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Ensemble perception: Stacking the hay to find the needle

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The visual clutter we constantly encounter in the world limits object recognition, a phenomenon known as visual crowding. A new study shows that ensemble perception counters this by condensing redundant information into summary statistical representations, which thus releases visual crowding's effect on individual objects.

The visual world is a cluttered place; every visual scene is rife with features and objects of all kinds. The very richness of typical visual scenes is problematic, however, as it is potentially overwhelming for the human visual system. One of the manifestations of the torrent of clutter in the visual field is a perceptual phenomenon known as 'visual crowding'^{1–3}. Crowding is a ubiquitous effect in which features and objects appear jumbled together in the presence

of nearby features and objects (Figure 1A). Along with the rampant clutter in the visual world — and its associated crowding effects — the usual existence of multiple similar objects and features means there is generally a great deal of redundancy in natural scenes. For example, consider collections of leaves in a tree, groups of faces in an audience, runners in a marathon, and so on. Fortunately, the visual system is able to harness these redundancies by encoding

the ensemble or summary statistical information that is present in these scenes⁴. Thus, ensemble perception allows us to perceive average features such as color, motion, shape, and facial expressions of crowds (Figure 1B). Ensemble perception is an efficient heuristic to access group-level information at a quick glance, without the need to scrutinize every individual object. A paper in this issue of *Current Biology* by Tiurina *et al.*⁵ demonstrates that these



ensemble percepts can gate or modulate how crowding happens (Figure 2).

The results pave the way toward understanding the delicate balancing act the visual system manages between the competing goals of recognizing particular objects in clutter and recognizing the clutter itself.

To demonstrate how ensemble perception modulates crowding, Tiurina *et al.*⁵ modified a display from Manassi *et al.*⁶ in which a target object was crowded by surrounding flankers (see Figure 2C for example). The clever manipulation was to choreograph the surrounding flankers into an ensemble: when those surrounding flankers were, themselves, seen as part of an ensemble — part of a larger group that is perceived as a single configuration — the flankers were effectively canceled out, and crowding on the single object was released (Figure 2D). In other words, the target was recognizable again, by virtue of the ensemble properties of the visual environment.

Tiurina *et al.*⁵ show that ensemble perception can occur when or before crowding happens. Conversely, there is extensive experimental evidence that crowded features and objects can get through the supposed bottleneck of crowding to subsequently determine an ensemble percept⁷. At first glance, this seems like a paradox. On one hand, the ensemble statistics can occur before crowding⁵. On the other hand, ensemble statistics can also include the crowded feature or object that was inaccessible to conscious report⁷. While these may seem like opposing results, in reality they may be complementary findings. To explain, we first need to briefly recall that crowding happens independently for different features and objects^{7,8}, that it is modulated by similarity at the feature or object level^{7,9,10}, and that it happens at multiple levels of visual processing^{2,7}.

In the findings of Tiurina *et al.*⁵, crowding is released when (and only when) there is a clear ensemble statistic in the nearby surrounding objects. The authors suggest that a normalization process^{11–13} could happen before or when the crowding is determined. This follows the ensemble coding model proposed by Haberman *et al.*¹¹, expanded by Hochstein¹² and Utochkin *et*

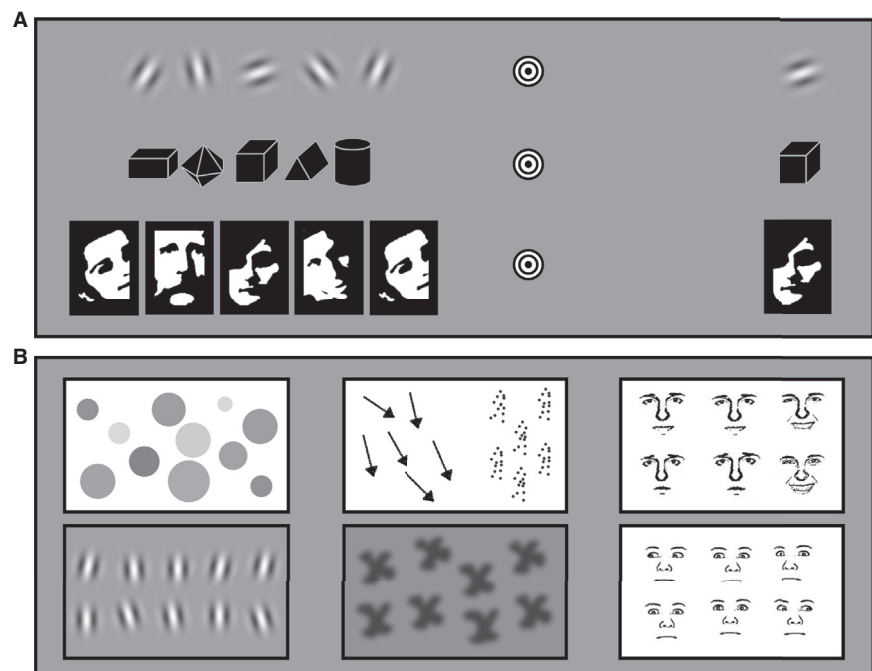


Figure 1. Two sides of clutter in vision: visual crowding and ensemble perception.

(A) Visual crowding is the deleterious effect of clutter on object recognition, typically in the peripheral visual field. Fixate the top bullseye and notice that the oriented patches embedded in the clutter on the left are difficult to recognize or identify. The same oriented patch is easy to identify when isolated at an equidistant location (right side of the bullseye). The ‘jumbled’ percept one experiences when objects in the periphery are among clutter is called visual crowding. Crowding occurs for features like orientation (top row) as well as object shape (middle row) and faces (bottom row), among other things. (B) Ensemble perception. Visual clutter in the periphery is often visually similar, and summary statistical information is easily registered in groups of similar things. For example, the average color, orientation, size, motion direction, biological motion, shape, facial expression, and gaze direction are readily recognized in crowds of objects.

*al.*¹³. In the case of similar orientation information in a visual scene (for example, the oriented patches in Figure 1B), a global population response tuning curve is extracted based on a subset (or the whole set) of locally orientation-selective tuning curves. This global population curve represents the average of local tuning curves, and it produces an ensemble percept. Importantly, the resulting global population response then normalizes the local orientation-selective units via feedback or horizontal connections. Any oddball or deviant local tuning curve (for example, an aberrant oriented patch) then pops out, and is uncrowded. Although most models of this sort^{11–13} focus on orientation, the same sort of normalization process would happen at every stage where an ensemble representation is formed (for example Chaney *et al.*¹⁴). Notably, this predicts that summary statistics about any particular feature (such as orientation,

color, or motion) or object (shape, identity, and so on) may release crowding for that particular feature or object — for example, the ensemble biological motion of the crowd in Figure 2 might release crowding of the name on the runner’s bib. Indeed, this is a prediction that could extend the results of Tiurina *et al.*⁵; manipulating summary statistics of other features, objects, or faces could modulate crowding.

Visual crowding is theoretically and practically important for a variety of reasons: it is associated with visual and cognitive impairments^{1–3}, it limits human performance in critical everyday tasks like driving¹⁵, and it sets a fundamental limit on object recognition and conscious vision². Given the many practical and health-relevant consequences of visual crowding, the link between ensemble perception and crowding revealed in the study from Tiurina *et al.*⁵ may have significant repercussions. For example,

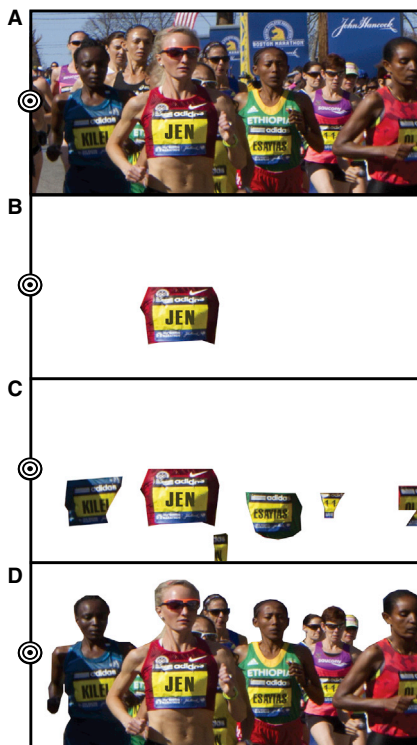


Figure 2. Ensemble perception can release crowding.

(A) Natural scenes are filled with redundant types of information, which are perceived in the form of ensemble statistics (average color, shape, facial expression, and so on). Tiurina *et al.*⁵ show that the ensemble statistics in a scene can modulate crowding. (B) When fixating the bullseye, the name on the label is identifiable, and uncrowded. (C) With flanking clutter nearby, the name on the label appears more jumbled and harder to recognize because of crowding. (D) The authors demonstrate that the addition of contextual ensemble statistical information can reduce crowding. In this case, the summary statistical information is the ensemble of runners who share similar shapes and average biological motion.

crowding is impacted in a variety of disorders such as dyslexia¹⁶, dyscalculia¹⁷, amblyopia¹⁸ and autism¹⁹. Thus, these disorders may have consequential changes in ensemble perception as well. Given the release of crowding by summary statistics⁵, manipulating ensemble information might be a way to relieve the debilitating impact of crowding in these groups.

The relationship between ensemble perception and crowding revealed in Tiurina *et al.*⁵ may also be relevant for more practical domains. For example, in medical image perception research, finding an abnormal radiograph or a particular tumor might depend on the

nature of the nearby clutter — other images or other tumors or patterns in nearby regions of the visual field. Because what counts as clutter — what crowds — depends on the summary statistics available in the scene⁵, it may be possible to alleviate some of the deleterious effects of crowding in medical image perception by focusing on the available ensemble information, such as the context, rather than focusing solely on the crowded target lesion. It is also worth noting that summary statistics could amplify crowding if the target falls within the summary statistic itself²⁰. In any case, it will be important in future work to consider how ensemble information and crowding could interact in practical and clinical settings.

Tiurina *et al.*⁵ have uncovered a causal link between two important phenomena of spatial vision: visual crowding and ensemble perception. Their results show how the interplay between perception of local elements (impaired by visual crowding) and the global properties of a scene (summarized into ensemble perception) are intimately tied to each other. On one hand, ensemble perception makes use of crowded objects, thus allowing us to see the hay even when individual straws go unrecognized. At the same time, when the visual scene is processed as an ensemble, cluttered objects can be released from crowding, showing that our visual system is able to stack the hay to find the needle.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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