# The gist of Anne Treisman's revolution

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## Abstract

Anne Treisman investigated many aspects of perception and in particular the roles of different forms of attention. Four aspects of her work are reviewed here, including visual search, set mean perception, perception in special populations, and binocular rivalry. The importance of the breakthrough in each case is demonstrated. Search is easy or slow depending on whether it depends on the application of global or focused attention. Mean perception depends on global attention and affords simultaneous representation of the means of at least two sets of elements, and then of comparing them. Deficits exhibited in Balint's or unilateral neglect patients identify basic sensory system mechanisms. And, the ability to integrate binocular information for stereopsis despite simultaneous binocular rivalry for color, demonstrates the division of labor underlying visual system computations. All these studies are related to an appreciation of the difference between perceiving the gist of a scene, its elements or objects, versus perceiving the details of the scene and its components. This relationship between Anne Treisman's revolutionary discoveries and the concept of gist perception is the core of the current review.

> "When we open our eyes on a familiar scene, we form an immediate impression of recognizable objects, organized coherently in a spatial framework. Analysis of our experience into more elementary sensations is difficult, and appears subjectively to require an unusual type of perceptual activity. In contrast, the physiological evidence suggests that the visual scene is analyzed at an early stage by specialized populations of receptors that respond selectively to such properties as orientation, color, spatial frequency, or movement, and map these properties in different areas of the brain (Zeki, 1976). The controversy between analytic and synthetic theories of perception goes back many years: the Associationists asserted that the experience of complex wholes is built by combining more elementary sensations, while the Gestalt psychologists claimed that the whole precedes its parts, that we initially register unitary objects and relationships, and only later, if necessary, analyze these objects into their component parts or properties. …
>
> "The Gestalt belief surely conforms to the normal subjective experience of perception. However, the immediacy and directness of an

impression are no guarantee that it reflects an early stage of information processing in the nervous system. It is logically possible that we become aware only of the final outcome of a complicated sequence of prior operations. "Topdown" processing may describe what we consciously experience; as a theory about perceptual coding it needs more objective support."

Anne M. Treisman & Garry Gelade (1980) A feature-integration theory of attention, *Cognitive Psychology* **12**, pg. 97-98

## Introduction

I will not attempt to summarize Anne Treisman's impact on the field of cognition – that's the goal of the entirety of this special issue. Rather, I wish to note links between the concept of "gist perception" and some of the revolutionary ideas promoted by Treisman in her now classical studies.

It has become clear that at first glance, we acquire rudimentary knowledge of the scene before our eyes, summarized as the "gist of the scene" (Biederman et al., 1974; Potter, 1976; Hochstein & Ahissar, 2002; Evans & Treisman, 2005; Guillaume et al., 2005; Oliva, 2005; Joubert et al., 2007, 2008; Greene & Oliva, 2009a,b; Wolfe et al., 2011). Though observers often believe that they know many, if not all the details of a scene, psychophysical tests show that we miss many details, and require prolonged scrutiny to build a more complete representation of scene elements. Examples of demonstrations showing we know fewer than all scene details include repetition blindness (Kanwisher, 1987; Kanwisher et al., 1996), change blindness (Rensink et al., 1997; Simons & Levin, 1997; Simons & Rensink, 2005), inattentional blindness (Mack & Rock, 1998; Simons & Chabris, 1999), the attentional blink (Raymond et al., 1992; Shapiro et al., 2017), the (almost opposite) phenomenon of boundary extension (Intraub, 1999; Kreindel & Intraub, 2017), detecting an object (e.g. an animal) in a scene but being unable to identify or localize it (Evans & Treisman, 2005), and perceiving summary statistics of a set of elements without knowledge of its individuals (Ariely 2001; Chong & Treisman, 2003, 2005a, 2005b; and see more references below).

Besides missing details when perceiving scene gist, there is also often confusion in associating details with each other and/or with the appropriate scene item, called the binding problem (Treisman, 1999). This might be due to inappropriate joining of results of computations on information originating from different specialized neural populations selective to different properties such as orientation, color, spatial frequency, or movement. In this sense, gist perception is a first approximation or best guess at integrating bottom-up information, prior to checking for inner consistency or for confirmation from prior knowledge.

Merav Ahissar and I summarized this understanding of the transition from gist perception following initial global-attention *vision-at-a-glance* to more detailed perception, based on slower, focused-attention, *vision with scrutiny*. We proposed that initial conscious gist perception depends on implicit visual system computations based on non-conscious representations of scene details in lower cortical areas, with awareness limited to the higher cortical area representations that result from these computations. We dubbed the transition from gist to detailed perception the “Reverse Hierarchy Theory”, because we proposed that the later acquisition of scene details includes a top-down guided return of conscious perception to lower cortical level representations, where details are represented (Hochstein & Ahissar, 2002). This Reverse Hierarchy Theory of visual perception followed our earlier suggestion that perceptual learning follows a similar path (Ahissar & Hochstein, 1997, 2004). Early, easier-case perceptual learning reflects modifications at higher cortical levels, where representations generalize over spatial parameters (position, orientation, etc.), so that learning, too, generalizes. Later learning includes more difficult perceptual situations (shorter presentation times, finer differentiations), reflecting modifications at lower cortical areas, where representations are finer but also more specific for spatial parameters, so that learning, too, is more specific.

There is a large degree of interplay between Anne Treisman’s Feature Integration Theory (FIT) and Reverse Hierarchy Theory (RHT). FIT suggests that initial global perception acquires certain aspects of the scene, such as detecting odd feature pop out, but not other aspects, such as feature binding, which require focused attention. I suggest that numerous Treisman studies underscore this difference between gist and detail perception. I review four groups of her studies in turn and show how each is related to gist perception: visual search, set mean perception, perception in special populations, and binocular rivalry.

## I. Rapid feature search versus slower conjunction search

The most quoted study by Anne Treisman is her 1980 paper with Gerry Gelade, called “A Feature-Integration Theory of Attention”. The opening paragraphs of the paper are quoted above, where the suggestion is made that it is “logically possible” that immediate and direct (gist) perception may not reflect an early stage of nervous system information processing, but rather that we become aware only of the outcome of a sequence of operations.

Five sets of experimental results are presented in the 1980 paper to support FIT: visual search, texture segregation, illusory conjunctions, identity and location, and interference from unattended stimuli. The function relating search times to display set size is nearly flat when a single feature defines the target (e.g. searching for a green O among green N’s, or for a green O among red O’s, demonstrated in the top panels of Figure 1) but increases linearly when a conjunction of features is required, shown in Figure 1, bottom panels. The difficulty in discrimination between target and distractor values of their defining characteristics determines the slope of the set size dependence for conjunction search. For example, searching for a red O target among green O and red N distractors is easier, with a slope of 17ms/item, than searching for a green T target among blue T and green X distractors, which is more difficult, with a slope of 50ms/item. See Figure 1 bottom, left and right panels, respectively. In these cases, participants rapidly perceive the gist of the display and the presence of different colors (green and red or blue and green) and different letters (O and N or T and X), but the conjunction or binding of color and letter identity, which letter is which color, is a detail that requires scrutiny. In Treisman and Gelade terminology, perceiving this level of detail requires serial focused attention – explaining the set size slope and the double slope for target absence – searching through all items to check that none matches the sought target – compared to target present – where, on average, the target is found after searching through half the items.

In a similar manner, texture segregation is rapid when defined by a single dimension feature, but very slow when defined by a conjunction of features. In addition, rapid viewing of a display with various shapes of various colors, observers often recall the shapes and colors but not which shape was which color, leading to illusory conjunctions (Treisman & Schmidt, 1982), so that there is a separation between the perception of features and of objects (Treisman, 1986, 1988, 1993; Treisman & Gormican, 1988). This latter finding relates to the controversial claim that very rapid feature search results in knowing “what” is in the display, i.e. presence or absence of an outlier pop out, but not “where” the odd element is within the presented array (Sagi & Julesz, 1985; Treisman, 1991).

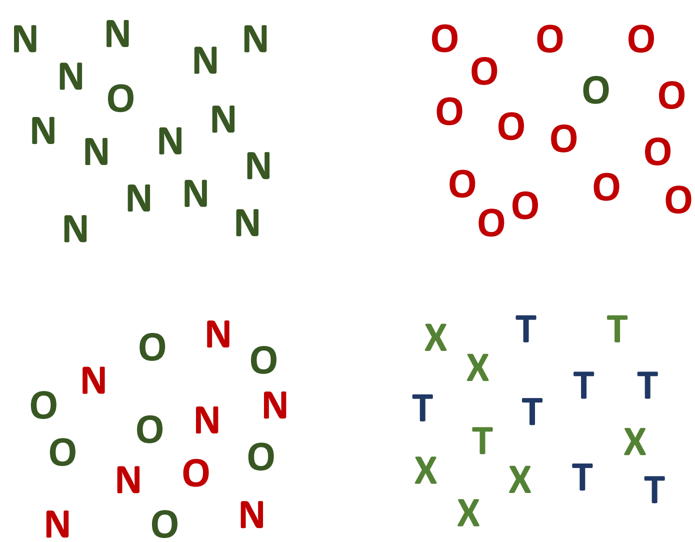

Figure 1. Feature search (top row) for form (left) or color (right), as described by Treisman & Gelade (1980) but not shown there (color figures were almost not heard of in 1980). Conjunction search, again as described but not shown by Treisman & Gelade (1980), with easier color and form discriminations (left) and more difficult discriminations (right). Note that the colors shown here are guesses as to the colors originally used there.

Thus, briefly viewing an array of elements – e.g. colored letters – one perceives the gist of the scene, including that there are colored letters present, the identity of the letters (if there aren’t too many letters present), and the colors present (again, if there aren’t too many). But the gist does not include the color of each letter, and an odd conjunction is not noticed at first.

Interestingly, Anne Treisman's studies usually allowed free viewing and the parameter measured was time to find the target. Since feature search is fast and conjunction search is slow, one may derive from these results that for very brief viewing, one would perceive color, orientation, or shape pop-out, but not presence of an odd conjunction.

## II. Set Summary Mean Perception

In more recent years, Anne Treisman turned to the study of set summary statistics perception (Ariely, 2001; Solomon et al., 2011) in a series of studies with Sang Chul Chong (Chong & Treisman, 2003; 2005a, 2005b) and others (Emmanouil & Treisman, 2008; Chong et al., 2008). Treisman and her colleagues showed that, besides perceiving the mean of sets, participants could perceive the means of two sets, simultaneously, and compare means of two sets, presented side by side or sequentially. Nevertheless, there is a decrement in perceptual speed when asked to judge means of two different features, especially for different features of different sets (Emmanouil & Treisman, 2008). Their novel conclusion is that attention to a feature dimension may be necessary for optimal statistical processing, and that a single dimension can be averaged in parallel across separate groups. Since statistical processing relies on distributing attention over space and objects, it makes sense that it should be more efficient at processing multiple groups than multiple dimensions, which requires applying different analyses to incoming stimuli, (just as feature search requires analysis of one dimension, and conjunction search requires simultaneous analysis of two dimensions). They found that mean perception did not depend on uniform distribution of set elements, and is robust to normal or two-peaked distributions (Chong & Treisman 2003). In response to the suggestion that participants could do as well by averaging only a few elements, they showed that indeed all are taken into account (Chong, Joo, Emmanouil & Treisman, 2008).

What led Anne Treisman to get interested in this new, presumably unrelated field? Perhaps it was the relationship with attention (de Fockert & Marchant 2008) or her interest in gist perception, and perhaps it was due to the relationship of set statistics and feature search (Haberman & Whitney, 2010), as my own studies demonstrated directly.

My lab turned to the field of set mean perception, showing that participants perceive both set mean and range, and that these are perceived automatically, implicitly (i.e. while consciously performing only a different task that is unrelated to set mean or range), and on-the-fly trial-by-trial (Khayat & Hochstein, 2018). We also studied the relationship between set statistics perception and feature search pop out (Hochstein et al., 2018). We used similar experimental displays for these two tasks, asking participants to compare two arrays of variously oriented bars and report either which set was oriented more clockwise on average (mean perception) or which contained an outlier (feature pop-out). We found that mean perception depended only on the difference in orientation means of the two arrays and not on their orientation range. In contrast, outlier detection depended only on the distance of the outlier from the set range edge (in order that it be an outlier) and again not on the range itself (Hochstein et al., 2018).

Thus, feature search and set summary statistics perception are intimately connected. First, set summary perception, including set mean and range, like feature search, is an aspect of gist perception, requiring global attention and not requiring focused attention to each presented element in turn. Furthermore, when observing a set of similar elements that differ in one feature, one perceives both the mean value and the range of values of that set feature. Feature search is an example of perceiving the range and drawing attention to an element that is clearly outside this range. While Treisman and colleagues usually used displays with homogeneous distractors, others have found similar "pop-out" effects with heterogeneous displays.

## III. Perception in Special Populations

Anne Treisman examined her theories of visual search, attention, and gist perception by testing special populations. In studies with Lynn Roberson, she studied patients with Balint's syndrome, who exhibit simultanagnosia, that is, they perceive single objects but can't perceive other objects at the same time. They also don't know where things are in the visually experienced external world, cannot report location of a seen object or reach for it, though they can touch their own body parts (Balint, 1909). One such patient, RM, showed severe binding problems between shape and color or shape and size (Friedman-Hill, Robertson & Treisman, 1995). When shown two different-colored letters, RM reported many illusory conjunctions, combining the shape of one letter with the color of the other, supporting Feature Integration Theory predictions that the loss of spatial information would lead to binding errors. Visual search for a conjunction target (requiring binding) was impaired, while detection of a single feature target was not (Robertson et al., 1997; see also Robertson & Treisman, 2006).

In their studies of patients with unilateral neglect, Anne Treisman and colleagues found that patients could find targets in the neglect field, but on average took longer to do so. Adding flankers that directed attention to the non-neglected side made it even more difficult to find neglect-side targets, perhaps by keeping attention in the "good" side for a longer time. In contrast, flankers on the neglect side helped neglect-side target search performance by directing attention here (Grabowecky, Robertson & Treisman, 1993).

In our own studies, we found that patients with left side hemi-neglect have much more difficulty generally with conjunction search than with feature search, suggesting that their difficulty is with focused attention rather than with global attention that includes items on the left (Pavlovskaya et al., 2002). Following a discussion with Anne Treisman, we also studied mean perception in neglect patients, as did a group with Lynn Roberson, and found that consistent with this finding, patients also take into account items on the left when computing the mean, though with a lower weight (Pavlovskaya et al., 2015; see also Yamanashi Leib et al., 2012). The conclusion seems to be that patients with unilateral neglect have focused attention deficits, leading to difficulties in conjunction search tasks, but maintain their perception of the gist of the scene, including items in the "neglected" field, enabling detection of outliers (pop out) and computing set mean. Thus, the division between rapid, global gist perception and slower, detailed perception with scrutiny carries over to the abilities of Neglect patients, who have difficulty focusing attention within the neglect field, but their gist perception is somewhat spared in their neglect field.

## IV. Depth perception in the face of binocular rivalry

One of Anne Treisman's earliest studies, performed in parallel with her doctoral work on dichotic listening, was an amazing investigation of binocular rivalry. Unfortunately, this study was neglected for many years. "Unfortunately,", because properly read, it could have changed the history of binocular rivalry studies.

An essential issue in binocular rivalry investigation is asking if rivalry is a low-level, truly "binocular" phenomenon, is it a computation that takes place at various levels of the visual hierarchy, or is it a very high level "interpretation" rivalry. In her Quarterly Journal of Experimental Psychology paper on "Binocular rivalry and stereoscopic depth perception" published in 1962, Treisman asked, among other issues, if it is possible that one aspect of a single stimulus, such as its color, is sometimes suppressed, while another aspect, such as the position of the figure, is retained? That is, is rivalry really between the images in the two eyes, so that one eye's view is totally suppressed when the other takes over, or is rivalry higher level where competing aspects of the two eyes' input rival, but other aspects, which are not incompatible, may be integrated. Her method was to see whether stereoscopic depth perception was retained when stimuli (with position disparity) were made sufficiently incompatible in the color dimension to produce rivalry and suppression.

Treisman's experimental stimulus consisted of red and green circles on a white ground. Each eye saw a smaller circle placed within a larger circle. When the larger circle was fused by the two eyes, the smaller inner circles would appear in different positions on the two retinas, producing stereoscopic depth information, and the inner circles were perceived as being in a different plane than the outer circle. After participants were familiarized with stereoscopic depth perception, they were tested with stimuli where the inner circles were of complementary colors, as demonstrated in Figure 2. Indeed, there was rivalry between the colors of the inner circle, participants reported seeing sometimes one color, sometimes the other. However, amazingly, the perception of stereoscopic depth was retained throughout. Since depth perception depended on seeing the two inner circles in different positions in the two eyes, participants must have been seeing the positions of both circles, in both eyes – even though their colors were rivaling. Thus, rivalry could not be wiping out the entire information coming from one eye. It had to be a high-level effect, now called interpretation rivalry. Rivalry could be explained as a central or centrifugal suppression of specialized cells carrying color information.

FIGURE 1

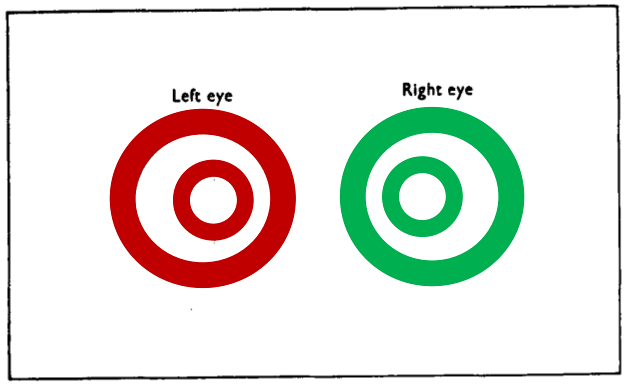


Figure 2. Anne Treisman's 1962 demonstration that stereopsis is maintained despite binocular rivalry in the color domain, proving that rivalry does not wipe out all information from one of the eyes. Reproduced here from Treisman (1962) where it appears only in black and white since journals did not usually provide color figures.

For many years, the dominant theory in the binocular rivalry scientific community was that rivalry results from a low-level mechanism, and is between images in the two eyes (e.g. see Blake, 1989). This was supported by evidence that all input to the suppressed eye is suppressed. But a slew of studies overcame this erroneous conclusion, including evidence that attention may impact rivalry by adding prominence to the attended stimulus and that a pop-out cue can force a stimulus out of suppression (Chong, Tadin & Blake, 2005). Furthermore, studies with novel paradigms (patchwork stimuli, Kovacs et al., 1996; rapidly swapping images, Logothetis et al., 1996) showed integration between the images in the two eyes before rivalry suppression. Recent studies in my lab confirmed that rivalry is, at least sometimes, high level, since we found different dominance times for words versus non-words and for Images of possible versus impossible objects (Wolf & Hochstein, 2011).

Binocular rivalry is akin to the other studies of Anne Treisman described here because it relates to features and to gist perception. The immediacy of feature search and difficulty of conjunction search derive from the former depending on one feature and the latter on two. It's easy to search for an element that differs from all its neighbors in one feature, and harder to find an element whose uniqueness depends on two features. In Treisman's view, quoting Zeki (1976), this is due to separate processing of different features in different cortical areas. The very same separation leads to the possibility of integrating information from the two eyes regarding one feature (position), and to rivalry suppression for another feature (color). Preceding Zeki by a decade, Treisman (1962) cites Granit (1955) and De Valois (1960), concluding that "color information is carried by different neurons from those that respond to intensities of light," which might be responsible for stereopsis. Treisman's binocular rivalry study also pertains to the issue of gist perception, finding that gist perception might be difficult for competing colors, but immediately forms stereopsis. The decision is split to produce a single coherent, first-order gist of the scene, avoiding internal conflict of color information deriving from the two eyes.

## Discussion

I have discussed four subjects central to Anne Treisman's groundbreaking work: rapid feature search versus slower conjunction search; set summary mean perception; perception in special populations; and depth perception in the face of binocular rivalry. In each of these groups of investigations, Treisman led the field, and redefined essential perceptual tenets. Her studies of visual search and defining of Feature Integration Theory revolutionized our understanding of the meaning, prerequisites and functions of focused attention. Her studies of set mean perception, showing that two sets can be perceived simultaneously and easily compared, dramatically increased the importance of set perception. And her demonstration that binocular rivalry does not wipe out all input from one eye was not only seminal in the appreciation of the complexity of rivalry, but also critical in the conceptualization of division of labor in cerebral sensory computation. Taken together, and together with Treisman's additional work on related topics, these form a fundamental breakthrough in our understanding of how we manage to perceive the gist of the scene without prior knowledge of its details.

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