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Reassessing the Evidence for Novel Popout

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J. Christie and R. Klein (1996) have reviewed some of our previously published evidence for *novel popout* (i.e., the possible attention-capturing power of unexpected or novel singletons in otherwise expected or familiar fields). They have questioned the reliability of some of the evidence and suggested that it, in any case, does not compel an attention-capture interpretation. In this rejoinder, we bolster the evidence with more recent data and argue that Christie and Klein's alternative interpretations are deficient on both empirical and theoretical grounds. However, we concede (a) that most of the evidence is not decisive with respect to whether the effects associated with novel popout reflect perceptual or retrieval (or both) biases toward novel singletons and (b) that innovative methodologies and converging lines of evidence could help resolve this issue.

For the last several years, we have investigated the role of input novelty in spontaneous attention when observers have a glimpse of a scene but are not looking for anything in particular. In a typical experiment, observers receive 33–200-ms exposures to four-word arrays that represent at least three ratios of novel (or nonrepeated) to familiar (or repeated) words: all novel (4:0), all familiar (0:4), and one novel (1:3). Each array is backward masked and followed about 400 ms later by a probe to localize one of the words. The typical pattern of results comprises three basic effects. Familiar items are more localizable than novel items when they are not intermixed in the same array, but this baseline effect diminishes when a novel singleton appears in a familiar field (e.g., Hawley, W. A. Johnston, & Farnham, 1994; W. A. Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990; W. A. Johnston, Hawley, & Farnham, 1993). The rise above the all-novel baseline in the localizability of novel singletons may be referred to as *between-arrays novel popout,* and the fall below the all-familiar baseline in the localizability of familiar field items as *between-arrays familiar sink-in.* Depending on their relative magnitudes, these three basic effects can define *within-array novel popout* in which novel singletons are more accurately localized than the familiar field items with which they appear. The full pattern of effects is evident in Figure 1.

Of these effects, between-arrays novel popout is the most interesting to us because we suspect it is an important product of biological evolution and continues to serve a valuable adaptive function. As we have suggested elsewhere, the bias toward novel singletons can counteract the well-documented biases toward familiar objects and events (e.g., priming and word-superiority effects and the baseline advantage of all-familiar over all-novel arrays), and these opposing biases can help strike a healthy balance between mental plasticity and mental stability (W. A. Johnston & Hawley, 1994; W. A. Johnston, Schwarting, & Hawley, 1996). An organism must represent and efficiently process the relatively stable features of its habitat and yet remain sensitive to any unexpected intrusions or other perturbations. Therefore, research and theory on novel popout have the potential to reveal how biological evolution has solved the problem of designing a mind/brain system that can be biased simultaneously toward what it most expects and what it least expects. Our most recent attempt to conceptualize this solution, called *mismatch theory,* is outlined below and described in more detail elsewhere (e.g., W. A. Johnston & Hawley, 1994).

On the basis of a careful review of the findings reported in our first three empirical papers (i.e., W. A. Johnston et al., 1990; W. A. Johnston et al., 1993; Hawley et al., 1994), Christie and Klein (1996; see also Christie & Klein, 1994) have critiqued our work on both empirical/methodological and theoretical grounds. In particular, they have suggested (a) that some of the experiments were flawed methodologically, (b) that the within-array novel popout is most diagnostic theoretically but is of dubious replicability, (c) that the complete pattern of effects, even if taken at face value, can be readily explained without assuming that novel singletons capture attention, and (d) that more suitable experimental paradigms are available to test this attention-capture assumption. The remainder of this article is a response to these arguments.

Empirical/Methodological Issues

The Critique

Christie and Klein (1996) devoted about half of their critique to the argument that within-array novel popout, which they consider the most important of the effects, is an artifact of two methodological details.

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We are deeply indebted to Kevin Hawley, who contributed to all phases of research and theory development on novel popout until his untimely death on October 20, 1994.

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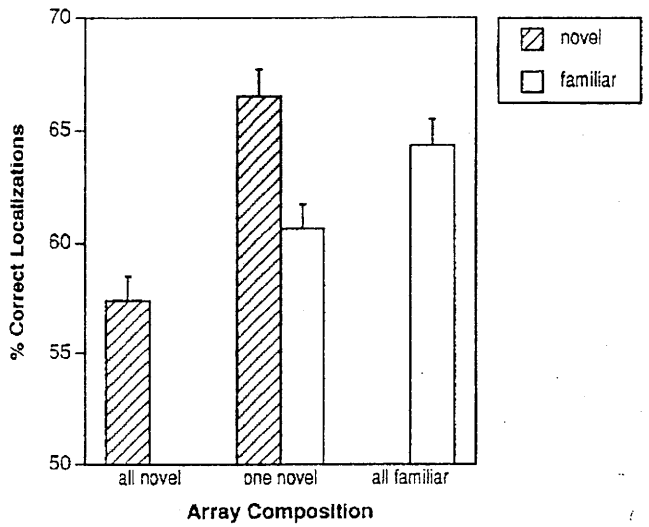

Figure 1. Mean accuracy of localization of novel and familiar words in the different array compositions observed by Johnston and Schwarting (in press) in a partial replication of Experiment 4 of Johnston et al. (1990). (Vertical bars indicate standard errors.)

1. In the first few studies summarized in our 1990 article (W. A. Johnston et al., 1990), novel items were both presented and probed more often than familiar items. This might have biased observers to search for novel items and contributed to the observed popout effects.

2. In the first few studies reported in our 1993 article (W. A. Johnston et al., 1993), novel singletons were probed in 50% of the one-novel trials rather than in proportion to their 25% representation in these arrays. This was done to improve statistical power and design economy, but might have biased observers toward the novel singletons and inflated the effect of novel popout.

Christie and Klein have correctly noted that, with respect to most of the research they reviewed, within-array novel popout attained statistical reliability only when one or the other of these possible biases toward novel singletons applied. For example, neither bias applied to Experiment 4 of W. A. Johnston et al. (1990), and the effect did not attain statistical reliability. In that study, 36 observers received 48 trials of all-familiar practice followed by a random sequence of 96 all-familiar trials, 96 all-novel trials, and 96 one-novel trials. Duration of array exposure was 200 ms. Novel singletons were probed on 24 randomly selected one-novel trials. Thus, familiar words were represented and probed nearly twice as often as novel words, and novel words were probed in proportion to their representation in the one-novel arrays. The failure of within-array novel popout to reach a conventional level of statistical significance is consistent with Christie and Klein's arguments.

Our Response

We respond to this part of Christie and Klein's critique by arguing that within-array novel popout is valid and replicable, but that, in any case, it is not as diagnostic theoretically as Christie and Klein have suggested.

More Recent Research

In several subsequent studies (see W. A. Johnston et al., 1996), within-array novel popout has attained statistical reliability under a wide range of conditions (e.g., types of input, array formats, and speed/accuracy emphases). In a recent replication of Experiment 4 of W. A. Johnston et al. (1990), we attempted to ensure ample statistical power by running 112 observers, more than three times the original number (W. A. Johnston & Schwarting, in press, Experiment 2). A summary of the results of that study is reproduced in Figure 1. The full complement of effects was observed, including a highly reliable within-array novel popout, $F = 27.28$, $p < .001$. Our more recent findings leave little doubt that the complete pattern of effects is replicable and that within-array novel popout is not limited to the methodological boundaries noted by Christie and Klein.

Theoretical Significance of Within-Array Novel Popout

The replicability of within-array novel popout notwithstanding, it is worth considering why this effect is not always observed and why it may not be as diagnostic theoretically as Christie and Klein have suggested. Logically, the effect is, at least to some extent, derived from the three basic effects and depends on their relative magnitudes. If the between-arrays novel popout and familiar sink-in effects are sufficiently large and the baseline effect sufficiently small, then within-array novel popout will necessarily occur. However, if the between-arrays effects remain relatively fixed but the baseline advantage of familiar arrays is dramatically increased, then within-arrays novel popout can be reversed. Indeed, the sensitivity of this effect to the magnitude of the baseline effect has been demonstrated empirically (e.g., W. A. Johnston & Schwarting, in press, Experiment 1). It is for this reason that the absence of this effect in some of our prior studies is not necessarily diagnostic theoretically. On the other hand, as we show below, the presence of the effect in other studies is diagnostic in that it renders inadequate or implausible some of the interpretations of novel popout suggested by Christie and Klein and others.

Theoretical Issues

Having shown that the pattern of effects is replicable, we turn now to its theoretical implications. In most of our prior papers, we have argued against accounts of novel popout in terms of serial search (e.g., an explicit search for novel singletons), suggesting instead that it is a conceptually-driven form of attention capture. In contrast to other types of object singleton that have been argued to capture attention, such as sudden-onset and color singletons (e.g., Folk, Rem-

ington, & J. C. Johnston, 1993; Yantis, 1993), the novel items in our studies are conceptually, rather than physically, defined. In particular, they are defined relative to the expectancies of the observers and do not differ from the field items in terms of simple physical features.

The Critique

Christie and Klein have challenged the attention-capture interpretation and offered some alternatives. They do not dispute that novel popout might reflect "rapid orienting of visual attention toward novel items," only that it "does not force these conclusions . . . [and] . . . remains an empirical question" (Christie & Klein, 1996, p. 202). We agree that novel popout is open to alternative interpretations and have never argued that our data "force" an attention-capture interpretation. However, we are compelled to respond to their theoretical critique for two main reasons. First, they have attributed to us a conception of attention capture that we no longer endorse, and second, we question the viability of their alternative interpretations.

Our Response

We consider, in order, interpretations of novel popout offered by Christie and Klein, conventional theories of attention, and our own mismatch theory of attention.

Christie and Klein's Interpretation

Christie and Klein have suggested that novel popout is not a phenomenon of attention at all. They propose two nonattentional accounts of novel popout: a cognitive-load account and what we shall refer to as a *retrieval* account.

Cognitive load. Christie and Klein suggest that, except for within-array novel popout, the entire pattern of effects "can be easily explained in terms of . . . overall-task difficulty" (1996, p. 202). Familiar arrays are easier to process than novel arrays, yielding the baseline effect. When a familiar item is replaced by a novel singleton, task difficulty is between the two baseline levels, yielding the between-arrays popout and sink-in effects.

We reject this account on both theoretical and empirical grounds. Theoretically, the account is vague, being little more than a description of the effects it purports to explain. How is task difficulty or cognitive load defined and conceptualized independently of the obvious performance differences between the different array types? What processes underlie cognitive load and produce these performance differences? Why does the insertion of a normally difficult novel item into a normally easy familiar field make the singleton more localizable and the field items less localizable? One might suggest, although Christie and Klein did not, that some amount of cognitive "resources" are withheld from the field items and bestowed on the novel item, but this begs more questions. What are these resources, who or what allocates them between array inputs, and how is this allocation so quickly and systematically done?[1] Our own mismatch theory outlined below goes beyond these descriptive concepts and natural-language metaphors and explicates the possible underlying dynamics that give rise to the observed popout and sink-in effects.

Even though its vagueness provides it with considerable interpretative latitude, this cognitive-load "explanation" faces empirical problems. Experiment 3 of W. A. Johnston et al. (1990) poses one problem. In that study, the ratio of novel to familiar words in mixed arrays was varied at three levels: 1:3, 2:2, and 3:1. Thus, task difficulty should have increased with this ratio, yielding a decrease in novel popout and an increase in familiar sink-in. However, although localization accuracy for novel words was higher when they were singletons in 1:3 arrays than otherwise, accuracy for the familiar-field words remained constant across the three ratios. The same basic finding was observed in Experiment 1 of the W. A. Johnston et al. (1990) series. Perhaps a more fatal problem, one pointed out by Christie and Klein themselves, is posed by within-array novel popout. Why should performance ever be higher for the difficult singletons than the easy field items? This question leads us to Christie and Klein's retrieval explanation.

Retrieval. Christie and Klein propose that novel popout is attributable to retrieval and decision processes initiated when the probes are presented. They extend the suggestion of W. A. Johnston et al. (1990) that novel singletons yield a form of figure-ground segregation characterized by a perceptual "trouble spot," the figure, in an otherwise fluently unfolding perceptual field, the ground. When a probe is presented after a one-novel array, the observer might, to some degree, remember the identities of all four words along with the trouble spot and correctly infer that the novel singleton had appeared at the trouble spot. We suggest that this explanation also faces both theoretical and empirical problems.

The main theoretical problem is what we regard as a tacit appeal to some sort of intelligent control processor that possesses sophisticated but unexplicated cognitive abilities of its own.[2] Moreover, even allowing the appeal to such a mechanism, far too much cognitive acumen is demanded of it. It must be able to retrieve and examine all of the identity, location, and perceptual fluency memories, compare them, make logical inferences, and initiate an overt response, all within the 800 ms in which observers usually respond to probes.

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[1] For a more detailed critique of the concept of resources, see Navon (1984).

[2] In their review of this rejoinder, Christie and Klein (1996) deny that their "decision diagnostic" appeals to a homunculus. They argue that this sort of sophisticated decision making is "precisely the type cognitive psychologists attribute to the intelligent participants in their experiments." However, in our view, an appeal to the intelligent behavior of the observers is not an explanation; rather, this behavior is precisely the phenomenon to be explained. It is for this reason that we regard this kind of "explanation," in the absence of an explicit model, as a tacit appeal to a homunculus.

This retrieval hypothesis is empirically challenged by the absence of familiar popout in arrays containing a familiar singleton (the fluent figure) in a novel field (the nonfluent ground), such as the 3:1 arrays in Experiments 1 and 3 of W. A. Johnston et al. (1990). If the observer is able to infer that a novel singleton must have appeared in the only perceptual trouble spot in an array, then that person should be able to infer that a familiar singleton must have appeared in the only perceptually fluent spot. In addition, Schwarting, Wilson-Leff, Malley, Strayer, and W. A. Johnston (1994) measured observers' event-related potentials (ERPs) during another replication of Experiment 4 of the W. A. Johnston et al. (1990) series. In addition to the performance differences depicted above in Figure 1, the three array compositions generated reliably different ERPs only on their onsets; ERPs to the subsequent probes were not affected by array composition.

Although we suggest that these theoretical and empirical arguments strain the credibility of the particular retrieval account of novel popout offered by Christie and Klein, we agree that they do not rule out the possibility that novel singletons may be more retrievable than items in all-novel arrays, if for no other reason than because they are perceived better to begin with.

Conventional Theories of Attention

Selective attention is usually thought to be either directed sequentially to items by a search process or automatically captured by particular items. This dichotomy follows from the conventional distinction between automatic, parallel preattentive processing and controlled, serial postattentive processing, where attention is a separate, gatekeeping mechanism between these two levels of processing. The gatekeeper can either admit the preattentive representations of array objects one at a time, as in serial search, or give priority admission to the representation of an object singleton of some sort, as in attention capture. Christie and Klein (1996) have referred to a conventional search account of novel popout proposed by Theeuwes, and they have attributed to us a conventional capture interpretation of novel popout.

In our view, this entire framework suffers from the theoretical flaw of appealing to an intelligent homunculus (or a gatekeeper, executive, central processor, or attention director). Moreover, we have recently found the conventional search and capture accounts of novel popout to fail explicit empirical tests (for details, see W. A. Johnston & Schwarting, in press). For example, if novel singletons captured attention, then they would be the first inputs through the attentional gate and their localizability would be relatively unaffected by manipulations, such as a reduction in duration of array exposure, that would be assumed to delimit the opportunity for further serial search. Hence, the fact that we have consistently observed accuracy of localization to be affected by duration of exposure as much for novel singletons as for any other items indicates that novel popout cannot be explained by the conventional conception of attention capture (e.g., W. A. Johnston et al., 1993, Experiment 7; W. A. Johnston & Schwarting, in press).

Mismatch Theory

Beginning with our second paper (W. A. Johnston et al., 1993), we began to reconceptualize attention in general and novel popout in particular within a totally different framework. Rather than accepting the conventional view of attention as a cause of selective perceptual processing, we began to conceive of it as an effect or epiphenomenon of selective perceptual processing (see, e.g., James 1890/1950; W. A. Johnston & Dark, 1986). In our mismatch theory of attention, there is no attentional gatekeeper; indeed, no distinction is even drawn between preattentive and postattentive processing. Instead, differential "attention" to simultaneous inputs such as novel singletons and familiar-field items is conceived in terms of differential degrees of a parallel spreading of excitation and inhibition across a two-tiered network of nodes.

Mismatch theory is summarized in several other reports and is presented in some detail in W. A. Johnston and Hawley (1994). We present it here in rough outline only. The basic idea is that because organisms already know their familiar habitats, it would be a waste of their time and energy to engage in detailed physical analyses of these habitats every time they are encountered. It would be more efficient to suppress the physical analyses of familiar scenes and rely on knowledge- or conceptually-driven processing of them. In mismatch theory, extensive spreading activation of the conceptual representations of expected inputs in the upper tier of nodes ricochets a proportional amount of top-down inhibition of the physical representations of these inputs in the lower tier. Thus, expected inputs generate a high degree of conceptual processing but a low degree of physical processing. A by-product of the suppressed physical processing of expected inputs and the lateral inhibition they engender in the lower tier is the enhanced physical processing of any unexpected inputs in their midst (i.e., novel popout).

In addition to explaining novel popout, mismatch theory shows how the mind/brain can be biased simultaneously toward both expected and unexpected inputs by locating these opposing biases at different levels of processing. A computational instantiation of mismatch theory has been found to produce the entire pattern of effects associated with novel popout, including its insensitivity to reductions in duration of array exposure (e.g., W. A. Johnston & Hawley, 1994; see also Christie & Klein, 1996, Figure 2). In short, we are inclined to interpret attention in general and search and attention capture in particular as epiphenomena of differential, parallel, processing of array inputs, not in terms of a mysterious internal processor whose own attention and other cognitive capabilities are granted but not explicated. Thus, the attention-capture interpretation of novel popout that Christie and Klein have challenged is not the interpretation that we now defend.

Concluding Comments

We conclude with reference to the four arguments that we extracted from Christie and Klein's critique. First, even if some of our earlier experiments were flawed methodologically, which is debatable, our more recent experiments show that the pattern of effects associated with novel popout is not an artifact of these possible flaws. Second, these more recent data show also that within-array novel popout, although of limited theoretical significance, is valid and replicable. Third, although our findings certainly do not force an attention-capture interpretation of novel popout, we submit that our mismatch theory interpretation is more tenable on theoretical and empirical grounds than the alternatives suggested by Christie and Klein. However, we concede that mismatch theory may not provide the whole story and that novel singletons may be more retrievable after they have been perceived as well as more perceptible when they are first presented.

We agree also with Christie and Klein's last point, namely, that there are other, possibly more suitable, paradigms with which to explore the basis of novel popout, especially to determine whether it arises during perception of the arrays or during subsequent retrieval. However, although there may be promise in the probe technique advocated by Christie and Klein (1995), we prefer the use of ERP methodologies of the sort used by Schwarting et al. (1994), because ERP measures can be taken nonintrusively during all phases of the task.

Finally, we reiterate our conviction that whether it is due to selective perception or selective retrieval a split-second later, novel popout provides an important and adaptive counterweight to an organism's biases toward expected and familiar inputs. Mismatch theory illustrates how conflicting biases toward both expected and unexpected inputs can operate simultaneously and symbiotically at different levels of processing. This feature of mismatch theory enables it to account for facilitatory effects of expectancy of the sort observed by Christie and Klein (1995) as well as inhibitory effects of the sort that may underlie novel popout and other phenomena (for several examples, see W. A. Johnston & Hawley, 1994). We hope that Christie and Klein's critique along with our rejoinder will encourage further investigation into both the phenomenon of novel popout and alternative theories of its bases.

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