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What guides attention when searching the mind?

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The phenomena of 'looking, but not seeing' is a growing cause of concern, causing issues such as traffic accidents due to missed obstacles. This research contributes to a growing body of work showing that people do not pay attention to an object, only the features that make it up (e.g., its colour).

Across three studies, we investigated the role of features when directing attention internally towards visual working memory. We have determined that both the guidance and the manipulation of objects in attention is a feature-based process. Furthermore, we have determined that the features that can guide attention internally is broader than it is for externally directed attention. Further research is required to determine whether these findings are due to the difference between visual perception and visual working memory, or whether this is a fundamental difference that occurs when changing the direction of attention.
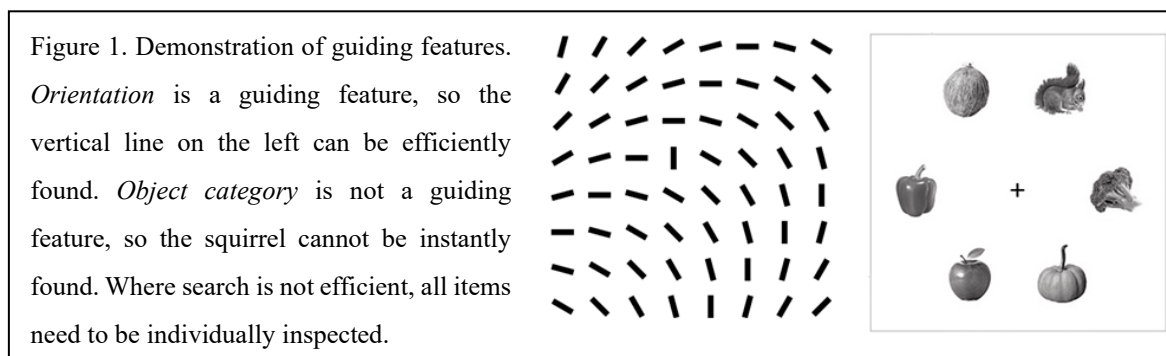
Experimental Psychology

Attention Visual Working Memory Visual Cognition

１．研究開始当初の背景

The amount of information that the brain perceives at any moment is far greater than our minds can process. To deal with this flood of information, we need to filter out noise and select only the most important information to process further. This filtering and selection is the result of attention.

Attention is surprisingly limited. Filtering is based on a narrow set of parameters, known as guiding features, e.g., color, shape, orientation (Wolfe & Horowitz, 2004; see Figure 1). This is why it is a common experience to be looking for but being unable to find something that is right in front of you—the guiding features cannot distinguish between the target and its surroundings.

Figure 1. Demonstration of guiding features. *Orientation* is a guiding feature, so the vertical line on the left can be efficiently found. *Object category* is not a guiding feature, so the squirrel cannot be instantly found. Where search is not efficient, all items need to be individually inspected.

Decades of visual search research has determined *what* the guiding features are, however, we do not yet know why we are restricted to such a small set. This is because attentional research has largely been tied to perception, to the point that there was once a misguided attempt to study basic perceptual building blocks using visual search (Nakayama & Martini, 2011). What is needed in order to further study guiding features is a way to study attention from outside the field of perception.

２．研究の目的

Attention is becoming one of the most significant cognitive abilities in modern society. In the professional world, around 31% of diagnoses of breast cancers were missed in a previous mammogram (Vreemann et al., 2018). In every day settings, thousands of car accidents occur because the drivers did not recognize a pedestrian or motorbike, despite clearly being in their field of view. This phenomena of 'looking, but not seeing' is a growing cause of concern as modern society becomes one of multi-tasking and divided attention.

The purpose of my research, therefore, is to understand why human attention is so limited. When the limitations are understood, it will be possible to either improve people's attention or teach people to more efficiently use their attentional resources. It will also inform designers of control systems and user interfaces how to draw attention to priority information, while making less urgent information easier to ignore.

３．研究の方法

This project was conducted using experimental psychophysics, namely the memory search technique (Kong & Fougnie, 2019; Figure 2) and the retro-cue technique (Griffin & Nobre, 2003). By carefully choosing the memoranda for the task, it is possible to answer many questions using these techniques. Figure 2 is an example of this. If participants are faster to move the grey items than the non-grey items, i.e., a *search asymmetry* (Treisman & Gormican, 1988), we can conclude that color can guide attention, even when directed internally towards memory. Similarly, if they can move vehicles faster than non-vehicles, then object category is also a guiding feature.

Figure 2. Example of a memory search trial. Participants remember the first display, which is then removed. They are then asked to update a subset of items, then signal that they have finished. The time taken indicates how easy it was to find the items. Finally, they answer a question about their memory.
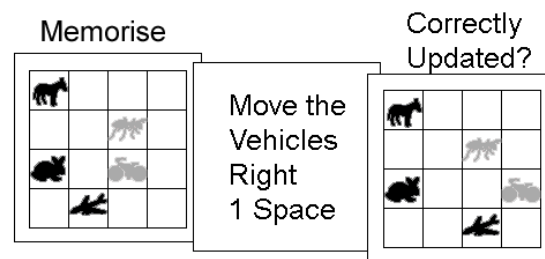

４．研究成果

Three studies were conducted as part of this project, all looking at the role of features in the utilisation of attention internally directed towards visual working memory. Study 1 was a solo project investigating how features are used to guide internal attention. Study 2 was conducted in conjunction with Edyta Sasin, Yunzhe Sun and Daryl Fougnie (New York University Abu Dhabi, UAE), and compared how features of different levels could guide attention both externally and internally. Finally Study 3 was conducted in conjunction with Huichao Ji, Kaiyue Wang, Huomin Mao, Xiaodan Zhang and Xiaowei Ding (Sun Yat-Sen University, China), and investigated how featural attention is used to enable the manipulation of items in visual working memory.

In Study 1, I investigated how featural attention is used when directed internally. In the more well-studied case of externally directed attention, guidance by any basic feature exhibits a near-flat search slope, such that set size has a minimal effect on search times (Buetti, Cronin, Madison, Wang, & Lleras, 2016). Does this remain the case for internally directed attention? As shown in Figure 3, participants remembered a display consisting of three or five stimuli (self-paced), before a mask was presented for 1000 ms, followed by a 1500 ms blank screen. Finally, the participant was asked to find a target and indicate whether it was left or right of fixation.

Figure 3. Trial sequence and example stimuli for all experiments in Study 1
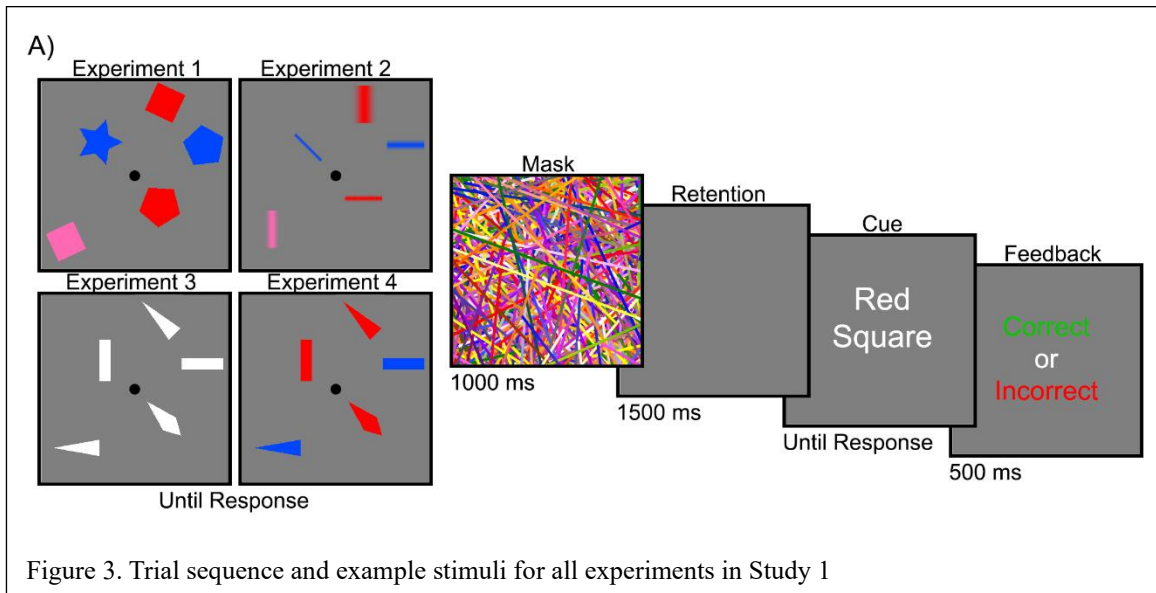
In Experiment 1, the target was identified by either its colour, shape or by its colour and shape. As in externally directed attention, participants were fastest when cued by its colour. However, participants were no faster to find cued by shape than when cued by the colour-shape conjunction. Experiments 2 and 3 confirmed that this effect is not due to the specific features chosen: colour is again dominant for colour-orientation pairings, while shape is dominant for shape-orientation pairings. Experiment 4 demonstrates that this primacy of one feature is under voluntary control, as shape is still dominant over orientation when the oriented shapes have irrelevant colours. These results demonstrate a difference in how featural attentional is guided internally to visual working memory compared to the usually studied external guidance. It appears that for internal featural attention, guidance is efficient for only a single dominant feature. Guidance towards the secondary feature is no different to search for a conjunction of features.

In Study 2, we investigated the ability of different features to guide internally directed attention. Externally directed attention can only be guided by a narrow set of features, such as colour, motion and orientation (Wolfe & Horowitz, 2017). While the reasons for this are debated, it is likely not coincidental that all of the guiding features are ones that are processed early and speedily in the brain. However, this is only a factor when direction attention externally towards perception. In the case if internally directed attention, the items are already processed, which may allow slower features to guide attention. We tested this possibility in a series of experiments, as seen in Figure 4. Each experiment was composed of two tasks, presented in separate blocks. In the visual task, participants were given a pictorial or semantic cue that would uniquely describe the target of the search, either through reference to a lower-level feature (e.g., colour), or a higher-level object descriptor (i.e., identity, category). After one second, they were then shown a display of four coloured objects, and they had to indicate whether the cued object was to the left or right of the screen. In the memory task, the order was reverse. Participants were first shown the four objects, and were given two seconds to remember them. After a one second mask, participants were then given the cue that indicated what the target of the search was.

Figure 4. Trial sequence and stimuli for all experiments in Study 2
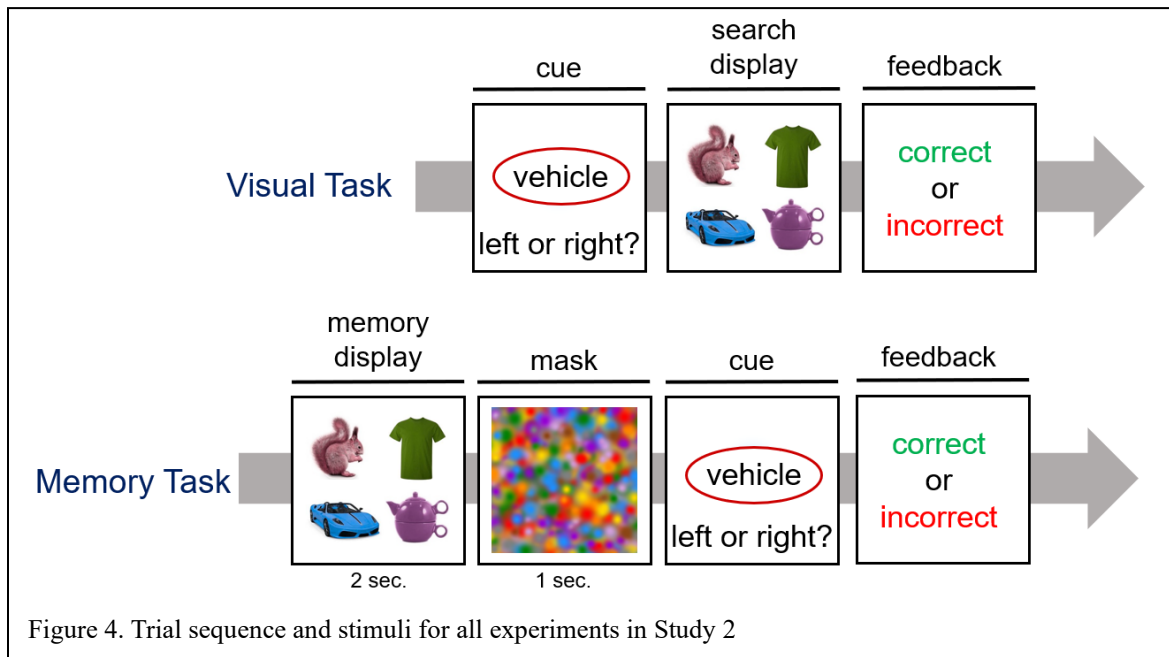
Across multiple experiments, we found the exact same result. In the visual task, searching for target by cueing its colour was much faster than searching for an object descriptor. However, in the memory task, this difference was significantly reduced or, in some cases, eliminated. This demonstrates that when directing attention internally, higher-level features are about as efficacious as the usual lower-level features.

In Study 3, we investigated not the guidance of attention, but the ability to use attention to manipulate items in memory. In my original memory search study (Kong & Fougnie, 2019), we used careful control of the memory stimulus and cues to identify whether internally directed attention would exhibit the guidance effects, as in visual search. For this purpose, it was only every necessary to update a single subset of similar items in memory, so the manipulation phase of the task was more or less ignored. In Study 3, we instead focused on this manipulation stage of the task to investigate how visual working memory operations are performed. Participants remembered multi-featured objects, before being asked to manipulate them via a spatial cue. A change probe was then used to encourage engagement with the task. By varying that memory stimulus and which items were spatially cued, we could compare the updating times to determine what makes it difficult to manipulate visual working memory.

Across a series of experiments, we found that the main determinant of updating difficulty was the number of features. The number of cued items had little effect on updating times, if all cued items had only a shared, single feature. Interestingly, orientation was an exception to this rule, such that updating multiple orientations did not cause the expected increase in updating difficulty. This is a unique prediction of the Boolean Map Theory of Visual Attention (Huang & Pashler, 2007), and provides unique evidence that the manipulation of objects in visual working memory is an attention based process.

In summary, across three studies, we have investigated the role of features when directing attention internally towards visual working memory. We have determined that both the guidance and the manipulation of objects in attention is a feature-based process. Furthermore, we have determined that the features that can guide attention internally is broader than it is for externally directed attention. Further research is required to determine whether these findings are due to the difference between visual perception and visual working memory, or whether this is a fundamental difference that occurs when changing the direction of attention.

Garry Kong
Objects in Visual Working Memory are Indexed by a Single Feature
Vision Sciences Society
2022

Edyta Sasin, Yunzhe Sun, Daryl Fougnie, Garry Kong
Visual Versus Memory Search: The Role of High Versus Low Level Features
Object Perception, Attention & Memory
2022

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Two manuscripts have been produced, relating to Studies 1 and 3 in the research report. These are currently being submitted and/or under review at academic journals.

A manuscript relating to Study 2 in the research report is currently in production.

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	Sun Yat-Sen University			