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## Feature Integration Theory



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### Synonyms

Pop-out; Saliency; Vision; Visual attention; Visual search

### Definition

Feature integration theory models how attention is guided, for example, when the visual field needs to be searched for a particular target. At its foundation, feature integration theory first employs separate but parallel, preattentive, and unconscious registration of basic visual features, and later on their integration to conscious controlled perception based on a master map of retinal locations. Attention can be guided (to facilitate object detection, for example) during either phase depending on the visual properties of the target

compared to other items in the stimulus, a process that allows either fast pop-out of the target or its detection via a slower serial attentional deployment process. Conceived originally for human vision, there are many ecological reasons, and now ample evidence, to support the argument that feature integration theory is universal and relevant to many animal species too.

### Introduction

Visual attention is one of our fundamental behavioral features. As seeing creatures, humans continuously scan the visual world around us and focus our visual attention on important visual objects. From searching for our friends in a crowd to looking for a car key in a drawer, from seeking a ripe fruit on a tree to looking for a foe in a computer game, such visual search tasks often (but not always) require much visual attention. But clearly, this visual behavior cannot be unique just to humans, as most nonhuman species could benefit tremendously from guided attention for survival, including mating, hunting, navigation, and predator avoidance. How visual attention is guided also in nonhumans species is thus crucially important and can inform us a great deal about universal behavioral principles and information-processing strategies across the animal kingdom.

## Feature Integration Theory in Humans

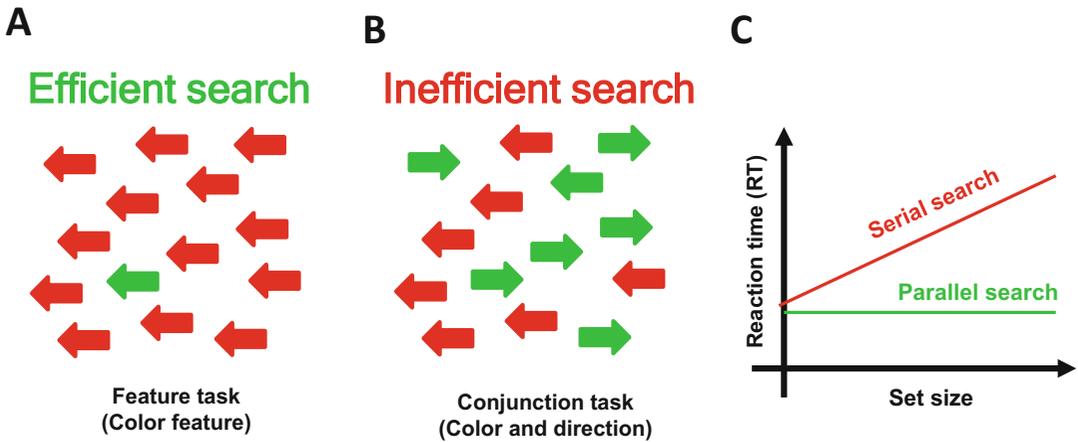
Introduced by Treisman and Gelade in the early 1980s (Treisman and Gelade 1980), Feature Integration Theory is one of the most influential theories that accounts guided attention. According to this theory, visual stimuli are processed in two consecutive stages. First, the visual system processes the visual stimulus to yield separate spatial maps of the distribution of basic visual features (such as color, orientation, motion, etc.). This first stage is called *preattentive* since it is performed before attention is deployed and before the organism becomes conscious of what it is looking at. The second stage is termed the *attentive* stage where the organism focuses its attention on a certain object or location in the visual field. This occurs within a master map of stimulus locations where features have been represented after processing of the individual maps from the first phase. After attention selects a certain location to focus on, the individual features at that location are integrated to facilitate the conscious perception of the relevant visual information.

Testing Feature Integration Theory and its applicability is typically done using controlled visual search experiments. In a typical experiment, subjects are asked to detect the presence or absence of a target in a display as quickly and as accurately as they can, where the target is characterized by a certain combination of features that distinguish it from other nontarget distracting items around it. Using this methodology, and under the classic framework of Feature Integration Theory, Treisman and her associates characterized two distinct visual search modes, which they dubbed *parallel* and *serial* (Treisman and Gormican 1988; Treisman and Gelade 1980).

The parallel search mode occurs in the preattentive stage where certain visual features are processed immediately throughout the entire visual field and in a massively parallel fashion. If any of these features uniquely characterizes the target, the latter pops out to complete the search. This automatic process is reflected in a reaction time that is relatively unaffected by the number of items (a.k.a. the set size) such that the slope of its reaction time graph as a function of the number of

distractors is around zero (Treisman and Gelade 1980; Wolfe 1998). This is illustrated in Fig. 1a where the green item pops out from the group of red distractors due to the difference in their color/luminance feature. While the green arrow would continue to pop out regardless of the number of red distractors, a target defined by a unique conjunction of features would not pop out similarly, forcing the observer to scan the displayed visual items one by one until it is found, as shown in Fig. 1b. Naturally, in such a scenario, the time to find the target will grow (typically linearly) with the number of distracting items, where the performance slope depends on how efficiently the visual system can process the visual features that contribute to the detection. Figure 1b illustrates the expected performance graphs in these two modes.

Following the above, the features of the target and the distractors, as well as their interrelation, determine the visual search mode that is ultimately exhibited in a search task (Nakayama and Silverman 1986). For instance, a considerable amount of evidence indicates that if a target is defined *uniquely* by either color, size, orientation, or motion, it will “pop out” of the display (Wolfe and Horowitz 2004). According to Feature Integration Theory, this is because such features are accessible efficiently to the human visual system during the preattentive stage and their uniqueness signals the location of the target already in the preattentive maps. In other visual search tasks, where targets are defined by less accessible properties or nonunique combinations of properties, the target does not always pop out, forcing the observer to serially search for the target (Wolfe and Horowitz 2004). Hence, which features drive visual attention in visual search scenarios is one of the fundamental questions addressed when conducting visual search experiments. A significant body of research and a variety of theoretical models have been studying this and other aspects of visual search in humans for more than two decades now, and new ways for running countless visual search trials for additional insights have been emerging in recent years. Additional properties of Feature Integration Theory in humans are discussed in recent surveys on this subject (Wolfe and Horowitz 2004).



**Feature Integration Theory, Fig. 1 Efficient and inefficient visual searches.** (a) When a target is defined by a unique color/luminance feature (the green arrow), it pops out regardless of the number of distractors, a result of a highly efficient search that appears to process all items in parallel. (b) Other searches, in particular, conjunction searches, are much more difficult to resolve, requiring the observer to scan each item separately until it detects the

unique target (in this case, a left pointing green arrow, just as in panel A). (c) Efficient search does not require more time with growing number of distractors, while inefficient search grows linearly. This behavior signals parallel vs. serial processing of the stimulus, expressed clearly by a zero vs. positive slope of the reaction time to target, respectively

## Feature Integration Theory Beyond Humans

Indeed, although the research effort mentioned above had followed the ideas of Feature Integration Theory, it has been restricted almost entirely to humans, leaving interesting questions open. Are Feature Integration Theory and its contemporary variations applicable beyond humans? If so, what features facilitate pop out in different animals? If a preattentive stage occurs in nonhuman animals, do different animals maintain different feature maps? And perhaps first and foremost, since visual search in humans is considered a cortical function, could animals that lack a fully developed cortex be able to perform efficient visual search, and if so, how? These questions are especially interesting given the numerous non-human species that depend on vision, and specifically on guided attention, for their survival.

Notwithstanding the extensive research into the visual systems, visual ecology, and visual behavior of nonhuman species, including the type of visual cues that drive their vision, relatively little work has explicitly addressed the features that guide attention, enable pop out, or

otherwise affect the efficiency of visual behavioral tasks. Thus, many questions relating to Feature Integration Theory in nonhuman species remain unanswered. And yet, certain studies *have* examined visual search in selected non-human species after all. In these studies, the efficiency of visual features is typically determined by the target selection rate (i.e., how often the animal actually finds and selects the designated target), but sometimes also by the reaction time and occasionally by both. Interestingly, many of these studies imply a great deal of similarity in the visual search behavior of humans and nonhumans in both feature search and conjunction search tasks, as this entry discusses below.

But before discussing these details, it is worth mentioning that like many other types of experiments, visual search tasks are far more complicated to perform with animals than with humans. Clearly, it is overwhelmingly simpler to communicate the task to human subjects while animals must be trained to implicitly understand what constitutes the target before it can participate in experiments. Such training can last up to several months (e.g., (Orlowski et al. 2018)) for a single type of experiment, a procedure that much care

and patience (by all parties). Furthermore, in the lack of verbal communication, training is required for every new target or visual search experiment. This entails a very time-consuming, multiple-training procedure, if the same animal is to be tested in multiple types of visual search tasks (as is usually the case in most studies). Another complication in nonhuman visual search tasks relates to the number of consecutive trials a typical subject can participate in. In humans this number is typically determined by cognitive capacity (such as boredom, fatigue, focus, motivation). Animals, on the other hand, are typically rewarded for participation by food portions (unlike payment, course credit, or no reward at all in humans), a mechanism that critically limits the number of trials based on the animal's food intake capacity. Indeed, in reality, an hour's worth of experimentation with human participants might require weeks or months to run on certain animals. Overall, visual search experiments with non-humans are thus challenging and requires much ingenuity to extract quality behavioral data while preserving the wellbeing of the subjects.

### Feature Integration Theory in Insects

Owing to the methodological difficulties involved, Feature Integration Theory and visual search in general was studied in insects relatively scarcely, where one of the most investigated species in the context of visual search being bees, especially their performance in color feature search tasks. As mentioned above, bees too must be trained for certain behavior in order to allow overt observation of their visual decision, in this case by visit a sucrose solution feeder placed inside an experimental arena near the hive. In a typical experimental trial, the bee enters the arena through a small entrance (Fig. 2a) and then faces a visual search task composed of various visual items (e.g., colored disks) located on the opposite wall. Each such item is equipped with a reward feeder attached to its back and accessible to the bee through a small opening (black dots in Fig. 2a). The bee is required to make a visual

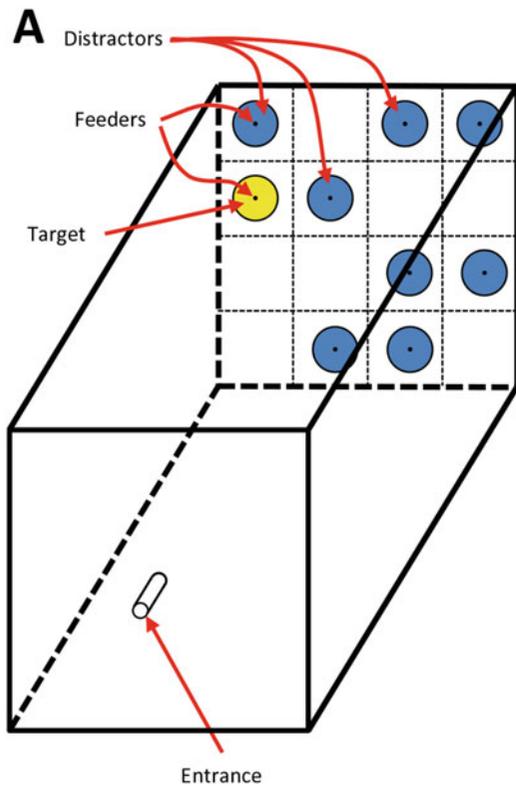
decision to obtain the reward while the location of the target and reward feeder change each trial.

The animal's decision, success rates, and response time are documented for the analysis and based on results in such experiments it was shown that performance in bees varies between species (Morawetz and Spaethe 2012). Specifically, error rates increased as a function of set size but only in honeybees and not in bumblebees (Fig. 2b). At the same time, response time in bumblebees was approximately 30% longer than honeybees (Fig. 2c), although neither species seems affected by set size in a significant way. These findings suggest that the speed-accuracy trade-off to detect the target is species dependent, which the authors attributed to ecological pressure. Given both decision time and error rate, color feature search elicits serial-like search in honeybees and parallel-like search in bumblebees.

### Feature Integration Theory in Birds

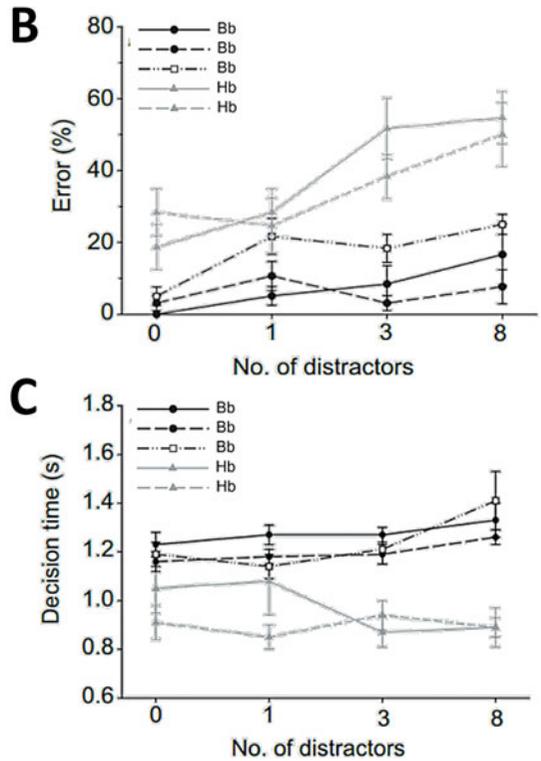
Among the earliest nonhuman visual search investigation, even before FIT was conceived, was carried out in the 1970s on pigeons, leveraging the fact that they are relatively easily trained to peck at a selected visual item on a monitor (Blough 1977). Read in the language of the then forthcoming Feature Integration Theory, results indicated that both geometric shape or letters (Blough 1977) were inefficient features that led to longer reaction times and drops in target selection rates as the set size increased. Moreover, pop-out and search asymmetries related to line terminators (Harmening et al. 2011; Orłowski et al. 2015, 2018) were shown to not exist in pigeons (Allan and Blough 1989), unlike in humans. Based on by target selection rates, however, it was shown that pigeons are more efficient at processing color, size, orientation, or shape feature searches conjunction search (Cook et al. 1996).

Using similar pecking response methodology in an operant conditioning chamber, it was later shown that visual search behavior of blue jays incorporates a fundamentally serial component (Bond and Kamil 1999). Trained to detect an



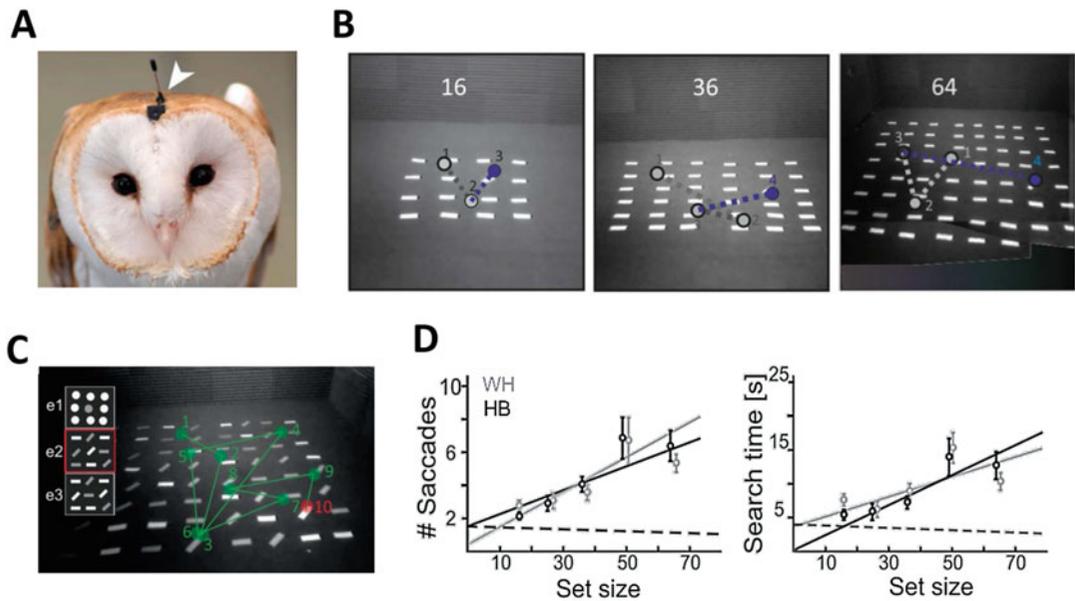
**Feature Integration Theory, Fig. 2 Visual search in bees.** (a) A typical experimental arena includes an array of visual items mounted around the access points of reward feeders (Sketch adapted from (Morawetz and Spaethe 2012)). The item in front of the feeder to which bees first approach are considered their visual decision (with some tolerance and decision lines, such as the dotted grid shown, typically employed by the experimenters). (b) Error rate as

image of cryptic moth (namely, the target) embedded in different backgrounds with different levels of crypticity, it was found that reaction time increased and the accuracy decreased as a function of stimulus complexity. However, instead of increasing the number of distracting objects as in a classic visual search experiments, the difficulty level of discriminating between the target and background was increased. In this sense, these results may fit less naturally into FIT. Also, rather than testing how the target’s and distractor’s features affect visual search per se, the study was aimed to test how the latter is influenced by different procedures (such as cuing and sequential priming) to attain initial focal attention (Bond and Kamil 1999; Goto et al. 2014).



a function of set size does not seem to change for bumblebees (dashed and solid black lines) but increases for honeybees (dashed and solid gray lines) (c) The decision time (as a function of set size) of bumblebees (dashed and solid black lines) is approximately 30% longer than for honeybees (dashed and solid gray lines). Values in both graphs are means  $\pm 1$  standard error of the mean (Morawetz and Spaethe 2012)

A significant progress using more robust methodology has been achieved in the last decade on what has become a major animal model in non-human visual search and saliency research – the barn owl (Harmening et al. 2011; Orłowski et al. 2015, 2018). Unlike most species, barn owls virtually lack eye movements, which in fact facilitates the overt observation of their visual behavior through gaze tracking from a head-mounted camera, dubbed the OwlCam (Fig. 3a). By using proper image processing and automatic computer vision analyses, it is possible to identify the “functional fovea” and thus the spatial and temporal order of the items that the bird fixates on during free behavior, including flying (Fig. 3b,c), just like the scan path that modern eye trackers



**Feature Integration Theory, Fig. 3 Visual search in barn owl.** (a) The OwlCam is a tiny wireless video camera that is mounted on the owl's skull and enables a bird's view of its frontal field of view. With proper processing it is possible to generate a panoramic field of view and identify the locations/items that the owl fixates on during search or other visual tasks (Image adapted from (Harmening et al. 2011)). (b) Examples of panoramic scene reconstructions, scan paths (dash lines), and fixations (circles) until the target was first fixated (blue disk) during an orientation task. The numbers near the circles indicate the fixation number. The stimulus arrays contain (from left to right) 16, 36, and 64 items. Note that the number of saccades to the target hardly varies despite the change in set size, indicating that the orientation feature elicits pop-out in

would extract from human observers. A series of studies that employed this methodology (Harmening et al. 2011; Orłowski et al. 2015, 2018) have shown that barn owls exhibit both parallel and serial search modes in a fashion extremely similar to humans. Stimuli in these experiments were either projected or physically organized as real objects on the floor in front of animal subjects, and the dependent variables employed were the number of saccades and search time until the target was found. Both indicators, when examined as a function of set size, have indicated that orientation and luminance-contrast search tasks elicit pop-out and parallel search mode (Harmening et al. 2011; Orłowski et al. 2015) while low-contrast feature tasks and certain

the barn owl (Images adapted from (Orłowski et al. 2015)). (c) A similar panoramic image and scan path during a conjunction search task (in this case, of a target defined by a particular contrast and orientation as illustrated in inset e2). Note the high number (10) of saccades till the target was found, indicating a much more challenging search task for the bird (adapted from Orłowski et al. 2015). (d) Number of saccades and search time as a function of set size clearly shows differences between serial search behavior (solid lines of positive slopes) in a conjunction task (in this case, conjunction of high contrast and orientation) vs. parallel search behavior (dashed lines of virtually zero slope) in feature search task (in this case, high contrast feature search). Data adapted from Orłowski et al. (2018)

conjunction tasks elicit serial search (Orłowski et al. 2018) (Fig. 3d).

### Feature Integration Theory in Fish

In the aquatic world, one of the most extensively studied species for its visual search behavior is the archerfish. This fish is especially well-known for its incredible hunting skill of *terrestrial* insects that rest on foliage and low-lying branches by shooting them with a strong accurate jet of water from his mouth. This extremely fantastic behavior is often attributed (in part) to excellent eyesight and unique neural computations (Ben-Tov et al. 2018; Vasserman et al. 2010), and since it is

possible to train the archerfish to shoot at artificial objects presented on a monitor, it allows controlled behavioral experiments where the fish's visual decisions can be easily observed.

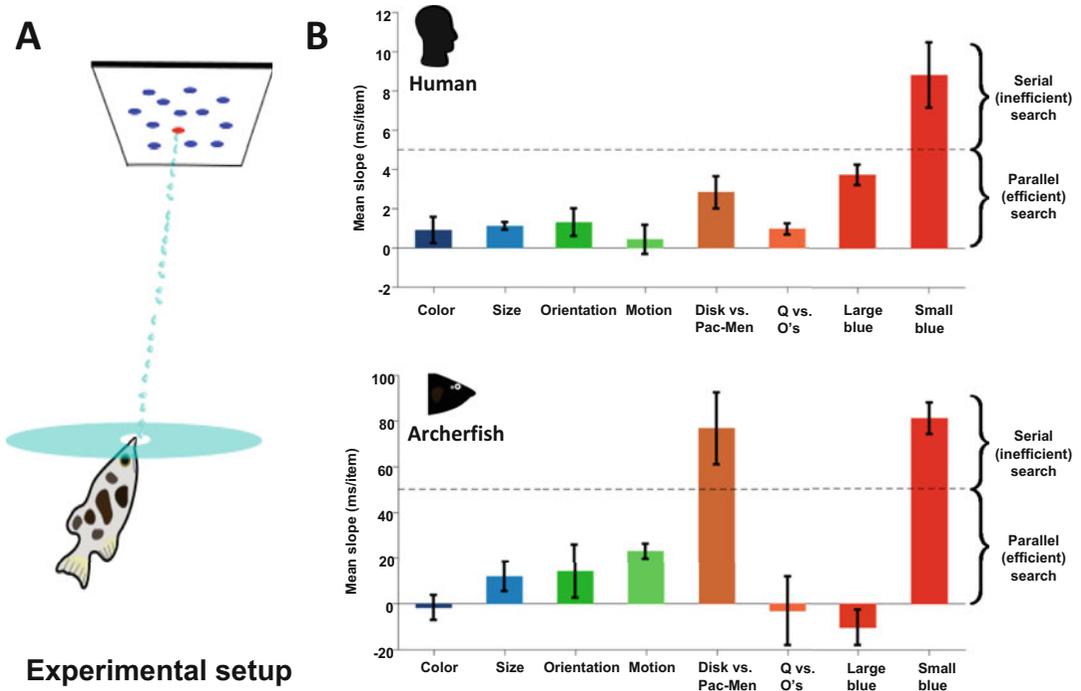
Using this animal model, it was first shown that the archerfish exhibits both parallel and serial search modes (Ben-Tov et al. 2015, 2018; Mokeichev et al. 2010; Rischawy and Schuster 2013). Since initial work sought to leverage the high responsiveness of the archerfish to movement, stimuli typically incorporated moving bars. However, more recent work showed that the archerfish not only exhibits pop-out behavior, but that the latter is facilitated by four common visual features known to elicit the same behavior in humans, namely color, size, orientation, and motion (Reichenthal et al. 2019). That was also an early demonstration that shape tasks elicit serial search, with reaction time that grows, and target selection rate that decreases, with the number of distractors. Additionally, it was also shown that conjunction search tasks of size and color are asymmetric. Parallel search was elicited in the archerfish when a large blue target was embedded in a field of small blue and large black distractors, but serial search was elicited for a small blue target amidst small black and large blue distractors.

A very recent follow-up (Reichenthal et al. 2020) has further extended these findings and explored the possibility that fish performance exhibits the same continuum found in human vision (Wolfe 1998). Unfortunately, at the time of this publication, the relatively small total number of trials in the literature that have tested archerfish in visual search still prohibits comparable conclusions, but given these scant data, and inspired by Feature Integration Theory, Reichenthal et al. (2020) have been able to categorized archerfish performance based on the classical bimodal (easy/efficient/parallel vs. difficult/inefficient/serial) Feature Integration Theory division (Treisman and Gelade 1980) in a rigorous fashion, concluding that  $\sim 45$  ms/item is a proper threshold between the two behaviors (as depicted by the black dashed line in Fig. 4b), compared to 5 ms/item attributed to humans. Apart from this expected species-dependent response time

threshold, performance of humans and archerfish was found qualitatively similar, and in particular all features of color, size, orientation, and motion elicited the same type of visual search behavior in both (Reichenthal et al. 2020). Similar behavioral similarity between the species also was observed in conjunction search tasks (in that case of size and color), both in the type of performance (i.e., parallel vs. serial) and in terms of performance asymmetries (i.e., when switching the role of targets and distractors). Note that as discussed above, these findings also match those in birds, where behavior was found qualitatively similar to humans, differing quantitatively only in the scale of response time (Harmening et al. 2011; Orłowski et al. 2015, 2018).

That being said, the same experimental methodology used to study the archerfish revealed qualitatively different behaviors compared to humans when the search is governed by target shape. For example, while searching for a solid disk amidst Pacman like distractors is easy (parallel) for humans, it was found difficult (serial) for archerfish. Yet, when the targets were Q-like shapes amidst full disk distractors, performance was qualitatively similar again, that is, parallel in this case. This inconsistent comparison in different cases could arise from the difference in familiarity of the species to certain shapes and/or to negative shape associations (e.g., due to fear, see e.g., Öhman et al. (2001), that certain shapes could generate in each species.

Overall, taken as a primary animal model, the archerfish indicates that Feature Integration Theory is indeed applicable to fish and humans alike, except when it depends on shape processing that may be species-dependent. While the archerfish provides an excellent platform for such research, exploring visual search (or any other visual) behavior in other (more "traditional") species of fish clearly requires other means of probing their visual decisions, for example by training them to approach the target. Using such methods, it was indeed demonstrated that zebrafish exhibits pop-out in color feature visual search (Proulx et al. 2014).



**Feature Integration Theory, Fig. 4 Visual search in fish.** (a) Archerfish can be trained to perform visual search tasks on a monitor, very much like human subjects. Their visual decisions are observed overtly (and recorded with a video camera) based on the target that the fish shoot at. (b) A summary of archerfish vs. human performance in various visual search tasks that were performed *identically* on the two species. The sole difference in the analysis is based

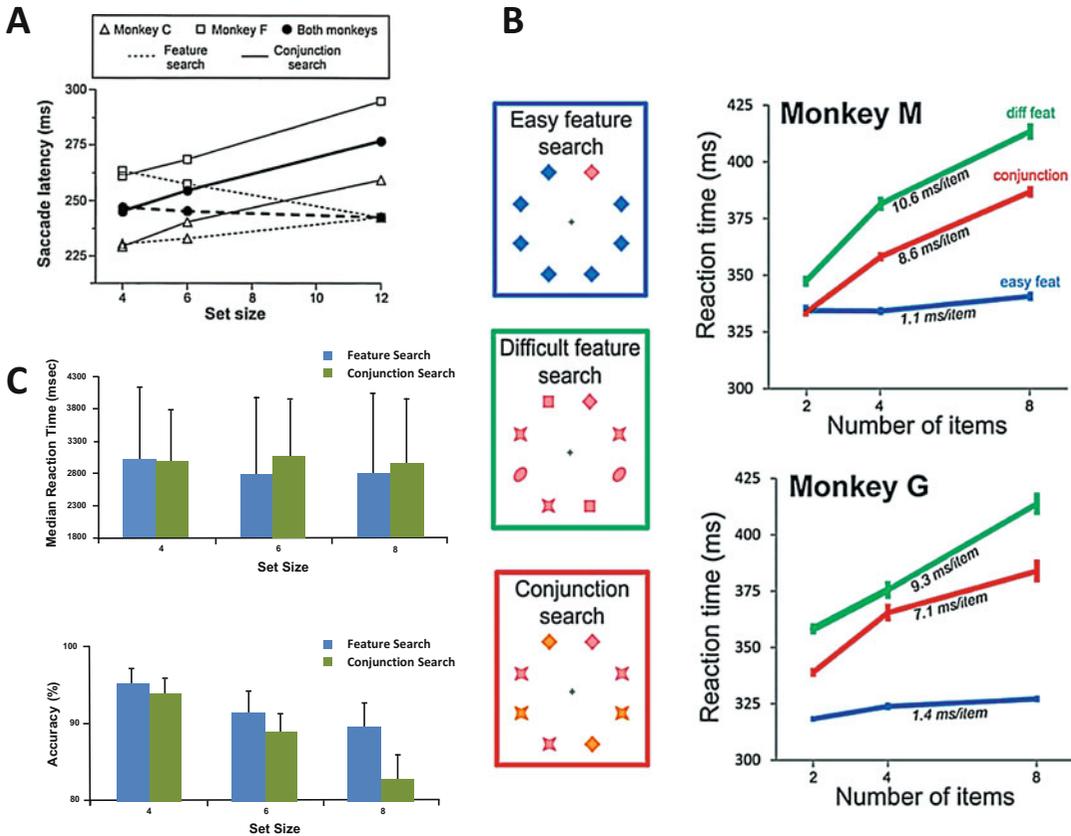
on the scale of response times that cannot be identical for both species. However, the threshold between parallel and serial modes can be determined by the same method for both species (as described in Reichenthal et al. 2020) and is marked by the dashed horizontal lines. Search mode that was elicited by both species is identical in virtually all search tasks, except for one specific case that involves shape processing (disk vs. Pacmen)

## Feature Integration Theory in Nonhuman Mammals

Given findings as described above, one would expect visual search in mammals to lead the way. It is thus surprising that nonhuman terrestrial mammals have not been widely studied in the context of visual search, with primates, and especially monkeys, being by far the most studied animal in this group. The methodologies employed in these studies vary significantly.

In the classic visual search experiment by Bichot and Schall (1999), both saccade latency slope and error rates were measured in macaque subjects as a function of the set size, to demonstrate that color and simple shape searches are more efficient than their conjunction counterparts (Fig. 5a). Such insights were further supported by

a forced-choice target detection paradigm that indicated that time-to-detection for targets defined by color does not depend on set size (hence, they pop out), whereas targets defined by shape, or a conjunction of shape and color, lead to reaction times that increase with set size (Buračas and Albright 1999; Wardak et al. 2012) (Fig. 5b). Unlike Bichot and Schall (1999), the latter used a more direct procedure where the task of the monkey was to press a lever only when the stimulus contains a target, and to abstain from response in target-absence trials. While more difficult to analyze from Feature Integration Theory's perspective, other visual search experiments also demonstrated influence of emotional aspects, like threat, of the efficiency of visual search (Shibasaki and Kawai 2009) as well as the capacity of monkeys to perform serial visual



**Feature Integration Theory, Fig. 5 Visual search in mammals.** (a) Saccade latency as a function of set size in macaques (Bichot and Schall 1999) suggests that feature search tasks elicit pop-out while conjunction searches lead to serial search. (b) Searching for the pink diamond in these tasks led monkeys exhibit pop-out (parallel search mode) in color feature searches, but serial mode in complex shape or conjunction searches (graph colors code the same

experiments as the panels on the left; adapted from (Wardak et al. 2012). (c) Visual search response time in rats did not change with set size in a feature task (dark gray) or a conjunction task (light gray). Accuracy, on the other hand, did decrease as a function of set size (Botly and De Rosa 2012), leaving the evidence so far ambiguous regarding the search mode or even the search goal employed

search based on more complicated combination of feature. Furthermore, monkeys also demonstrate the classic speed-accuracy tradeoff found also in human visual search (Tomonaga and Imura 2015).

Unfortunately, very little visual search exploration has been performed thus far on nonprimate mammals, perhaps a result of methodological complexities. A notable exception involving rats has demonstrated that unlike monkeys this species exhibits a somewhat mixed performance, with essentially fixed reaction times but error rates that increase with set size, all for targets defined by luminance, shape, and certain conjunctions (Botly and De Rosa 2012) (Fig. 5c).

**Epilogue: Is Animal Advantage Possible?**

To date, the literature on Feature Integration Theory in animals that has been summarized above supports (at least implicitly) the idea that visual search behavior is similar in humans and in many animals, and in particular that whatever pops out to animals also pops out for humans. The converse, however, is not always true and a few experiments have indicated that while certain shape tasks pop out to humans, they do *not* do so for animals. This “one way” advantage in performance may be explained by the fact that the human visual system is much more developed

and facilitates complex processing much faster and better than animals, whereas many basic pop-out features are universal in nature and thus affected many species in the course of evolution. This intuition thus raises a simple but interesting question of whether there are any visual tasks on which animals outperform humans. Clearly, Feature Integration Theory neither excludes nor necessitates this possibility, and to date this question remains largely open.

And yet, some speculations can be made. Obviously, visual properties that humans cannot observe at all will naturally give animals (that can sense them) an edge when such properties define the target. For example, if the target is composed solely of the polarization of the light it reflects or by wavelengths outside the visible spectrum, it may pop out to certain animals but not for humans. Naturally, our open question does not refer to such cases. But in the spirit of ecological vision, and hard evidence about the effect of the natural environment on neural processing, a habitat abundant with a certain visual cue, feature, or property that are rare in human life could pop out to certain animals living in that environment but not to humans. For example, it is tempting to hypothesize that certain visual search experiments based on unique shapes would elicit effective (parallel) search in a particular animal but serial search in humans. This type of experiment would need to revolve around a typical shape from the animal's habitat, which rarely exists or completely absent in human environments. For example, human face targets, but not animal faces, pop out to human observers when presented amidst non-face objects, and this is despite the many similarities one can draw between animal and human faces (Hershler and Hochstein 2005). If such effect also generalizes to other species, one may that a fish figure or fish face would pop out for fish and not for humans. Recent preliminary investigations in this direction have yet to generate a suitable demonstration of such animal advantage and dedicated research is needed to resolve this open question.

## Cross-References

- ▶ [Attention](#)
- ▶ [Bottom-up Processing](#)
- ▶ [Operant Chamber](#)
- ▶ [Parallel Search](#)
- ▶ [Saccadic Eye Movement](#)
- ▶ [Two Alternative Forced Choice Task](#)
- ▶ [Visual Perception](#)
- ▶ [Visual Search](#)

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