind require that not all observed stimuli in a scene can be processed concurrently, but instead, a small number of them can be prioritized over others (Shiffrin & Schneider, 1977). Similarly, available processing resources are not sufficient to process all representations in short-term memory at a particular moment. The developing processing capability of short-term memory (Shimi & Scerif, 2017), which reaches a maximum of four objects in adults (Luck & Vogel, 1997), is exceeded by its maximum storage capacity (Sligte, Scholte, & Lamme, 2008; van Moorselaar, Olivers, Theeuwes, Lamme, & Sligte, 2015). In both cases, selective attention is the process by which items in either perceptual (Petersen & Posner, 2012; Posner, 1980) or mental space (Griffin & Nobre, 2003; Oberauer & Hein, 2012) are selected over others in accord with one's current goal.

Controlled behavior is nevertheless not always for one's benefit. A careless action in some case means that current goals are distracting. A road, for example, is seemingly safe to cross unless our thoughts are interrupted by the horn of a high-speed passing lorry. Goals of selective attention and decision-making - to observe an apparently empty street and decide to cross - are changed by the automatic detection of a stimulus - to hear the horn of the passing lorry and decide to wait. In the second event, the distracting stimulus captures attention (Yantis, 1993), it automatically loads short-term memory and gets processed. Automatic processing of salient stimuli in the scene is called bottom-up processing. There are also automatic top-down processes which facilitate information processing. A main effect is the automatic guidance of attention by the contents of working memory to relevant perceptual information (Pan, Lin, Zhao, & Soto, 2013; Soto, Heinke, Humphreys, & Blanco, 2005; Soto, Hodsoll, Rotshtein, & Humphreys, 2008). A woman, for example, holds in her mind a shampoo of green color when she reaches the relevant shelf at the supermarket. Her gaze is then automatically captured by a shampoo of green color, though not necessarily the one in the search.

The realization of attentional capture was based on the findings of an experiment by Chelazzi, Miller, Duncan, & Desimone, (1993) that the enhancement of a representation in the inferior temporal cortex precedes saccades to a relevant attended object. The findings suggested a causal relationship between the visual area activation and the subsequent gaze orientation. In a relevant behavioral study, Downing (2000) set different goals for the strategic attention in the visual array and for the representation held in working memory. He demonstrated that attention to an object with a matching representation precedes selective attention to the search goal. The work of Downing. triggered research on the possible automaticity of the orientation of attention to an object that matches a representation held in visual areas (Olivers & Eimer, 2011; Soto et al., 2008).

The findings of Chelazzi et al., (1993) additionally inspired the biased competition model of attention (Desimone & Duncan,1995), which asserts that attending to an array of objects, sets a mutually suppressive competition among their representations in the neural substrates of the visual areas. The model further asserts that attention to an object of the array resolves the competition in favor of the relevant representation. Single cell recordings in primates (Chelazzi, Duncan, Miller, & Desimone, 1998) and fMRI in humans (Kastner, Weerd, Desimone & Ungerleider, 1998) respectively, verified the model's assertion. The findings were assumed to support a filtering mechanism of irrelevant information in complex visual scenes when attention to a stimulus counteracts the suppressive impact of neighboring stimuli.

The biased competition model was extended by studies which demonstrated that attention to visual representations increases the activity in the fusiform and parahippocampal gyri, which are involved in the maintenance of faces and scenes respectively (Lepsien & Nobre, 2007). This increase in activity was further shown by complementary behavioral tasks to increase working memory performance in terms of reaction time and accuracy of recall in accord with previous studies (Griffin & Nobre, 2003).

These results indicate a common mechanism of interaction between the visual areas and strategic attention in the processing of information in either the perceptual field or the visual areas. In both cases, strategic attention enhances a visual representation which in turn improves processing of the relevant information. A further aspect of the mechanism is the facilitation of strategic attention to an object in the visual field by attentional capture. This is demonstrated in the task of the study of Soto et al., (2008). Participants had to keep an item in working memory and search for an object in a subsequent array of objects. There were three conditions; the item held in working memory appeared in the same position with the object in the search in the array or it did not or the memory item was not displayed in the array. When the object in search and the memory item positions matched, the reaction-time to identify the object in the array was faster than when the memory item was absent from the array. This reaction-time benefit indicates facilitation of search for an object when there is associated information in working memory. Equivalently, it can be said that there is an initial automatic attentive stage which is influenced by the contents of working memory, which precedes and facilitates strategic attention and the associated search in the visual field when the working memory contents and the search goal match.

In the current study, I assumed an equivalent effect in the visual areas. The strategic attention in the visual areas (Griffin et al., 2003; Lepsien et al., 2007) could be facilitated by a preceding automatic orientation of attention to a representation when relevant information is kept in working memory. Similarly to the facilitation of attention to a visual stimulus by the working memory contents (Soto et al., 2008), the search in a visual memory array for a representation should be facilitated when the working memory contents and the search goal match.

Since no previous research had addressed the automatic orientation of attention to a representation I relied on the methodology of relevant processes to address the issue. Attention to a representation was expected to produce similar reaction-time and accuracy of recall benefits to the strategic attention to the visual areas (Griffin et al., 2003; Lepsien et al., 2007). The automaticity of orienting attention to visual representations was addressed by relying on the assumptions for demonstrating the automaticity of attentional capture in the visual field (Han et al., 2009; Soto et al., 2008; Woodman & Luck, 2007).

In the following paragraphs, I first review the biased competition model of attention (Desimone & Duncan, 1995) and how it is related to attentional capture (Chelazzi et al., 1993; Downing, 2000; Soto et al., 2005, 2008). The second paragraph presents studies that place further assumptions on the automaticity of attentional capture (Han & Kim, 2009; Woodman & Luck, 2007). In the third paragraph, I review the research evidence on the strategic orientation of attention to visual representations and the associated retrieval mechanisms. In the fourth paragraph, I present the premises and results of a study that suggests an integrative framework for the various mechanisms of recall by the strategic orientation of attention in the visual areas (Olivers, Peters, Houtkamp, & Roelfsema, 2011). The framework is used in the current study to interpret the experimental results of the retrieval accuracy of the visual representations.

Biased Competition and Attentional Capture

Competition for processing in a scene is evidenced when multiple objects are observed, and the capacity of the visual system is incapable of dealing with their simultaneous processing. For example, when two different objects are displayed simultaneously, it is less efficient to identify their features than when they are presented in isolation (Duncan, 1984). Competition for processing is resolved by the facilitation of processing of an object in an array by attending the object location before its appearance (Posner & Cohen, 1984). The attention to a location before the stimulus appearance modulates neural processing in the visual cortex. The modulation of visual activity is thought to be a top-down bias that facilitates processing of stimuli representations at the attended locations of the stimulus (Desimone & Duncan, 1995). Top-down signals due to attention, bias neural competition for processing in the visual areas in several other ways. An attended stimulus enhances a corresponding neuron response, it filters irrelevant information by counteracting the suppression that is induced by adjacent distractors, it biases signals in favor of an attended location by increasing the baseline neuron activity in the absence of visual stimulation and increases the stimulus salience by enhancing the neuron's sensitivity to stimulus contrast (Kastner & Ungerleider, 2000) .

An initial model of a biased competition mechanism of attention was proposed by Duncan and Humphreys (1989). The first element of the mechanism is a memory template of the target object. The second element is a parallel perceptual input that generates a group representation of the observed objects of a scene. Part of the scene is selected with a particular goal. The selection process matches an object of the group representation with the target object of the memory template. The biased competition mechanism resolves the competition in the group representation in favor of the representation corresponding to the target object of the template. Search efficiency for an object in the parallel input is determined by the similarity between targets and non-targets.

The model challenged the feature integration theory (FIT) of Treisman & Gelade (1980). According to FIT, there is an initial attentive stage, where each primary feature, such as color or orientation, is parallel coded by spatio-topically organized maps of the visual field, without integration. In the second attentive stage, the visual field is serially scanned by selective attention and information is integrated into whole objects. The experiments by Treisman and Gelade., in which the visual search is for features or their conjunction, gave potential evidence for the theory. In the search for features in a display of objects, the target object differs from the non-targets by a single feature, such as orientation or color. In the conjunctive search, the target is a composite of features and shares at least a feature with other display objects. The results of the two experimental manipulations were distinguished by the slopes of the linear function relating reaction-times with display size. In feature search, reaction-times remained constant with display size, while in conjunction search reaction-times showed a linear increase as a function of the display size. These results were interpreted by parallel and serial processing of attended stimuli.

The model of Duncan et al. (1989) challenged FIT on the distinction between parallel and serial processing, by producing a continuum of search efficiency, determined by the feature sharing between targets and non-targets. According to the model, there is only a parallel processing mechanism biasing competition in a group representation in favor of a memory target object, whose efficiency depends on the similarity between the memory and the display objects.

The competition for representation and processing is evidenced in a multitude of visual areas which are organized into two specialized processing streams with distinct functions (Ungerleider & Haxby, 1994). The dorsal stream or occipitoparietal pathway is specialized for the determination of spatial relations among objects. The ventral stream or occipitotemporal pathway is specialized for the identification of objects. Both streams originate from a shared visual field input, area V1, and branch into multiple visual areas.

In the object processing pathway or ventral stream, object features are processed progressively from simpler to more complex ones. In V1 simple spatial filtering of features occurs, while in the inferior temporal cortex, a higher processing area, whole object features are processed, such as shape or volume (Desimone & Ungerleider, 1989). The receptive neuron fields (RF) in primates, increase from primary V1 cortex towards the TE. They initiate at 1.5^{o} in V1, to 4^{o} in V4 and 26^{o} in the inferior temporal cortex (Desimone et al., 1989). Likewise, neuron RF sizes increase progressively in human visual areas from V1 to TEO (Kastner et al., 1998; Smith, 2001).

Biased competition is evidenced in the visual areas when stimuli are simultaneously projected into the neurons' RF (Reynolds, Chelazzi, & Desimone, 1999). A particular neuron in the visual areas of the ventral stream shows a selective processing activity for specific stimuli, called the effective stimuli for that particular neuron, while it rejects processing for another kind of stimuli, being called the ineffective ones. For example, a vertical line may be an effective stimulus for a neuron while a horizontal line may be an ineffective stimulus. When both an effective and an ineffective stimulus are simultaneously presented in the RF of a single neuron, but not attended, the neuron response is the average of the responses when stimuli are presented alone. When the effective stimulus is subsequently attended, the response of the neuron increases to the level when this stimulus is presented alone. Similarly, when the ineffective stimulus is attended, the neuron response reduces to the level when the ineffective stimulus is presented alone. The average response of the neuron, when both stimuli are simultaneously projected into its RF, demonstrates a suppressive competition for representation processing. When the neuron response shifts to the response of the attended stimulus, its behavior is interpreted as biasing of competition in favor of the attended stimulus and against the unattended one.

The biased competition theory of attention is evidenced by fMRI studies in the human extrastriate cortex (Kastner, Weerd, Desimone, & Ungerleider, 1998; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999). Competition for representation in humans is evidenced when stimuli are presented simultaneously in the visual field and produce representations that interact suppressively in the cortical pathway of object recognition in comparison to the response when stimuli are presented sequentially (Kastner et al., 1998). The competition is nevertheless biased in favor of one representation when the corresponding object is preferentially attended which amounts of attention to one object in the visual field counteracts the suppressive influence of adjacent object representations in the cortical visual area. Equivalently, the prefrontal cortex (PFC) directs the selection of an object in the visual field, and the corresponding representation is enhanced against other simultaneous object representations. A matching representation of an attended object is enhanced by about 30% compared to the unattended ones. The effect was registered by multivoxel fMRI analysis of large-scale integrated visual representations in the fusiform face area (FFA), the para-hippocampal place area (PPA) and the visual occipital-temporal cortex (OTC) (Reddy, Kanwisher, & VanRullen, 2009). A more recent study has shown that biased competition likewise occurs when the location of a representation itself is retrospectively attended (Kuo, Stokes & Nobre, 2012), that is top-down modulation directs spatial selection to an object representation in the visual neuron field, which is enhanced against other simultaneous object representations.

The biased competition theory of attention has provided evidence for an automatic mechanism for the orientation of attention to visual stimuli, which is most relevant to the current study. The evidence was provided by an experiment of Chelazzi et al., (1993). Chelazzi et al. demonstrated that in monkeys, the representation of an attended memory-matching object is enhanced at about 90-120 ms before gaze is directed to it. The effect might have indicated, according to the authors, a causal relation between gaze orientation and the previous enhancement of the representation by the memory-matching shape. However, the experiment by Chelazzi et al. (1993) was not tuned to sense the dichotomy between selective PFC bias and automatic visual areas impact on the orientation of attention by memory-matching stimuli, as the search goal was identical with the required gaze orientation. Instead, Downing (2000) succeeded to distinguish between the search goal and the initial orientation of gaze to a memory-matching item. Downing. findings suggested that attention to a memory-matching item steadily preceded goal-oriented selective attention, which correspondingly implied that gaze orientation was most likely executed automatically by the visual areas (Kastner et al., 1998) before top-down selective orientation to the target by the PFC (Zanto, Rubens, Thangavel, & Gazzaley, 2011).

Attentional Capture and Automaticity

Automaticity, the second feature of the presumed automatic orientation of attention by the working memory contents, is an intricate issue that is explored in the literature of attentional capture. A paradigm task has been employed by some researchers to establish guidance of attention by working memory representations. The task requires search for an item in an array with a particular feature that is occasionally different from a memory matching item in the same array (Downing, 2000; Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; Olivers, Meijer, & Theeuwes, 2006; Soto et al., 2005; 2006). In his founding study, Downing (2000) initially presented one human face to participants to retain it in memory. It was followed by the display of two other faces, one matching the face in memory. Then a bracket appeared in the position of one of the two faces, and a speeded response about the orientation of the bracket was required. Lastly, a face was displayed, and participants had to decide whether it matched the one in memory. The results of the experiment showed a delay when the bracket position did not match the face matching the memory content. The findings were interpreted as gaze had been first oriented to the memory-matching face before selective attention was oriented to the search goal, the bracket. The evidence hinted that orientation of attention to the memory-matching face was probably automatic, as it did not form part of the search goal. However, while the experiment by Downing showed that memory content influences attention, it did not provide substantial evidence for automaticity. That is, attending to a distractor was not detrimental to the task, and participants had chosen to attend to a non-target object when they were instructed to keep a corresponding object in memory because they might have thought that it could help them in the task.

The memory task should be separate from the strategic attention task to demonstrate that the memory content drives visual attention (Soto et al., 2005). Soto et al. required participants to hold an item in memory with a particular shape and color, i.e., a green square. They then had to detect a slanted line, among vertical distractor ones, which was embedded in a geometrical shape that was either matching or non-matching to the one retained in memory. They finally had to perform a memory task. Soto et al. found that when the slanted line was placed in the memory-matching object, reaction-times were faster than when it was placed inside another object. This pattern of results was repeated even when the slanted line was never embedded in a memory matching object. The findings suggested that attentional capture by a memory-matching object occurs even when this is detrimental to the task. Soto et al. (2006) confirmed their conclusions by performing a similar experiment to parietal patients with visual extinction to contra-lesional stimuli. Their results showed that visual extinction was reduced when the contra-lesional stimulus matched a memory representation. Pan et al. (2013) additionally exhibited that guidance of attention from short-term memory may occur by a stimulus, which was rendered unconscious by masking.

Other researchers have found evidence of no guidance of attention by the contents of working memory. Woodman & Luck, (2007) set more stringent criteria for automaticity of the guidance of attention by memory contents, by requiring that despite holding a representation in visual areas, there was no motivation for attending a matching item in the search task. For that purpose, Woodman, and Luck. made memory matching items never to be part of the search goal. Woodman et al. argued that if the automatic guidance of attention to memory-matching items occurs, it should develop even under this condition. They found no evidence for attentional capture by memory-matching items. Correspondingly, Downing & Dodds, (2004) divided representations to "memory" and "search" ones. The 'memory' representations were simply held in visual areas while the 'search' representations were used for search in the subsequent array. They found evidence for attentional capture by the "search" representations, but not for the "memory" ones.

Han & Kim, (2009) attempted to find an integrative framework for these diverging findings. They argued that Woodman et al. (2007) fail to report attentional capture because they used a perceptually demanding task. To reconcile the conflicting results of the tasks by Soto et al. (2005) and Woodman et al. (2007), Han et al. used a common experimental task in which they varied search time and perceptual difficulty, to simulate the two experimental tasks. The perceptual difficulty was manipulated by the increasing similarity between the target and destructor (Duncan & Humphreys, 1989). Fast search reaction-times were estimated to be below 1100ms. Their results showed that the attentional capture by visual representations only occurs when the search task was perceptually straightforward, and the search was fast enough to prevent the implementation of cognitive control.

Carlisle & Woodman, (2012) instead, turned to classic studies of attention and automaticity (Posner & Snyder, 1975) to investigate attentional capture within the same experimental method. The classic experiment by Posner et al. (1975) required to attend a probe item and then searching for it in the subsequent array. They argued that strategic attention to the probe would increase when it facilitated the search for the matching item. Consequently, an increased occurrence probability of the matching item would increase attention to the probe and subsequently slow reaction times. Increased probability of the matching item practically means that if the trials containing the memory-matching item increase in different versions of the same task, then reaction times should increase. Equivalently, if the orientation of attention to the memory-matching item is exclusively automatic, then reaction times should have a constant value as a function a variable probability of its occurrence. Carlisle et al. (2012) used the same argument in the standard paradigm task of attentional capture and found that it is driven by both automatic and strategic interactions.

The debate about the automaticity of the memory guidance of attention is inevitably transferred to the issue of automaticity of the anticipated AM. Nevertheless, the studies of Han et al. (2009), Posner, (1975) and Carlisle et al. (2012), offer the most relevant criteria for automaticity. By these criteria, the enhancement of a probe-matching visual representation and the subsequent attention to it would prove to be automatic, if the strategic search for it is prevented by fast search times and it is perceptually straightforward to be probed (Han et al., 2009). Moreover, reaction-time differences should remain constant across different probabilistic occurrence of a memory-matching item (Carlisle et al., 2012; Posner et al., 1975).

Another crucial criterion for the demonstration of the automaticity of AM regards the access to the representation matching the contents of working memory, which is an enhanced representation in the visual areas. In tasks, where attentional capture occurs by memory-matching objects, a minimum requirement for exhibiting automaticity, is the absence of the representation matching the object in working memory from the search goal in the visual array (Downing, 2000; Soto et al., 2005). By this task design, any response-time delay is attributed to the automatic guidance of attention to or attentional capture by the memory matching object. In a biased competition task in the visual areas, a representation is enhanced when it matches a probe object and presumably captures attention automatically. Analogously, an essential requirement for the demonstration of the automaticity of AM is that the probe-matching representation should not be part of the search in a memory array.

Strategic Retrospective Attention Mechanisms

Strategic retrospective attention to visual representations has been shown to produce equivalent reaction-time and percentage accuracy results to selective attention on visual stimuli (Griffin et al., 2003). Strategic retrospective attention to an array of visual representations was attained by a cue following the presentation of the array, called the retro-cue, which indicated the position of one object of the previously presented array. Strategic attention was attained by a cue preceding the presentation of the array and indicating the position of one object of the forthcoming array. Strategic retrospective attention to a memory array gave mean reaction-time benefits when comparing a cued representation with a probe object (valid condition) than by comparing the probe with an uncued representation (invalid condition), similar to when attention preceded the array, in agreement with Posner et al., (1984). The 'no' condition did not involve a matching representation to the probe. The pattern of percentage accuracy indicated for the valid and the invalid condition, similar benefits and costs compared to the 'no' condition. However, this pattern, which is crucial in interpreting corresponding results of AM, differed from subsequent research investigating the retro-cue mechanism.

Strategic attention to a visual representation using a retro-cue has been shown to have a positive impact on the recall accuracy of representations in visual areas (Griffin et al., 2003;

Landman, Spekreijse, & Lamme, 2003) and is known as the retro-cue benefit effect. The state of noncued representations is vital in understanding the mechanism of the retro-cue benefit effect because it reveals how the attended representation has been modulated compared to the unattended ones. Noncued representation recall accuracy has given variant results and consequently differing propositions for the retro-cue mechanism. Proposed retro-cue mechanisms based on the accuracy of retrieval of noncued representations are reviewed in the following sections.

Protection-from-Interference Mechanism

The protection mechanism asserts that a cued representation is protected from interference from accompanying representations (Makovski, Sussman, & Jiang, 2008; Souza, Rerko, & Oberauer, 2016; van Moorselaar, Gunseli, Theeuwes, & Olivers, 2015). Makovski et al. (2008) used three recall procedures in three separate experiments to verify the assertion of the protection mechanism. The first was a whole recall procedure and consisted of the comparison of two successive four object arrays without a retro-cue. The second recall procedure involved a so-called simultaneous cue in the second display, which indicated an object of the array to be compared with an object in the corresponding position of the first array. The third recall procedure involved a retro-cue, which followed the first display and indicated the position of a representation to be compared with an object of the second display in the corresponding position. The last task was again a partial report of the similarity of objects in corresponding array positions. The findings indicated that the third recall procedure, which involved a retro-cue indicating a representation of the first array, was better than both the whole report and simultaneous retro-cue recall procedure. The findings were interpreted as indicating that the cued representation is protected from interference from concurrent ones.

Direct interference in the form of masking was applied by van Moorselaar et al. (2015) to a memory array to test the same protection mechanism. An array of four objects was followed by a retro-cue indicating the position of one of the object representations. Two conditions of the experiment either included or not a masking array which succeeded the retro-cue. Participants in either condition had to compare the probe object with the cued representation. Results indicated that recall accuracy was reduced from the no-mask to the masked condition when no cue was involved in the recall, while it remained constant between the conditions when a cue was involved. The results directly indicated the protection of representation from interference.

Removal Mechanism

The removal mechanism is supported by evidence showing that noncued representations are removed when one representation is being retro-cued (Kuo et al., 2012; Souza, Rerko, & Oberauer, 2014). Kuo et al., (2012) used event-related potential (ERP) to investigate the modulation of the contralateral delay activity (CDA) when attention is selectively oriented to a spatial location in the visual areas. CDA is a lateralized ERP marker of visual areas maintenance, which is produced when participants selectively encode items to memory from one hemifield. They found that when attention is oriented to a particular representation, recall performance was improved and the CDA level was reduced to a value indicating a reduction of the memory load. These results suggested the removal of noncued representations.

A behavioral approach by Souza, Rerko, and Oberauer, (2014) suggested the same removal mechanism. In the Souza et al. experiment, participants had to encode two successively presented object sets. When an item from the first array was retro-cued, the memory for the second array was improved. These results were interpreted as, that removal of irrelevant information from the first set, after one of its representation is retro-cued, facilitates recall of the second set. Similarly, Astle, Summerfield, Griffin, and Nobre, (2012) found that, when working memory four object capacity is exceeded, top-down biasing by a retro-cue offers a slight benefit compared to the ‘no’ condition. The unattended items are lost, and there is a substantial cost of invalid trials over ‘no’ ones, suggesting a removal mechanism.

Prioritization Mechanism

The prioritization mechanism suggests that a cued representation is set to a robust representational form, which improves recall without disturbing noncued representations (Myers, Walther, Wallis, Stokes, & Nobre, 2015; Rerko & Oberauer, 2013). Rerko et al., (2013) cued non-cued representations and found that their recall was improved. Retrospectively attending to a representation, therefore, improves its recall, but does not eliminate noncued representations. The finding supports the prioritization mechanism of retrospective attention.

Prevention of Rapid Forgetting

While the protection mechanism refers to interference from stimuli presented after the retention interval, the prevention of rapid forgetting mechanism refers to the protection of the cued representation during the retention interval. The cued representation may be protected from rapid forgetting, probably due to temporal decay or due to interference among concurrent representations during retention (Pertzov et al., 2013). In their experiment, Pertzov et al. used a continuous feature space report to investigate the quality of recall with varied ISI between the retro-cue and the report stage. The logic of the experiment resided on a prediction of the protection mechanism that memory of a cued representation should remain stable during the retention interval, while noncued representations should fade. They found that when four representations had to be remembered without a cue, they degraded faster over time. However, the decay of a representation was prevented when it was validly cued, even long after the presentation of the memory array. Invalidly cued representations degraded even faster than noncued ones. The results support the protection mechanism by which a retro-cue enhances the temporal stability of representations and associated recall, while noncued representations are degraded but not lost.

An Integrative Framework for Selective Retrospective Attention Mechanisms

The various mechanisms may suggest the inconsistency of findings concerning the fate of noncued representations, as expressed by the percentage accuracy response, or that different mechanism is employed under different experimental settings. Nevertheless, the variability of percentage accuracy results, between cued and noncued representations, was found to depend on the reliability of the retro-cue to predict the probe-matching representation (Gunseli et al., 2015). Cue-reliability, which is defined to be the ratio between valid and invalid trials, categorizes previous research on the retro-cue benefit effect into low and high cue-reliability groups. The low cue-reliability group, 50 % valid in Landman et al. (2003) and 66.6 % valid in Rerko et al. (2013), did not detect a cost in the invalid trials. However, the high cue-reliability group, 80 % valid in Griffin et al. 2003, 80 % in Astle et al. (2012), 75 % in Matsukura, Luck, & Vecera (2007), 70 % in Pertzov et al. (2013), 73% in Myers et al. (2015) and 100 % in Souza et al. (2014), registered a cost. In the high cue-reliability group attention seems to be devoted to the cued representation while the uncued representations (removal mechanism) are ignored since there is little chance of being tested on them. In the low cue-reliability group the uncued representations are maintained by the anticipation of being tested on them. In this case, the cued representation might just be prioritized over uncued representations (prioritization mechanism). In their study, Gunseli et al., (2015), found invalid trial, no-cost and cost corresponding to 50 % and 80 % cue-reliability groups. The pattern of results suggests, according to the authors, that the retro-cue mechanisms are strategically adjusted on perceived retro-cue reliability.

These results were relevant in the current study, in that they might have revealed a retrieval mechanism for AM. The differing reliability of an object representation in working memory to direct attention to a relevant representation in the visual areas would have revealed a model for AM.

Hypotheses

Hypothesis 1

The main hypothesis of the current study states that automatic orienting of attention to a visual object-representation in the visual areas occurs when there is a search goal in the visual areas representations and a relevant object is subsequently kept in working memory. The hypothesis is suggested by the corresponding interaction of working memory and attention in the visual field (Olivers, 2009; Soto et al., 2008). The automatic orientation of attention to an object in the field occurs when there is a relevant representation in working memory. When the working memory contents and the search goal in the visual field match then the initial automatic orientation of attention facilitates strategic attention to the object. Similarly, the hypothesis suggests a corresponding interaction of working memory and strategic attention in the visual areas. The process would facilitate strategic attention in a memory array when the search goal and working memory content match.

Hypothesis 2

Hypothesis 2 regards the conditions for automaticity of AM suggested by Hypothesis 1. It is assumed that three conditions for automaticity of attentional capture in the visual field are analogously valid for the automaticity of the AM:

(a) When the focus of attention on a visual representation is fast enough strategic attention is prevented.

(b) The task in the array of the representations of the visual areas should not premise attention to a visual representation relative to an object in the working memory.

c) The comparison of an object and a visual representation should not demand high perceptual and cognitive load.

The validity of preceding hypotheses was investigated by three experiments. Experiment 1 investigated whether reaction-time benefits could be produced when the three conditions for automaticity were applied. The emergence of these benefits could suggest that orienting of attention to a representation relevant to an object in working memory occurred and it was automatic. Experiment 2 aimed to validate the assumption of Experiment 1 by one prediction of the assumption: Reaction-time benefits should remain constant across variable probability of an object to validly cue a relevant visual representation. Experiment 3 aimed to further verify the assumption of Experiment 1 by verifying one prediction based on the same assumption: If one of the three conditions for automaticity does not apply then, the automatic attention to a representation relevant to an observed object should not occur. Therefore, the reaction time and accuracy benefits observed in Experiment 1 should vanish.

Experiment 1

Experiment 1 investigated whether attention to a representation relevant to an object in working memory could produce reaction-time benefits similar to retrospective attention in the visual areas when the three conditions for automaticity of orienting attention to the visual areas were employed. The first condition for automaticity presumed that the orientation of attention to a visual representation should be fast enough to prevent strategic employment of attention (Han et al., 2009). The second condition presumed that the orientation of attention to a visual representation which is relevant to an object in working memory should not be part of the search goal in the memory array (Downing, 2000). The third consideration presumed that the contrasting of the object in working memory and a visual representation should not be perceptually and cognitively demanding (Han et al., 2009). The three conditions for automaticity presumed that, if attention to a relevant visual representation to an observed object produced similar reaction-time benefits with retrospective attention in the visual areas, then these were automatically produced. Thus, the current experiment aimed to investigate whether reaction times similar to the ones reported for strategic attention in the visual areas occurred when the three conditions for automaticity were applied. If such effects occurred, then the assumption for automatic orientation of attention in the visual areas when the three conditions for automaticity apply would be verified.

In the task of Experiment 1, an array of four objects was initially presented, followed sequentially by an object to be held in working memory and a retro-cue. The sequence of events of Experiment 1 is shown in Figure 1. The task in every condition of Experiment 1 required the comparison of the object kept in working memory and a representation of the memory array which was strategically attended using a retro-cue.

There were three conditions in Experiment 1. The valid condition, in which the probe object had a corresponding representation in the array and the retro-cue was subsequently pointing to the same representation. The invalid condition, in which the probe object also had a corresponding representation in the array, but the retro-cue was pointing to another representation. And finally, the 'no' condition in which the probe object did not have a corresponding representation in the array, and the retro-cue was pointing to an arbitrary representation. The design of the experiment aimed to demonstrate automatic orientation of attention in visual areas by the response-time and accuracy of recall benefits in the valid and the invalid condition compared to the 'no' condition. More specifically, the directly comparable conditions were the invalid and the 'no' condition where the task was identical. Any difference between the two conditions would amount to attention effects on the visual representation which was relevant to an attended object in the invalid condition.

The first condition for automaticity of orienting attention in the visual areas was employed in Experiment 1 by allowing a stimulus onset asynchrony (SOA) of 250ms between the probe and the retro-cue. The time required to strategically attend a visual representation relevant to the object in working memory estimated by saccade latencies to be about 150ms (Hollingworth, Matsukura, & Luck, 2013). It is implied that not sufficient time was offered to serially scan the array by attention for a particular representation.

The second condition of automaticity of orienting attention to visual areas was employed, as the search task in the memory array did not require attention to a representation that was relevant to the object in working memory. The task did not exclude this event but it rather allowed for the possibility for it to occur under the conditions for automaticity.

The third condition was employed by using stimuli objects, which were formed by combining basic geometrical figures and were adequately complex that they were easily discriminable and unfamiliar (Fiser & Aslin, 2001). The stimuli objects of Experiment 1 are shown in Figure 2. Moreover, the complexity of the shapes prevented the Gestalt emergence of new shapes from the combination of adjacent basic geometrical figures.

The order of presentation of the probe object before the retro-cue was an important component in the design of Experiment 1. To prevent any impact of the retro-cue benefit effect, the probe object was presented before the retro-cue. Additionally, the 200ms ISI between the memory array and the object to be kept in working memory ensured that representations did not fade considerably before being attended and therefore were optimally recalled (Pertzov et al., 2013). The 200ms is also the time by which iconic memory ceased to exist (Jiang & Kumar, 2004; Phillips, 1974) and guaranteed no interaction of iconic memory and the representations in the visual areas.

Due to design, each of the three conditions of Experiment 1, necessarily gave a positive or a negative answer in response to the comparison for similarity between the probe and the retro-cued representation. The response in the valid condition was thus always positive, as comparing similar objects, while in the invalid and the neutral condition it was always negative, as comparing different objects. To avoid bias, the negative and positive answers were equally proportioned in each section of the experiment. The valid condition, which gave positive answers, occurred by a 50% proportion and the invalid and the neutral condition, which gave negative answers, occurred equally by a 25% proportion.

In a pilot version of Experiment 1, the author noticed that a probe-matching representation in a four-object memory array was visually recalled at the initial object position on the screen. The visual recall also occurred automatically when representations were retro-cued, a fact which is in accord with results demonstrating low strategic control or equivalently, high automatic use of arrow retro-cues (Berryhill, Richmond, Shay, & Olson, 2012). Participants of pilot Experiment 1 were asked to report anything noteworthy in the task. Their answers were irrelevant to the visual recall effect and indicated that they did not perceive the retrieved representations. When, however, they were prompted to relate either the probe or the retro-cue with the corresponding retrieved representation they could clearly report the effect.

Method

Participants.

Twenty-nine undergraduates of the University of Cyprus, male and female (age: 18-26), participated in the experiment for course credit. They had normal or corrected-to-normal visual acuity and gave informed written consent for participation in the study.

Materials.

The stimuli used in the experiment were sixteen composite geometrical shapes similar to those used by Fiser et al., (2001). The stimuli were black on a white background. Stimuli were presented by a Lenovo computer, using the OpenSesame software (Mathôt, Schreij, & Theeuwes, 2012).

Procedure.

Separate one-way Analyses of Variance (ANOVAs) were performed on mean reaction-times and percentage accuracy of recall. The *within* factor had three levels which were the three conditions (valid vs. invalid vs. neutral).

The experiment consisted of five successive displays on a 17-inch monitor, at 1366 x 768 resolution and viewed from about 0.8m distance. Initially, a fixation circle of 0.29^{o} of visual angle was projected in the center of the display for 300ms. The ensuing memory array consisted of four dissimilar stimuli that they were randomly selected from the sixteen stimuli pool shown in Figure 2. They were simultaneously and crosswise projected at the center of the screen for 130ms. The extent of the stimuli supporting imaginary cross was 3.65^{o} of visual angle, and the maximum size of an individual shape was 0.93^{o}. The memory array was succeeded by a single stimulus figure that was displayed in the center of the screen for 200ms. A retro-cue, a star-shaped figure with four ends, of 0.93^{o} visual angle, was next displayed, 50ms after the offset of the probe, in the center of the screen, for 130ms. In each trial, one end of the cue was filled black and indicated one of the four locations of the previously displayed memory array. A blank display was finally projected for 2000ms. Participants were allowed to respond during this time interval otherwise the trial was invalid. Participants responded by using a keyboard. They were instructed to press the key “S,” when the probe matched the memory array representation indicated by the cue and press the key “L,” when it did not match the representation. They were also given instruction to attend to the visually retrieved representation indicated by the retro-cue and use to benefit their response. This intervention was made to avoid unnecessary confusion with the probe-matching visually retrieved representation, an effect confirmed during the piloting of the experiment.

Each participant was tested in all three conditions of the experiment, the valid, the invalid and the neutral condition. Reaction-time and correct response were registered for each condition in every trial. The independent variable had three levels corresponding to each condition, and the dependent variables were reaction-time and percentage accuracy in each condition.

Participants were tested in groups of four in a dimly lit laboratory room. They were given instructions both verbally and in writing on the computer screen before the start of the experiment. Participants initially completed a 20-trial practice session during which they received sound feedback for every incorrect response. The experimental trials were completed in three sessions of 72 trials each, during which no feedback was given.

Results

Reaction-time.

Three extreme cases were detected to violate the multivariate normality assumption and were removed from the analysis. The validity condition caused statistically significant changes in mean reaction times; $F(2, 50) = 19.539$, $p < 0.001$, partial $\eta^2 = .439$, with mean reaction time values increasing from 688.154 ± 30.218 ms for the valid condition, to 720.577 ± 30.647 ms for the invalid condition and to 755.154 ± 32.076 ms for the 'no' condition. Results are displayed in Figure 3. Post hoc analysis, with Bonferroni adjustment for multiple comparisons, revealed that mean reaction time was statistically significantly increased, from the valid to the invalid condition with a mean difference of 32.423 ± 11.292 ms, $p = .025$. It was also increased from the valid to the 'no' condition with mean difference 67.0 ± 11.963 ms, $p < .001$ and from the invalid to the 'no' condition with mean difference 34.577 ± 8.609 ms, $p = .001$. The 'no' condition presented the largest mean reaction-time among the three conditions, demonstrating reaction-time benefits produced in the valid and the invalid condition.

Accuracy

One case was removed from the analysis because it did not satisfy multilinear normality. The attention-shift conditions elicited statistically significant differences in response accuracy; $F(1.278, 34.502) = 12.957$, $p < 0.001$, partial $\eta^2 = .324$, which was 61.286 ± 2.759 % for the valid condition, 77.179 ± 2.308 % for the invalid condition and 72.393 ± 2.466 % for the 'no' condition. Results are displayed in Figure 4. Post hoc analysis, with Bonferroni adjustment for multiple comparisons, revealed that mean percentage accuracy was statistically significantly increased from the valid to the invalid condition with a mean difference of 15.893 ± 3.122 %, $p < .001$and from the valid to the 'no' condition 11.107 ± 4.145 %, $p = .037$. It was marginally statistically significantly decreased from the invalid to the 'no' condition 4.786 ± 1.963%, $p = .065$.

The effect of the accuracy cost and reaction time-benefit of the valid condition compared to the invalid one indicated a possible speed-accuracy trade-off (SATO) in the valid condition. To test for that effect, a Pearson Correlation Test was carried out between reaction-time intervals of 200ms and corresponding mean accuracy of all participants. A negative correlation between accuracy and reaction-time was significant, $r = -0.883$, $p = 0.019$. The results are depicted in Figure 5. The accuracy is decreased as reaction-time is increased and the SATO effect was likely not involved in the valid condition.

Discussion

Reaction-time results of Experiment 1 demonstrated benefits of the valid and the invalid condition compared to the 'no' condition. The invalid condition demonstrated a benefit compared to the 'no' condition despite the fact that participants had to perform the same task in both conditions. The task comprised of the comparison of the object in working memory with the representation indicated by the retro-cue. In the invalid condition, there was a corresponding representation of the object in working memory and the object in the memory array. The existence of the reaction-time benefits of the invalid condition compared to the 'no' condition showed that the search in the memory array was facilitated by the presence of an object in working memory that matched a visual representation in the memory array. This fact suggests that strategic attention to a representation in the memory array was facilitated when the representation matched the object in working memory. Analogously to attentional capture in the visual field, such an effect would occur if there is an initial automatic orientation to the representation that matches the object in working memory. These initial results implied the guided attention to a representation matching an object in working memory. The three conditions for automaticity restrict performance in the task such that guided attention in the memory array was automatic. This can not be a definite conclusion unless it is shown that the three conditions are sufficient for automaticity.

Accuracy results demonstrated a cost of the valid condition compared to the invalid and the ‘no’ condition. The invalid condition accuracy had a marginally significant benefit over the ‘no’ condition. As the invalid and the ‘no’ condition task was the same, the accuracy benefit in the invalid condition can only be attributed to the facilitation of search in the memory array by the orientation of attention to a representation matching the object in working memory.

The valid condition demonstrated an accuracy cost compared to the other two conditions while the reaction-time in this condition was shorter than the other two. The analysis of the results demonstrated a significant negative correlation between reaction-time and accuracy of recall. Therefore, no SATO effect was detected in the valid condition, and the results presumably were not due to a task particular feature but rather reflect a property of the visual areas such as interference.

An interpretation of the results in the valid condition, based on the retinotopic property of visual representations, could be readily offered. The valid condition shows reduced reaction-time compared to the ‘no’ condition. This finding is in accord with the behavior in the invalid condition where the implied automatic orientation of attention facilitates search in the memory array. The valid condition also demonstrates a reaction-time benefit compared to the invalid condition. The result may be explained by the retinotopic nature of the memory array representation. In the invalid condition, attention was shifted between two locations in the memory array. In the valid condition, the same representation was attended twice, once by the probe and once by the retro-cue in the same location. In the invalid condition, the attentional shift in the two representations in respective locations in the memory array was more time demanding than the single location orientation of attention to a single representation in the valid condition. The accuracy cost of the valid compared to the invalid condition may be explained by both AM and the retinotopic property of the memory array. In the valid condition, the AM to the same representation in the same location might have caused interference in working memory between the AM and strategic attention to the same representation. Therefore, the valid condition demonstrated reaction-time benefits compared to the invalid condition due to a more time-demanding attentional shift in the invalid condition. The valid condition, additionally, demonstrated an accuracy cost compared to the invalid condition due to interference between the AM and strategic attention to the same visual representation. These suppositions need, of course, further investigation.

Experiment 2

In Experiment 1 it was demonstrated there is a facilitation of strategic attention to a representation when it matches an object in working memory. This fact implied that attention was initially oriented to the representation matching the object in working memory. The orientation of attention was further implied by the automaticity conditions to be automatic but the assertion cannot be definite unless it is shown that the conditions are sufficient for automaticity. The current experiment aimed to verify the sufficiency of the three automaticity conditions by verifying an analogous assumption for attentional capture in the visual field. Carlisle et al., 2012 and Posner et al., 1975 presumed that strategic attention to an object and therefore reaction time is increased when it is validly used to attend another object in a subsequent visual array of objects. For AM to be automatic, this means that attention to the object to be kept in working memory and therefore reaction time does not change with the probability to the direct attention to a cued representation to be recalled.

To verify the constancy of attention to the object to be loaded in working memory in Experiment 2, the reaction-time benefits or costs between conditions were measured, when the object unevenly predicted a retro-cued visual representation. Experiment 2 replicated the task in Experiment 1 in three groups that were determined by the varying reliability of the retro-cue. The three groups corresponded to 20%, 50% and 80 % of valid retro-cue. The reliability of a retro-cue to indicate a previously attended representation determined the probability for a valid trial. Thus, the three groups of a percent valid retro-cue included respectively trials of 20%, 50% and 80% probability of a valid retro-cue.

Method

Participants.

Thirty-Six University of Cyprus undergraduates, different from Experiment 1, male and female (age: 18-26), participated in Experiment 2 for course credit and had normal or corrected-to-normal visual acuity. All subjects gave informed written consent for participating in the experiment. They were equally and randomly assigned to three groups of 20 %, 50 % and 80 % of valid-cue.

Materials and Procedure.

Separate mixed-design Analyses of Variance (ANOVAs) were performed on mean reaction-time and percentage accuracy. Cue-validity was the *within-subject* variable, and the valid-cue probability was the *between-subjects* variable. The cue-validity variable had three levels that corresponded to the three conditions of Experiment 1, the valid, the invalid and the ‘no’ condition. The cue-validity probability had three levels, the 20%, 50% and 80% probability of valid retro-cue.

The materials used were the same as in Experiment 1. The procedure in each probability group was also the same as in Experiment 1, but the display time of the array was increased to 1000ms (from 130ms in Experiment 1), to allow selective attention to every object in the array. This arrangement excluded the possibility that the orientation of attention to a representation which is relevant to an observed object could only occur in perceptually grouped representation. The ISI between the probe-object and the retro-cue was additionally increased from 50ms to 250ms to restrict the possibility that the probe interacts with the retro-cue in iconic memory. Participants were asked at the end of the experiment whether they observed anything unusual during the task to investigate possible conscious access to the reported visually recalled representation. The sequence of events of Experiment 2 is shown in Figure 5.

Results

Reaction-time.

One extreme case was detected to violate the multivariate normality assumption and was removed from the analysis. There was no statistically significant interaction between validity and valid-cue probability on reaction time; $F(4, 64) = .153$, $p = .961$, partial $\eta^2 = 0.009$ and there was no statistically significant probability main effect; $F(2, 32) = .201$, $p = .819$, partial $\eta^2 = .012$. There was a main effect of cue-validity with a statistically significant difference in mean reaction-time at the different validity conditions, $F(4, 64) = 22.934$, $p < .001$, partial $\eta^2 = .417$. Reaction-times increased from the valid, 608.541 ± 23.347 ms to the invalid, 629.51 ± 24.131 ms to the ‘no’ condition, 689.341 ± 29.295 ms. Results are displayed in Figure 6. Post hoc analysis with a Bonferroni adjustment revealed that the reaction-time was not statistically significantly increased from the valid to the invalid condition. It was statistically significantly increased from the valid to the ‘no’ condition by 80.808 ± 12.301 ms, $p < .001$, and from the invalid to the ‘no’ condition by 59.831 ± 10.678 ms, $p < .001$. The main effect of reaction-time repeats the results of Experiment 1, where the valid and the invalid condition have a benefit compared to the ‘no’ condition. The results indicated that mean reaction time was the same and the mean differences or benefits and costs were constant across the three probability groups.

Accuracy.

There were two cases with extreme values that were removed from the analysis. Results are displayed in Figure 7. The validity and valid-cue probability groups demonstrated a statistically significant interaction, $F(4, 62) = 14.036$, $p = .03$, partial $\eta^2 = .156$. The simple main effects analysis demonstrated no significant percentage accuracy difference between valid-cue probability groups in the valid condition and the invalid condition and a significant a difference in the ‘no’ condition $F(2,31) = 4.106$, $p = .026$. Percentage accuracy in the valid condition was significantly greater in the 20% group than the 50% group, (12.2 ± 4.305 %, $p = .024$). Simple main effects analysis for validity within valid-cue probability groups indicated a statistically significant effect of validity in the 20% group; $F(2,18) = 11.293$, $p = .001$, partial $\eta^2 = .595$, in the 50% group; $F(2,22) = 7.899$, $p = .003$, partial $\eta^2 = .418$ and in the 80% group; $F(2,22) = 5.583$, $p = .011$, partial $\eta^2 = .337$. For the 20% group, percentage accuracy was statistically significantly different between the valid and the invalid condition (11.2 ± 1.849 %, $p = .001$), and between the valid and the ‘no’ condition (10.5 ± 2.888 %, $p = .016$). For the 50% group, percentage accuracy was statistically significantly different between the valid and the invalid condition (10.5 ± 3.401 %, $p = .031$), and between the invalid and the ‘no’ condition (14.667 ± 3.115 %, $p = .002$). There were no statistical significant differences between validity conditions in the 80 % valid-cue probability group with the Bonferroni adjustment.

Discussion

The valid and the invalid condition in Experiment 2 demonstrated corresponding reaction-time benefits in recall compared to the 'no' condition, as in Experiment 1. These reaction-time benefits were invariant across the three retro-cue reliability groups. Thus, the invariant reaction-time benefits in the three experimental groups are consistent with the prediction of the current experiment.

While reaction-time results indicated the automatic orientation of attention to the probe-matching representation, the percentage accuracy results were expected to show how this effect was used in the task. First, the results in the 50% cue-reliability replicated the results of Experiment 1: The invalid condition had a significant accuracy benefit over the 'no' condition, and the neutral condition had a significant cost over the other two conditions. The accuracy benefit of the invalid condition compared to the 'no' condition was not present at the 20% and 80% cue-reliability groups. Therefore, the accuracy benefit of the invalid condition compared to the 'no' condition did not depend on the retro-cue reliability. This accuracy benefit emerges as the 'no' condition accuracy shows a significant decrease in the 50% cue-reliability group compared to the other two groups. Since this decrease does not depend on cue-reliability, it must rather be due to some other factor, probably due to the difficulty of the task for the 'no' condition in the 50% cue-reliability group.

The costs of valid cues compared with the invalid ones which are observed in all cue-reliability groups are in contrast to previous findings, where the valid cues always demonstrate benefits compared to the invalid ones. Nevertheless, valid-cue costs should have varied with cue-reliability and the associated anticipation for an invalid cue (Gunseli et al., 2015). Valid-cue accuracy costs did not differ in the three cue-reliability groups. Equivalently, anticipation for an invalid cue did not influence the accuracy of retrieval in the invalid condition. The findings suggest that retrieval from the visual areas by both the probe-object and the retro-cue was not strategically adjusted by the retro-cue reliability when both the automatic or the strategic orientation of attention occurred in the visual areas. Therefore, the findings of Experiment 2 imply that both strategic and automatic orientation of attention in the visual areas resulted in automatic retrieval of the attended representations.

Experiment 3

In Experiment 1 reaction-time benefits were observed in the valid and the invalid condition compared to the 'no' condition. Such effects could only be produced if attention was directed to the memory array as they were corresponding to effects of strategic orientation of attention in visual areas. Additionally, the invalid condition percentage accuracy compared to the 'no' condition, indicated that the orientation of attention in visual areas facilitated recall. In Experiment 3 the condition regarding the perceptual contrasting of the memory representations and the probe object was removed by increasing theirs between similarity. It was anticipated that if this condition was necessary for automatic orientation of attention in visual areas, then the additional reaction-time and accuracy benefits and costs between the valid and the invalid condition compared to the 'no' condition should have vanished.

The task in Experiment 3 was the same with the task of Experiment 1. The stimuli were geometrical figures formed only by rectangles of similar size that there were attached to each other without gaps. They are shown in Figure 8. In addition to the perceptually demanding task, the cognitive effort was increased by rotating the probe object by ninety degrees compared to a corresponding object in the visual array. Thus, in every trial, each participant had to necessarily perform a mental rotation (Shepard & Metzler, 1971) before an object comparison with the corresponding representation.

Method

Participants.

Fifteen undergraduates of the University of Cyprus, male and female (age: 18-26), participated in Experiment 3 for course credit and had normal or corrected to normal visual acuity. All subjects gave informed written consent for participating in the experiment. Two participants' data was removed from the analysis due to not having consistently performed the task.

Materials.

The stimuli of Experiment 3 are shown in Figure 8. They were formed by combining black squares and rectangles, which did not differ substantially in their dimensions. The maximum dimension of an object did not exceed 0.93^{o} of visual angle. All other materials were the same as in Experiment 1.

Procedure.

Separate one-way Analyses of Variance (ANOVAs) were performed on mean reaction-times and percentage accuracy. The *within* factor had three levels which were the three conditions (valid vs. invalid vs. 'no').

The procedure was the same as in each particular group, of Experiment 2. The probe object was also rotated by ninety degrees compared to a matching object in the memory array, and participants were informed about this arrangement. The sequence of events of Experiment 3 is shown in Figure 9.

Results

Reaction-time.

A participant was removed from the analysis because his scores violated multilinear normality. The validity conditions did not elicit statistically significant changes in response time; $F(2, 22) = .733$, $p = .49$, partial $\eta^2 = .044$, with mean reaction-time increasing from 897.5 ± 50.932 ms in the valid condition, to 902.2 ± 42.502 ms in the invalid condition and to 921.917 ± 51.237 ms in the 'no' condition.

Accuracy.

Two participants were removed from the analysis because their scores violated multilinear normality. The three conditions did not elicit statistically significant differences in mean percentage accuracy; $F(1.265, 12.652) = 1.482$, $p = .254$, partial $\eta^2 = .129$, which was 60.182 ± 3.130 % for the valid, 68.545 ± 3.108 % for the invalid and 63.273 ± 4.309 % for the 'no' condition.

A one-sample t-test was subsequently run on mean percentage accuracy in each condition, to evaluate whether it was significantly different from chance-level 50 %-accuracy. The valid-condition mean, 60.182 ± 3.130 %, was significantly different from 50 % accuracy; $t(10) = 3.253$, $p = .009$, $d = .98$. The invalid-condition mean, 68.545 ± 3.108 %, was significantly different from 50 % accuracy; $t(12) = 5.967$, $p < .001$, $d = 1.799$. The 'no'-condition mean, 63.273 ± 4.309 %, was also significantly different from 50 % accuracy; $t(10) = 3.08$, $p = .012$, $d = .928$.

Discussion

In the current experiment, the reaction-time benefits in the valid and the invalid condition compared to the ‘no’ condition vanished. The reaction-time and accuracy of recall benefits of the invalid condition compared to the ‘no’ condition in Experiment 1 demonstrated the orientation of attention to a representation relevant to an observed object. Thus, the absence of those benefits in the current experiment shows that the orientation of attention to a representation relevant to an object kept in working memory did not occur. However, the strategic orientation of attention to a retro-cued representation did occur since the accuracy of recall was above chance level. The accuracy would have been at the chance level if a participant could not compare a retro-cued representation with the probe object. If AM was strategic, the benefits and costs in the valid and the invalid condition compared to the’no’ condition would have persisted since the strategic orientation of attention to the array is possible. Thus, the vanishing of these benefits and costs shows that the orientation of attention to a visual representation relevant to an observed object was not strategic and therefore was automatic.

The automatic orientation of attention to a visual representation relevant to an observed object did not occur when one condition of automaticity was removed. Thus, the condition regarding an easy perceptual and non-cognitively demanding task was necessary for automaticity.

General Discussion

The research question of the current study was: When there is a search goal in a memory array and an object is kept in working memory, does the object automatically guide attention to a relevant visual object-representation in the memory array? The automaticity of orienting attention to a visual representation was assumed by three conditions of automaticity.

Experiment 1 investigated whether attention to a representation in the visual areas guided by an object in working memory produces similar reaction-time benefits with retrospective attention in the visual areas. It was assumed that those benefits would have been produced automatically when the three conditions for automaticity were involved in the experiment. The experiment produced reaction time benefits in the valid, and the invalid condition compared to the 'no' condition and indicated that the attention to a representation relevant to the observed object actually occurred. The invalid condition produced accuracy benefits that demonstrated that attention to the relevant visual representation of the observed object facilitated recall. The conditions of automaticity implied that the attention to the visual representation relevant to the object in working memory was automatic. However, the conclusion was not definite since there was no proof that the conditions for automaticity were sufficient.

Experiment 2 aimed to verify the assumption in Experiment 1, that when the conditions for automaticity for orienting attention in visual areas apply, then attention to a representation relevant to an observed object is automatic. The assumption was confirmed by the validation of the prediction that reaction-time benefits of recall should remain constant with a varied probability of a valid retro-cue. Further, the accuracy of recall demonstrated that it was not based on the anticipation of a valid retro-cue as the difference in accuracy between the invalid and the 'no' condition remained constant with valid cue reliability. This fact indicated that the recall of the attended visual representation relevant to an observed object was automatic. The automatic orientation of attention in visual areas revealed an automatic recall mechanism which differs from the removal (Kuo et al., 2012; Souza et al., 2014) and the prioritization (Myers et al., 2015; Rerko et al., 2013) mechanisms of strategic attention in visual areas.

In Experiment 3 one of the conditions for automaticity was removed. The reaction-time benefits of the recall were diminished. The similarity and relative orientation between the object in working memory and the cued representation were increased. If attention to a representation that is guided by a relevant object in working memory is strategic then the reaction time benefits would be preserved. The accuracy benefits were diminished as well, but accuracy in every condition was above chance level indicating that strategic attention by the retro-cue occurred. Therefore, the removal of reaction-time benefits indicated that the automatic orientation of attention to the representation relevant to observed object did not occur. This fact implies that the reaction-time benefits in Experiments 1 & 2 were not due to the strategic orientation of attention in visual areas.

The findings of the current study mark both similarities and significant differences from other research findings on the attention in the visual representations. There is an agreement of the of the findings of the current study, and previous related studies on reaction-time benefits when attention is directed in visual areas and the similarity between objects and the cognitive demand of the task is low. The reaction-time benefits vanish when the similarity between objects and the cognitive demand of comparing objects and visual representations are high. This fact suggests that reaction-time findings of previous related research (Griffin et al., 2003) depend both on automatic and strategic employment of attention in visual areas. The accuracy of recall from visual areas marks differences from previous research. Prioritization of an attended representation (Myers et al., 2015; Rerko et al., 2013) and removal of unattended representations (Kuo et al., 2012; Souza et al., 2014) label the main recall mechanisms when strategic attention is oriented in visual areas. The two mechanisms are explained in the same framework as being emerged by the anticipation of a representation to be attended and recalled. The findings of the current study indicated that recall of a visual representation did not depend on the anticipation to be attended. Thus, they suggest that the recall of a representation is automatic when it is automatically attended.

The current study contributes in complementing a pattern of interaction between working memory and attention. Strategic orientation of attention to an object may occur when relevant information is held in working memory. In the biased competition model of attention, a short-term description related to the current goal called the attentional template, a function of working memory, can be used to control competitive bias in the visual system. The attentional template can be a spatial cue or a feature (Bundesen, 1990, Duncan & Humphreys, 1989). The automatic orientation of attention to an object which is relevant to a visual representation in working memory is another implication of the biased competition model of attention (Olivers, 2009; Soto et al., 2008). It is complementary to strategic attention and assists search in the visual field when the contents of working memory are identical to the search goal. Attention may be strategically oriented to a representation in a visual array by spatial, object or feature cues (Griffin & Nobre, 2003). Attention to a memory template is known to be oriented only strategically. The current study supplements this pattern by the realized automatic orientation of attention to a representation in visual areas due to an object in working memory. The strategic attention to a memory representation is facilitated by the initial automatic orientation of attention to a visual representation that matches an object in working memory. Thus, the new effect expands the behavioral consequences of the biased competition model. An attentional template is used to control competition for attention in both the visual field and the visual areas. In both processes, strategic attention is facilitated by an initial automatic orientation of attention guided by the attentional template.

From a practical point of view, the automatic orientation of attention in the visual areas may contribute to the understanding of related cognitive mechanisms. There is considerable research on the impact of attention in the visual areas on the retrieval of object representations. It has been shown that proposed retrieval mechanisms are shaped by task-related issues and consequent top-down control which are not intrinsic to the retrieval mechanisms (Gunseli et al., 2015). Instead, these issues may be resolved if the automatic orientation of attention is used in the tasks as it excludes the top-down contribution to response. The current study, therefore, would contribute to future research on the understanding of retrieval mechanisms from the visual areas.

AM could serve as a Tool for the Investigation of the Retro-cue Benefit Effect

A relevant subject of research, which can be profitably investigated by AM, is the retro-cue benefit effect mechanism. The retro-cue mechanism underpins both the attended and non-attended representations by a retro-cue in the visual areas. The status of non-attended representations is vital in identifying the retro-cue mechanism because it shows the way an attended representation prevails over non-attended ones. The retro-cue benefit effect has been investigated by accuracy benefits with a resulting variety of mechanisms, which are shaped by top-down modulation (Carlisle et al., 2012). The insufficiency of selective retrospective attention methods, for the investigation of the retro-cue benefit mechanism, is substantiated by the finding that non-attended representations are enhanced after being retro-cued (Kuo et al., 2012). The finding indicates that the status of a non-attended representation is changed by the action of a retro-cue and therefore its initial status is not known.

The initial status of a non-attended representation in the retro-cue tasks may be successfully disclosed by reaction-time benefits or costs produced by AM. Reaction-time benefits by AM have been exhibited in the current study to be utterly automatic. For research studies, which investigate the retro-cue mechanism and rely on accuracy response to examine the course of non-attended representations, top-down modulation of response is inevitable. Nevertheless, to reveal the initial status of a non-attended representation in a retro-cue task, the representation should necessarily not be perturbed by top-down modulation. AM provides for this matter an automatic mechanism which may detect the presence or the absence of a non-attended representation in a retro-cue task, without top down-influence. Corresponding prioritization or removal mechanisms in visual areas recall may then be established.

AM could Resolve Questions in the Investigation of the Visual Areas Capacity Limit

The current study has shown that AM is an automatic filtering mechanism in the visual areas representations. Experiments 1, 2 & 3 were performed with arrays of four objects, which is the limiting capacity of working memory (Luck et al., 1997, 2013). Can then AM, occur in a memory template that exceeds the working memory capacity limit, which is formed by a simultaneous broad focus of attention to four objects (Cowan, 2001; Oberauer et al., 2012)? Accordingly, the ecological validity of AM would prove to be more important when comparing different scenes; if more than four objects could be held in the visual areas and one can automatically access one of them by AM, his processing capabilities could have dramatically increased.

Investigations on the capacity limit of working memory are based on tasks which exclusively involve strategic access and manipulation of several representations (Luck et al., 1997, 2013) a fact that presumes that both the PFC and visual areas such as V4, TEO, and TE cooperate for this processing. However, other studies that use a retro-cue to access consolidated visual areas representations find a higher capacity limit (Sligte et al., 2008; van Moorselaar et al., 2015). These studies seem to dissociate PFC manipulation and visual areas storage during the consolidation of representations of attended objects. The higher capacity limit then is preferably a capacity limit of the visual areas' short-term memory. PFC is later employed for processing the consolidated visual areas representations using internal attention.

Research employing retrospective attention has nevertheless given controversial results for a higher capacity limit of visual areas (Matsukura & Hollingworth, 2011). Matsukura and Hollingworth. questioned a proposed fragile memory store (Sligte et al., 2008), which occurs before working memory and has a higher capacity limit, on the basis that the stimuli used could form groups that their number does not exceed four. Despite criticism, subsequent research on the capacity limit of a proposed fragile memory store used the same stimuli (van Moorselaar et al., 2015), which are small rectangles displayed with a different orientation. The fragile memory store shares feature with visual areas (Pinto, Sligte, Shapiro, & Lamme, 2013) such that it is an object- and location-based with its representations subjected to interference. In addition to the fact that the fragile memory store is doubtable regarding its higher capacity, it has not been given a functional role in the manipulation of visual representations.

A higher capacity visual areas store could be shown by AM-an automatic filtering mechanism in visual areas-to hold an increased processing capacity of the mind. A task similar to the one employed in Experiment 1, but with an array of more than four objects, could show, regarding reaction-time benefits or percentage accuracy response, whether the visual areas maintain the properties of the fragile memory store, especially the higher capacity limit. Two issues of using AM, as in the task of Experiment 1, to investigate a higher capacity limit of visual areas, provide an advantage to previous methods. First, the objects used in the task are discriminable and unfamiliar, and their complexity prevents the Gestalt emergence of new shapes from their combination when they are adjacently displayed (Fiser et al., 2001). Secondly, reaction-time benefits rely on the automatic guidance of attention in visual areas and are independent of accuracy response. In effect, the validation of a higher capacity limit for visual areas would be enabled even if representations cannot be accessed strategically.

AM is Distinct from Attention in Iconic Memory

A marked difference between the current study and the research literature is the interpretation of the consequences of the short 200ms ISI between the probe object and the memory array. In the research literature, access to the visual areas representations is assumed to occur at an ISI of about 1000ms between the memory array and the probe stimulus or the retro-cue. A shorter ISIs of the order of 200 ms is considered to offer access to iconic memory. (Astle et al., 2012; Makovski et al., 2008; Rerko et al., 2013; Shimi et al., 2017; Souza et al., 2014). In the current study, the 200 ms ISI between the memory array and the probe stimulus was set to have an optimum effect of AM in the visual areas representations. This arrangement was based on two facts; first, iconic memory ceases to exist at 200 ms (Jiang & et al., 2004; Phillips, 1974) and secondly, rapid forgetting in visual areas is prevented (Pertzov et al., 2013). Visual areas representations may be argued to be accessible even for corresponding ISIs shorter than 200 ms since a visual areas representation of an object is consolidated 50 ms after the object is being attended (Vogel, Woodman, & Luck, 2006).

It can further be argued that a visual areas representation is accessible after the 50 ms consolidation time, while it still coexists with the iconic representation of the same item since the two memory stores fulfill different functions. That is, the duration of an iconic representation is not necessarily a prerequisite to the emergence of a visual areas representation. Iconic memory is retained to preserve the smoothness in observing the visual field during eye blinking or during observation of changing scenes. The new icon does not erase the previous information on the primary cortex (Nikolić, Häusler, Singer, & Maass, 2009). The visual areas representations, on the other hand, are formed in visual areas of V4, TEO, and TE, which regard the perceptual analysis of a visual object. Representations in higher visual areas, in contrast to iconic memory representations, are erased when new information loads the supporting visual areas (Pinto, Sligte, Shapiro & Lamme, 2013; Souza et al., 2014).

Representations which are reached by using a centrally displayed retro-cue or probe objects should be visual areas representations, rather than the iconic ones as the number of remembered objects is small-not exceeding eight objects- despite that the relevant ISI is below 200 ms (Astle et al., 2012; Shimi et al., 2017). Instead, iconic memory has unlimited capacity in the case that the task requires contrasting of successive icons (Phillips, 1974). The argument regarding the distinction between iconic memory and visual areas representations presumably resides more on the means by which the visual representations are being accessed in each memory store than on the ISI between the memory array and the probe object or the retro-cue. Hence, the results of the current study regard attended visual areas representations and not iconic ones, since either a centrally displayed probe object or a retro-cue were employed to direct attention to these representations.

AM could Serve as a Supplementary Tool to fMRI and SCR

AM can be used as a tool to investigate complex processes of the human mind, which are not attainable by current methods of SCR and fMRI. The current study has shown, through demanding perceptual and cognitive tasks, that a visual representation can be accessed by attention automatically. The effect was demonstrated by a temporal resolution, between experimental conditions, of the order of tens of milliseconds. These results are not attainable by anyone of the three current experimental methods: SCR (Chelazzi, Duncan, Miller, & Desimone, 1998; Chelazzi et al., 1993; Reynolds et al., 1999), univariate fMRI (Kastner et al., 1998; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999) and multi-voxel fMRI data analysis (Reddy et al., 2009). Each method is characterized by individual capabilities and constraints, which advance and limit access respectively to visual processing areas of the brain.

SCR is accurate both spatially and temporally. Dimensions of a single neuron determine spatial accuracy and the averaging of neuron responses in binwidths of 10–50 ms specify temporal accuracy (Chelazzi et al., 1998). Even with this temporal and spatial specificity, SCR cannot be applied to human subjects a fact that limits their search capability to simple visual processes that can be performed by primates.

The fMRI methods for biased competition tasks determine responses within the order of seconds (Kastner et al., 1998, 1999) and spatial specificity within the volume of a voxel, which is of the order of $1mm^3$. Although fMRI methods customarily apply to human subjects, they cannot show a sequence of events in the brain separated by intervals of the order of milliseconds, which is essential when identifying close relations between causes and effects in the responses.

AM has instead produced sequent behavioral results which are separated by tens of milliseconds. Reaction-times of this order, which are not influenced by top-down modulation, can reveal the actual status of a visual representation after a specific process in visual areas, which can be performed only by the complex human response. AM can, therefore, be used as a tool to directly investigate complex processes in visual areas of the human mind and their interaction with PFC control.

Conclusions

The current study has established that for a search in the visual areas, the orientation of attention to a representation is automatically guided by the matching contents of working memory. The effect produced reaction-time patterns which were compatible with corresponding patterns generated by the retrospective attention in the visual areas. The accuracy results, which have been exhibited to be influenced by automatic causes, are nevertheless incompatible with corresponding effects of the prioritization and removal mechanisms of retrospective attention. This finding makes AM, distinct from selective retrospective attention. The guided attention to the visual areas by the contents of working memory has an ecological validity of facilitating search in the visual areas, in analogy to search facilitation in the visual field by attentional capture from visual objects, and therefore constitutes an automatic filtering mechanism in the contents of the visual areas. Furthermore, the unmodulated by top-down control access to visual areas by the effect provides excellent opportunities to investigate complex processes in human visual areas and their interaction with top-down control, which are not attainable by current behavioral and neuroscientific methods.

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Figures

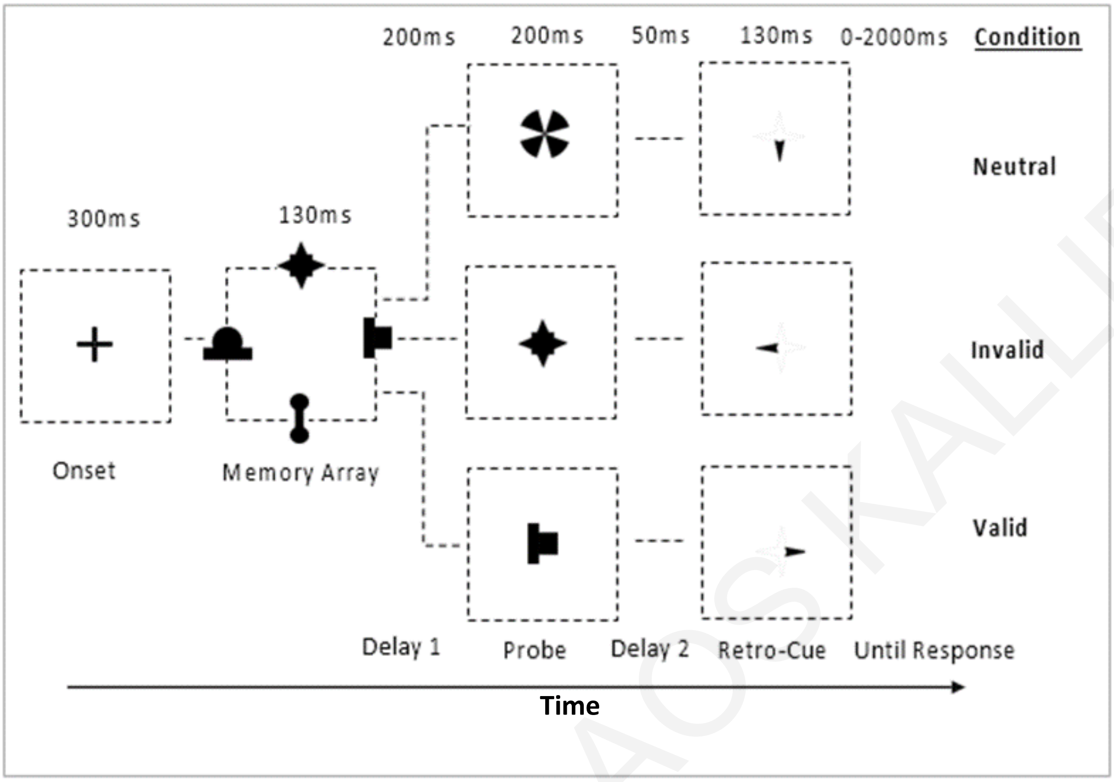

Figure 1. The sequence of events in Experiment 1. Three sample cases are shown corresponding to the three cue-validity conditions of the experiment.

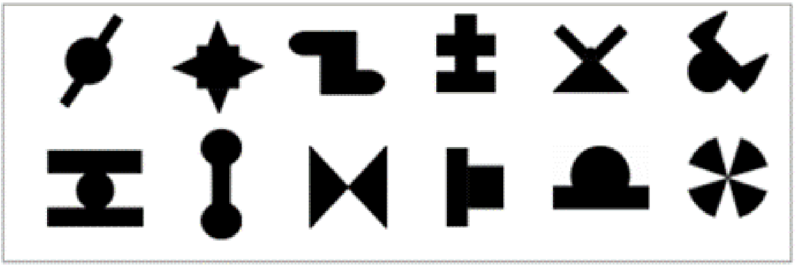

Figure 2. The stimuli used in Experiment 1 were similar to the figures used in Fiser et al., (2001).

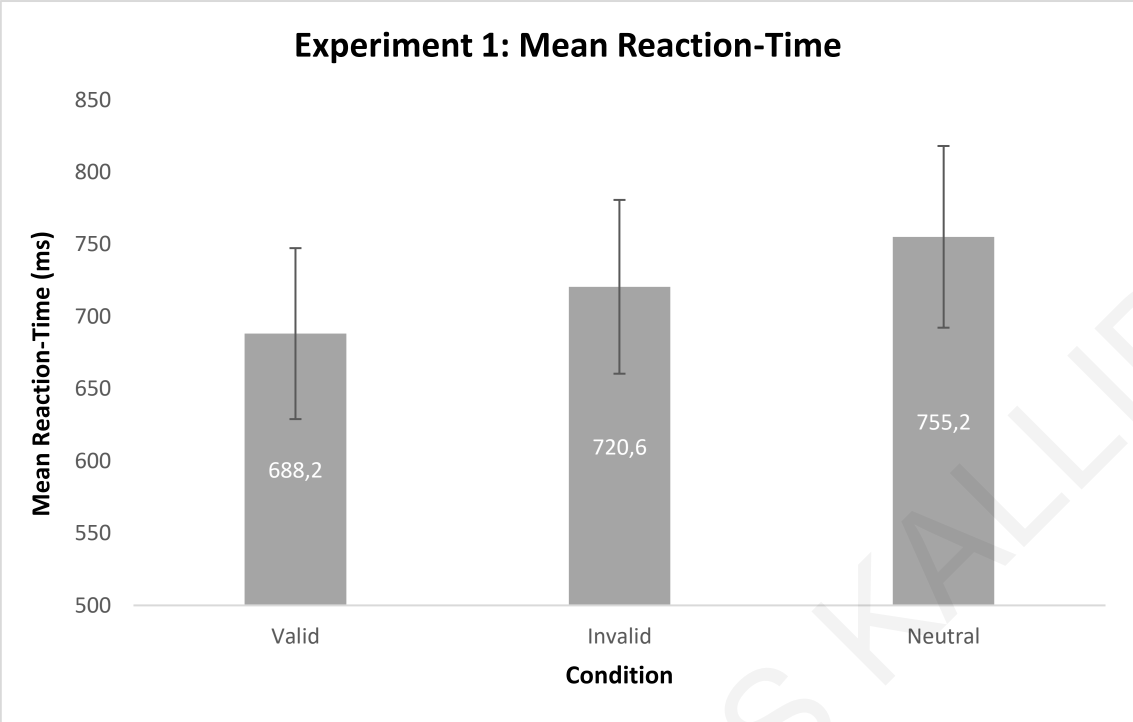

Figure 3. The mean reaction-time response of the three conditions of Experiment 1. The error bars represent 95% within-subjects confidence intervals.

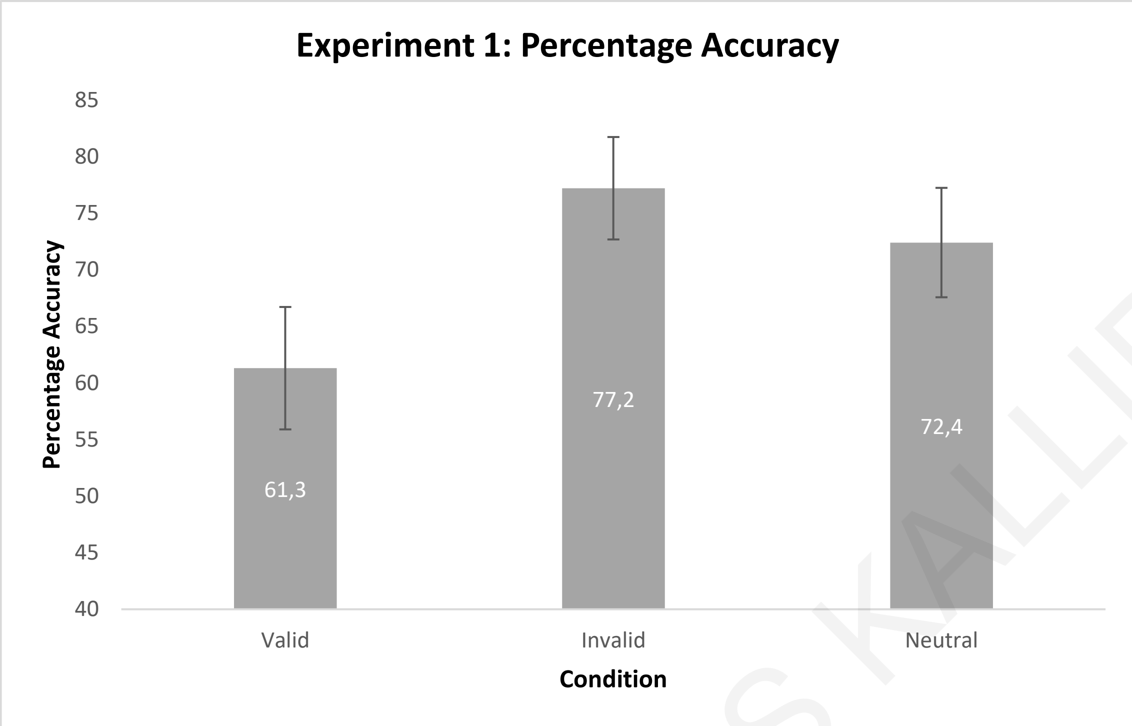

Figure 4. The percentage accuracy response of the three conditions of Experiment 1. The error bars represent 95% within-subjects confidence intervals.

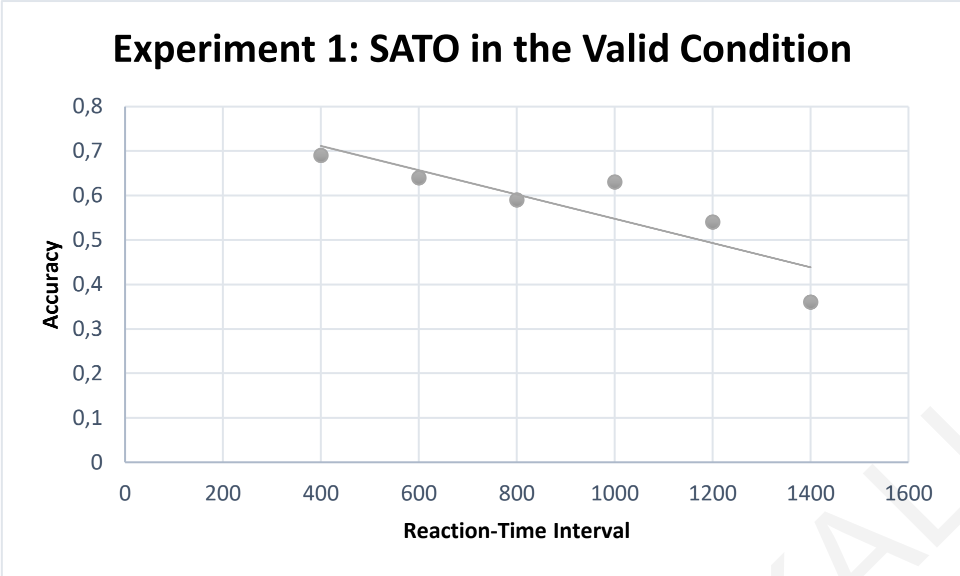

Figure 5. The accuracy response correlation to reaction-time.

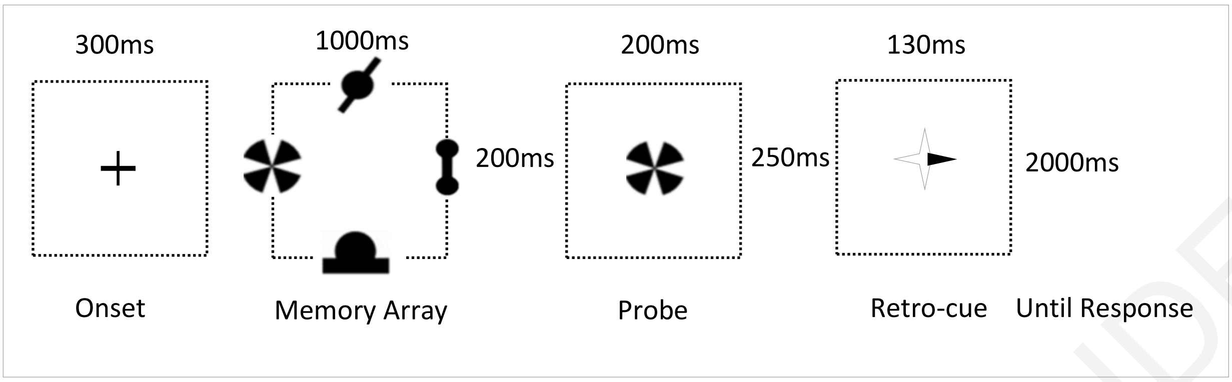

Figure 6. The sequence of events in Experiment 2. A trial in the invalid condition is displayed.

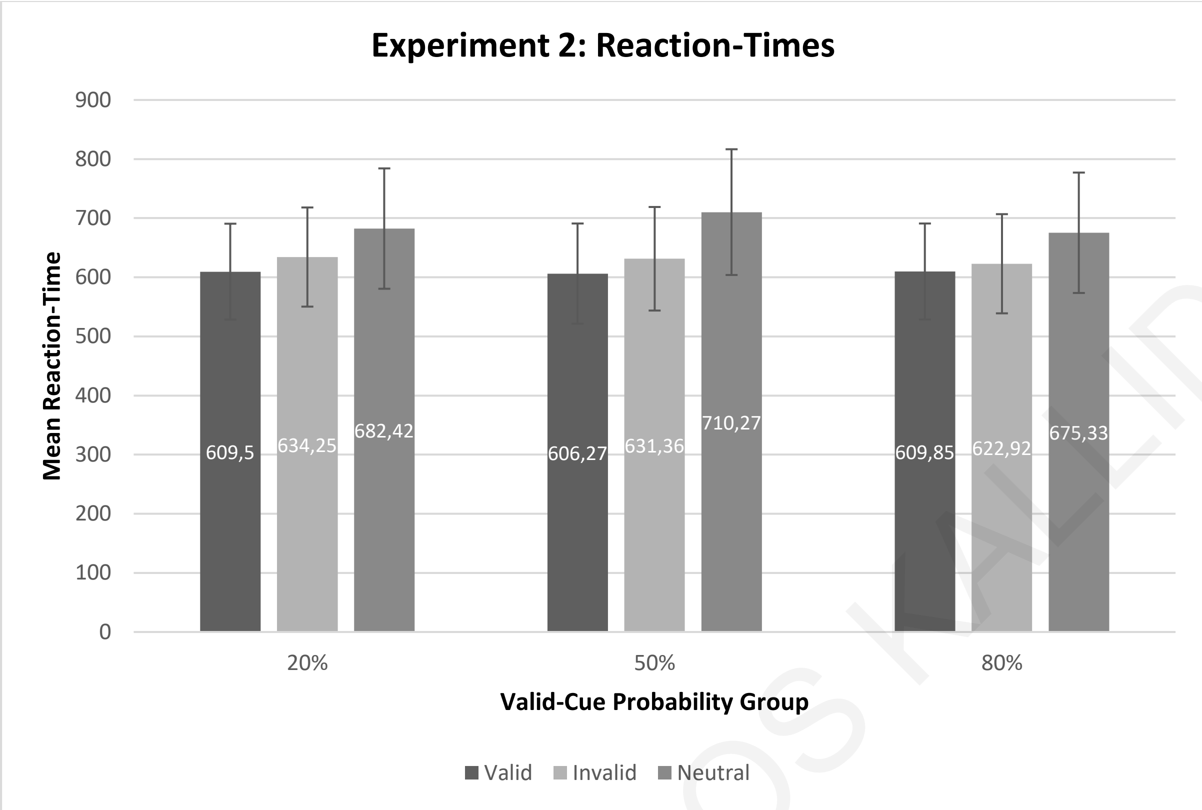

Figure 7. The mean reaction-time response of the three conditions in the three valid-cue probability groups in Experiment 2. The error bars represent 95% within-subjects confidence intervals.

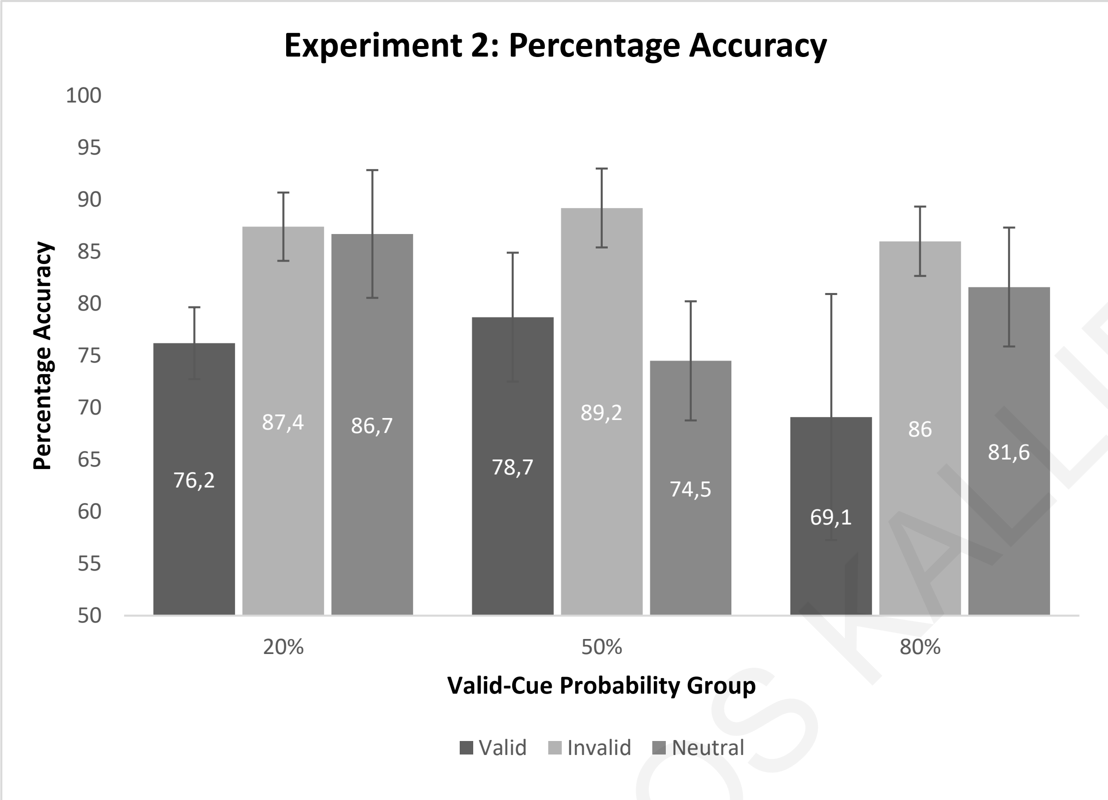

Figure 8. The accuracy response of the three conditions in the three valid-cue probability groups in Experiment 2. The error bars represent 95% within-subjects confidence intervals.

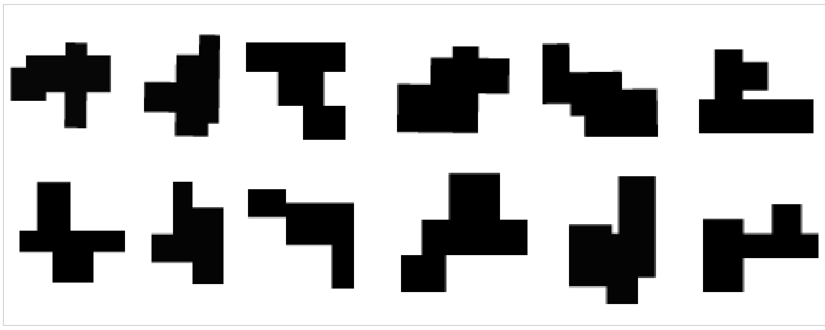

Figure 9. The stimuli used in Experiment 3.

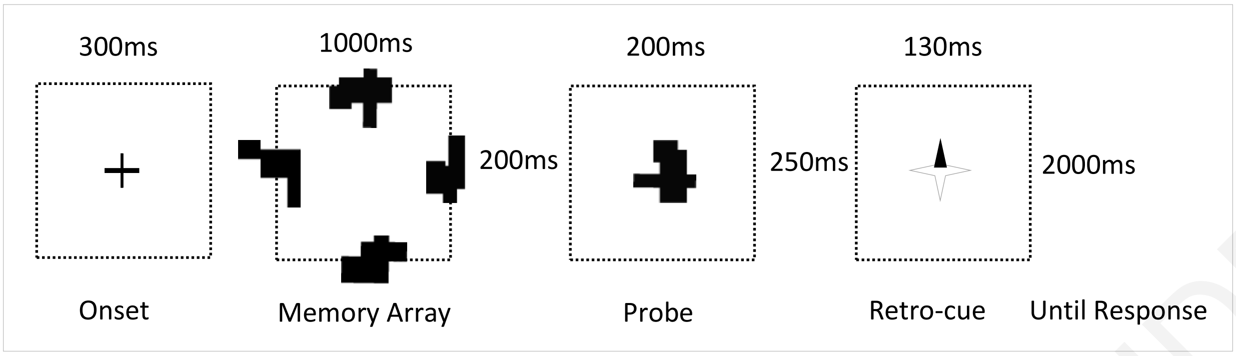

Figure 10. The sequence of events in Experiment 3. A trial in the valid condition is displayed.