



# Reliability and generality of the novel pop-out effect following passive pre-exposure to array items

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Accepted: 15 March 2023  
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## Abstract

Novel pop-out refers to the relative ease in locating an unfamiliar target against a background of familiar distractors in visual search tasks. For instance, when one novel item is presented along with three familiar items, it is located faster than when the target is itself familiar, or when all items are novel or familiar. However, the reliability and generality of the novel pop-out effect has been questioned. Three experiments with human participants examined the reliability of within-array novel pop-out effects, and explored the conditions under which these effects can be obtained. The degree to which subjects could identify a novel item when presented against a background of familiar items, or against a background of other novel items, was assessed using two different visual search tasks. Experiments 1 and 3 replicated the theoretically important within-array novel pop-out effect, using the original procedure adopted by Johnston and colleagues. In the current studies, the array items were rendered novel or familiar by virtue of their previous absence or presence, respectively, in a pre-exposure phase, which allowed greater control over their novelty or familiarity. However, the use of this procedure abolished the typically-reported advantage for all-familiar versus all-novel arrays (Experiments 2 and 3). It is suggested that any model of attention should be sensitive to the present goal state of the subject, and that the literature on latent inhibition may provide one such mechanism through which such a set of effects could be explained.

**Keywords** Novel pop-out · Familiar sink-in · Attention

The situations under which stimuli that are expected or unexpected, familiar or novel, control behaviour have been the focus of extensive research across multiple paradigms (Born et al., 2011; Diliberto et al., 1998; Johnston et al., 1990; Lubow & Kaplan, 1997; O'Donnell et al., 2021; Pearce & Hall, 1980; Sokolov, 1963; Vatterott & Vecera, 2012; Yang et al., 2009). Many well-established theories suggest two simultaneously operating but opposing mechanisms control behaviour: organisms respond to regularities, but also are highly attuned to violations of those regularities, and the degree to which novel or unexpected stimuli capture attention (pop-out) has played a role in theoretical debate (e.g., Brascamp et al., 2011; Johnston & Hawley, 1994; Pearce & Hall, 1980; Sokolov, 1963; Vatterott & Vecera, 2012).

The novel pop-out effect (Brascamp et al., 2011; Johnston et al., 1990) contributed substantially to this debate, especially around whether attentional processes are stimulus-driven (bottom-up), or conceptual and top-down (see Christie & Klein, 1995; Diliberto et al., 1998; Horstmann, 2005; Johnston & Hawley, 1994; Vatterott & Vecera, 2012). The novel pop-out is also important in that it has been employed to investigate real world effects (Sauter et al., 2020), individual differences in attentional processing between 'familiarity-seekers' and 'novelty-seekers' (Christie, 2006), as well as deficits associated with a range of clinical disorders, such as schizophrenia and Parkinson's disease (Leonard et al., 2020; Lubow et al., 1999, 2000).

Although much research of the last 20 years has accepted the existence of novel pop-out as the basis for analyses of these issues (cf. Born et al., 2011; Brascamp et al., 2011; O'Donnell et al., 2021; Vatterott & Vecera, 2012), a number of challenges can be made to the findings on which these subsequent studies were based (Christie & Klein, 1995; Diliberto et al., 1998). The existence of these challenges makes the subsequent theoretical interpretations and applied

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implications of the novel pop-out effect ambiguous (Horstmann, 2005; Johnston & Hawley, 1994; Vatterott & Vecera, 2012; Yang et al., 2009). This suggests that the original findings are need of re-visiting and re-exploration to establish their robustness and potential boundary conditions.

A seminal demonstration of pop-out was obtained in a visual search task by Johnston et al. (1990), where locating an unfamiliar target against a background of familiar distractors was noted to be easier than locating a familiar target against a background of unfamiliar distractors (see also Brascamp et al., 2011; Diliberto et al., 1998; Vatterott & Vecera, 2012; Yang et al., 2009). In this task, brief displays of four-word arrays are presented, and, shortly afterwards, participants are probed for the location of a particular word from that array (Born et al., 2011; Diliberto et al., 2000; Johnston et al., 1990). Three types of word-arrays are often presented: all-familiar, containing words that have been repeatedly presented together throughout the experiment; all-novel, containing words that had never been presented before in the experiment; and mixed-arrays, containing three familiar words and one novel word. Johnston et al. (1990; see also O'Donnell et al., 2021) noted location accuracy was greatest in all-familiar arrays, and lowest in all-novel arrays. However, when a novel or unexpected word appears in a familiar field, localisation accuracy is higher for this item than for the familiar items. This effect has been referred to as 'within-array novel pop-out' (Diliberto et al., 2000; Johnston et al., 1990). An advantage in localisability of a novel-singletons in a mixed-array, compared to novel items in an all-novel array, is referred to as 'between-arrays novel pop-out'. The decrease in localisability for familiar items in a mixed-array compared to the all-familiar baseline is referred to as 'between-array familiar sink-in', and this effect is akin to the similar latent inhibition effect (Lubow & Kaplan, 1997; Lubow et al., 2000).

However, the between-array effects that are critical for many views (e.g., Johnston & Hawley, 1994; Johnston & Schwarting 1997) are subject to a task-difficulty explanation (Christie & Klein, 1995) that does not rely on attentional capture, and is not strong evidence for any one theory (see also Vatterott & Vecera, 2012; Yang et al., 2009). Christie and Klein (1995) argue that, if it is assumed familiar items are easier to process than novel items, and that there is a limit to the time or resources available for such processing, then overall processing demands will be proportional to the number of novel items in the display. Thus, relative to all-familiar arrays, localization of a familiar item in a mixed-array should be more difficult. In contrast, relative to all-novel arrays, localization of a novel item in a mixed-array should be easier.

Whether or not such assumptions regarding load are valid, they cannot accommodate within-array effects; thus,

these effects become central to the demonstration of novel pop-out. Unfortunately, these effects are not always empirically demonstrable, or are often obtained under circumstances in which potential experimental flaws exist (see Christie & Klein, 1995; Diliberto et al., 1998; Horstmann, 2005; Vatterott & Vecera, 2012). For example, in many studies in which a within-array novel pop-out effect was noted, the novel item might have had an advantage as it was probed more often than the familiar items (Johnston et al., 1990; Lubow et al., 1999, 2000). When test probes are proportional to item presentation, the within-array effect has been somewhat elusive. This effect appears statistically in the studies reported by Johnston and Schwarting (1997) and Diliberto et al. (1998); numerically, but not statistically, in the report by Johnston et al. (1990; Experiment 4); not at all in the study by Johnston et al. (1993; Experiment 7), and not in the study by Hawley et al. (1994).

There are several, so far, uninvestigated reasons, related to procedural aspects of the studies, why the within-array novel pop-out effect may be elusive. A possible influential factor, of some theoretical importance, is that of item-relevance during the pre-exposure phase of the study which establishes familiarity of items. In the paradigm developed by Johnston et al. (1990), the items presented in the arrays were always relevant to the participant, in that every item presented in those arrays was probed for item location at some point in the study. As this procedure encourages extensive sampling of each array presented, it could be conjectured that representations of the items would be elaborated in order to increase the efficiency of the subsequent target matching (Houghton & Tipper, 1994; Johnston & Hawley, 1994). Such a process would boost performance on familiar words, producing a baseline advantage with all-familiar displays, and masking the within-array novel pop-out effect through an enhancement of familiar word performance. This procedure may also aid the development of field-representations (configural processing), which would tend to reduce the impact of single item novelty or familiarity (Johnston & Hawley, 1994). If this is the case, the manipulations that serve to reduce the degree of processing of items during the pre-exposure (familiarisation) phase of a study, should serve to increase the robustness of the within-array pop-out effect. Such manipulations could include not requiring participants to make a response to the items during pre-exposure (which was required in the original study by Johnston et al., 1990). Additionally, reducing the numbers of exposures to the pre-exposed stimuli should increase the effect of novelty by decreasing the degree to which field-representations could be developed (see Davis et al., 2020; Vatterott & Vecera, 2012).

Another factor that may mask novel pop-out is the use of randomised trials. Johnston et al. (1990) presented subjects

with a random sequence of all-familiar, all-novel, and mixed, arrays, and familiarisation was achieved by repeatedly presenting particular arrays throughout the study. This design was implemented to counteract any expectancy of array type, but it also could have attenuated the novel pop-out effect. Evidence from habituation studies with repeated distractors suggests there is disinhibition when new distractors are introduced (Lorsch et al., 1984; Sokolov, 1963). Therefore, mixing of different array types will produce less habituation than the constant presentation of a particular array, and reduce the development of familiarity for putatively familiar arrays.

Given the above range of considerations, prior to further development of theorising or applied implications, it would seem important to be confident in which aspects of the procedure are central to obtaining the novel pop-out effect. To this end, three experiments examined novel pop-out effects after introducing changes into the paradigm primarily to assess the effect of making the items during pre-exposure irrelevant to the test demands, altering the degree to which they were familiar, as well as addressing procedural issues (proportional cueing, and non-random presentation of array items). The first experiment examined the effects of: making a response to the pre-exposed stimuli unnecessary in order to highlight its irrelevance to the test probe; decreasing the numbers of exposures to the initial array prior to test to reduce possible field-representations; and adding an active sampling procedure. The first two manipulations were hypothesised to increase the within-array novel pop-out effect, relative to the original demonstration (Johnston et al., 1990); whereas, active sampling was hypothesised to restore processing during pre-exposure and decrease novel pop-out. The second experiment used the same manipulations to examine between-array advantages for localisation after familiar- versus novel-arrays. It was hypothesised that decreasing array pre-exposure would reduce the all-familiar advantage, due to reducing the overall conceptual processing of the array, but active sampling would re-instate this effect by making the stimuli more relevant. The final study examined all of these effects, and also used a different method for manipulating the amount of familiarity (i.e. continuous exposure, as opposed to numbers of discrete exposures, to stimuli) with the stimuli. It was hoped to investigate whether any of these changes, introduced to help overcome previous criticisms of demonstrations of novel pop-out would impact the degree to which such effects were observed. In doing so it was hoped to explore the reliability and generality of this potentially theoretically and practically important effect.

## Experiment 1

Experiment 1 served to investigate the robustness and generality of the theoretically important within-array novel pop-out effect, using two changes to the procedure described by Johnston et al. (1990) designed to maximise the likelihood of the within-array pop-out effect. The first change was to familiarise words during a pre-exposure segment of the trial, as is often employed in studies of latent inhibition (Lubow et al., 2000). During this segment of the trial, arrays were repeatedly presented, but subjects were not probed for a response. This would make explicit the irrelevance of the pre-exposure by removing any task-dependent reinforcement. Under these conditions, it is expected that a reduction in sampling will be observed. By removing the possibility of disinhibition, it should be possible to induce a sampling decline following relatively few repetitions of the stimuli. Johnston et al. (1990) had familiar words repeated 96 times throughout the course of the experiment. However, the literature shows that the orienting response will decline in as few as 5–10 repetitions of an item (Sokolov, 1963), which may actually reduce the size of the novel pop-out effect. Therefore, a primary prediction of this study is that an increased pop-out effect size relative to that seen by Johnston et al. (1990) will be observed with only a few repetitions of the items.

Nested within the above manipulation, a second change explicitly manipulated stimulus relevance by focusing on the task demands during pre-exposure. One group of subjects was instructed to simply watch the arrays until probed (passive group), while a second group of subjects was instructed to name the words in all of the arrays presented (active group). With the active group, an attempt was made to re-introduce the relevance of the words in the array. It was anticipated that performance for unfamiliar words would be enhanced in the active pre-exposure condition, relative to the passive pre-exposure condition. Therefore, the novel pop-out effect should be larger with the passive pre-exposure condition.

## Method

### Subjects

Subjects were recruited through adverts sent through the Psychology Department subject pool. A total of 40 subjects (31 female; 9 male; 0 nonbinary), with an age range of 18 to 38 years, served in the present experiment. All were unpaid volunteers, naive to the purpose of the experiment, and were allocated randomly to the two groups: Passive group ( $n=20$ ; 15 female) had a mean age of  $21.23 \pm 2.76$ ; Active group ( $n=20$ ; 16 female) had a mean age of  $20.99 \pm 2.92$ .

These participants were randomly allocated to two groups. G-Power calculations suggest that for a medium effects size ( $f' = 0.25$ ), using a rejection criterion of  $p < .05$ , for 80% power, that 24 participants would be needed to establish a three-way interaction for a mixed-model analysis of variance (ANOVA), and 34 for a two-way interaction. Ethical approval for this study, and for all subsequent studies reported here, was obtained from the University's Psychology Department Ethics Board, and all subjects gave their informed consent.

### Apparatus

The stimulus pool of 288 five-letter, concrete nouns was compiled. From this pool, words were randomly allocated to one of three sets. The frequency of these words was assessed using the Kucera-Francis scales; their imaginability using the data provided by Gilhooly and Logie (1980), where 1 = great difficult arousing image, and 7 = arousing images most easily; and their concreteness using the lists provided by Brysbaert et al. (2014), where 1 = very abstract and 5 = very concrete. The means for these measures for the three-word sets were highly similar to one another: practise set (Set-P = 48) – frequency =  $85.21 \pm 75.28$ , imaginability =  $5.32 \pm 1.10$ , concreteness =  $4.01 \pm 1.23$ ; repeating set (Set-R = 192) – frequency =  $93.74 \pm 87.76$ , imaginability =  $5.10 \pm 1.21$ , concreteness =  $4.10 \pm 1.73$ ; and the novel set (Set-N = 48) – frequency =  $87.04 \pm 90.32$ , imaginability =  $5.90 \pm 1.03$ , concreteness =  $4.05 \pm 1.34$ . Arrays containing four words were presented to the subjects. Each word in an array subtended a visual angle of  $1.9^\circ$  horizontally, and a  $.64^\circ$  vertically, from a viewing distance of 50 cm. The entire array subtended an angle of  $5.1^\circ$  horizontally, and  $4.5^\circ$  vertically.

### Procedure

The subjects were divided into two groups ( $n = 20$ ); one group received the passive condition, and the other received the active condition. Each subject received 6 practice trials, and 48 experimental trials. Each trial was split into three segments: pre-exposure, orienting, and probe.

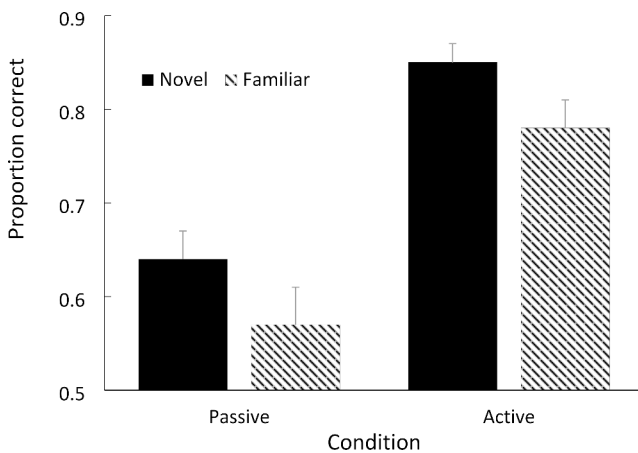
**Pre-exposure** The stimulus array in the pre-exposure segment of the trial consisted of four words, randomly selected from the repeating stimulus set (Set-R). The array was displayed on the screen for 500ms. The subjects were presented with 5–8 repetitions of this array. Each repetition was followed by a 50ms presentation of a masking array (consisting of a 'xxxxxx' stimulus in the same positions that the words had occupied). Each array in the pre-exposure phase was separated from the previous array by an inter-stimulus

interval of 800ms. The positions of the words within the arrays were randomised with each repetition. The use of a variable number of pre-exposure displays was introduced to counteract any expectancy of word position during the subsequent orienting phase.

**Orienting** Following the repetitions of the pre-exposure displays, the subjects were presented with an orienting display. The orienting displays were composed of three repeated words from the previous pre-exposure part of the trial, plus one novel word drawn from the novel stimulus set (Set-N). The orienting array was presented 800ms following the final pre-exposure stimulus. The positions of the repeated words were randomised, relative to the previous pre-exposure display.

**Probe** The array presented in the probe comprised 4 identical stimuli. This probe was presented 800ms following the orienting display, and remained visible until a localization response had been made. On 12 of the 48 trials, the probe was a novel stimulus from the orienting display. For the remaining 36 trials, the probe was a repeated stimulus that had been presented in the previous orienting display. On all trials, subjects were required to indicate where the probe stimulus had appeared in the previous orienting display. The probing of either repeated or novel stimuli during experimental trials was randomised over the course of successive probe trials, with the restriction that novel stimuli were probed on 25% of trials, and repeated stimuli were probed on 75% of trials.

**Group manipulation** The subjects in the passive pre-exposure condition were instructed only to observe the displays until they were presented with a display containing 4 identical stimuli (the probe). They were warned of the probe by the 200ms appearance of a red fixation-cross in the centre of the screen, presented 1500ms following the orienting trial. When the probe display appeared, subjects were asked to indicate the position in which the probe stimulus had appeared in the previous display (the orienting array). Subjects' responses were collected via the keyboard. Subjects in the active pre-exposure condition were instructed to vocalise the words in all displays, apart from the probe. They were warned of the probe by the appearance of a red fixation-cross in the centre of the screen. When the probe was presented, subjects were required to indicate where the



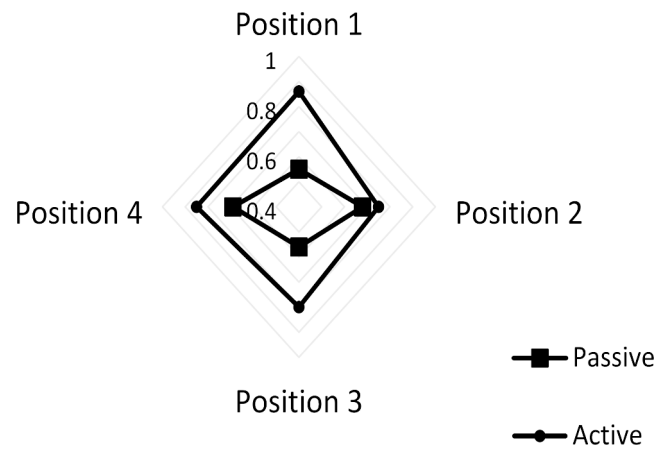
**Fig. 1** Results from Experiment 1. Mean proportion of correct word localizations, for both novel and familiar words in a mixed array, for both pre-exposure conditions. Passive=no reading of pre-exposed words. Active=reading pre-exposed words. Error bars=95% confidence limits

probe had appeared in the previous display (the orienting array). Subjects' responses were collected via the keyboard.

## Results and discussion

Figure 1 displays the mean proportion (standard deviation) of words correctly localised on each probe test, in each condition, as a function of pre-exposure condition (passive versus active), and word type (novel versus familiar). These data were analysed by a three-way, mixed-model, analysis of variance (ANOVA), with pre-exposure condition (passive versus active) as a between-subject factor, and word type (novel versus familiar), and word position (four places), as within-subject factors. Inspection of Fig. 1 reveals that overall performance was superior with active compared to passive exposure,  $F(1,38) = 16.55, p < .001, \eta^2_p = 0.303[95\%CI: 0.082:491]$ . There was also a consistent word-localization advantage for novel over familiar words,  $F(1,38) = 7.36, p = .009, \eta^2_p = 0.162[0.010:361]$ , but there was no interaction between pre-exposure condition and word type,  $F < 1$ .

Thus, the novel pop-out effect (Johnston et al., 1990) was replicated across both pre-exposure conditions, with fewer repetitions than previously used. The effect size from the novel versus familiar advantage in the current study ( $\eta^2_p = 0.162[0.010:361]$ ), was over twice that ( $\eta^2_p = 0.074[0.000:234]$ ) calculated from the results reported by Johnston et al. (1990). This suggests that the current procedure involving reducing pre-exposure generated a more robust within-array pop-out effect, as would be predicted on the basis of data from orienting response studies (Sokolov, 1963). The finding that localization performance for novel items was enhanced in both the active group and passive



**Fig. 2** Results from Experiment 1. Mean proportion of correct word localizations as a function of word position, and type of pre-exposure condition. Passive=no reading of pre-exposed words. Active=reading pre-exposed words allowed

group suggests that the process generating within-array novel pop-out are independent of the sample strategy during pre-exposure repetition. Whatever process is occurring to boost performance under conditions of active sampling, it is blind to the repetition status of the words. The overall advantage for the active group may reflect sampling differences, or the addition of a verbal code.

The only other effect of potential interest obtained is illustrated in Fig. 2. Points on the horizontal and vertical axes represent the mean probability of localization at each of the four array-positions, for both passive and active pre-exposure conditions. The spatial distribution of attention across the two pre-exposure conditions (passive versus active) was different, and there was a significant interaction between pre-exposure and word position,  $F(3,114) = 4.60, p = .004, \eta^2_p = 0.109[0.012:204]$ , although not between word-type and position, not all three factors,  $F_s < 1$ . The dominance of the horizontal axis during passive pre-exposure suggests an attentional bias to words in the array based on a left-to-right reading process, prevalent in the UK. However, the distribution of localization performance across the four possible word conditions was more symmetrical with active pre-exposure. The failure to show any significant interaction involving word type (novel versus familiar), and word position, suggests that within-array novel pop-out is independent of these changes in word position, or sampling strategy. This finding is consistent with the analysis of novel pop-out provided by Johnston and Schwarting (1997).

## Experiment 2

The second study investigated a pre-exposure effect using all-familiar and all-novel arrays, employing the same methodology for the generation of those displays as Experiment 1. Typically, it has been noted that it is easier to locate items in all-familiar fields, than in all-novel fields (e.g., Johnston et al., 1990; Johnston et al., 1993). Part of the power of this evidence stems from the fact that the all-familiar advantage in locating probe words, relative to localization of probe words in the all-novel array, is unexpected on the basis of the literature concerning the orienting response, stimulus repetition, and latent inhibition (Pearce & Hall, 1980; Sokolov, 1963). All of these literatures suggest that declining sampling should occur with repetition of a stimulus, thus, favouring localization of novel items, rather than familiar items. The all-familiar advantage obtained by Johnston et al. (1990) suggests that another factor is operating to enhance performance.

A potential candidate for such a mechanism that has been discussed in the context of novel pop-out effects, is the enhancement of the conceptual representations of expected arrays (that is, the degree to which the overall stimulus array is represented), which may inhibit representations of the individual stimuli (Houghten & Tipper, 1994; Johnston & Hawley, 1994; Vatterott & Vecera, 2012). An important variable thought to modulate the development of such conceptual-representation is the relevance of repeated objects. More specifically, it is assumed that the process will only be enhanced if the objects are continuously relevant to the subject (Davis et al., 2020; Johnston & Hawley, 1994). Consequently, if the pre-exposure is irrelevant to the task demands, as is the case with the present design, then there should be no development in the target matching process. In the context of the present experimental paradigm, this would eliminate the all-familiar advantage in probe-item localization. If the relevance of the item array is reinstated, perhaps by requiring subjects to actively sample items during pre-exposure, then the target matching process will be reinforced to produce the all-familiar advantage observed by Johnston et al. (1990).

## Method

### Subjects and Apparatus

Subjects were recruited through adverts sent through the Psychology Department subject pool. 40 subjects (24 female; 16 male; 0 nonbinary) were recruited, all between 18 and 32 years old. All were unpaid volunteers, different to the subjects in Experiments 1 and 3, naive to the purpose of the experiment, and were allocated randomly to the two groups: Passive group

( $n=20$ ; 22 female) had a mean age of  $19.06 \pm 1.38$ ; Active group ( $n=20$ ; 22 female) had a mean age of  $20.31 \pm 2.02$ . The stimuli and equipment were identical to those used in Experiment 1. From the original pool of 288 words, words were randomly allocated to one of three sets: the practise set (Set-P,  $n=48$ ; frequency =  $81.21 \pm 81.25$ , imaginability =  $5.78 \pm 1.23$ , concreteness =  $4.23 \pm 1.00$ ); the repeating set (Set-R,  $n=160$ ; frequency =  $79.87 \pm 78.77$ , imaginability =  $5.04 \pm 1.65$ , concreteness =  $4.01 \pm 1.11$ ); and the novel set (Set-N,  $n=80$ ; frequency =  $84.03 \pm 86.84$ , imaginability =  $5.11 \pm 1.11$ , concreteness =  $4.21 \pm 1.16$ ).

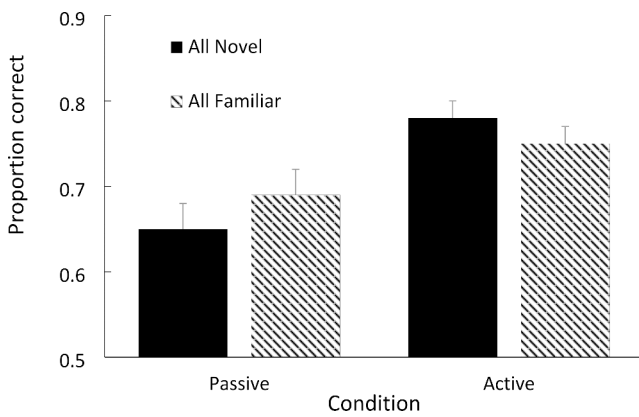
### Procedure

The experimental design was  $2 \times 2 \times 4$ , mixed-model design used in Experiment 1. The between-subject manipulation was type of pre-exposure sampling (passive versus active). The within-subject manipulations were word type (novel versus familiar), and word position in the array. 20 subjects were randomly assigned to the passive exposure group, and 20 to the active pre-exposure group. All subjects received 6 practise trials, and 40 experimental trials, as in Experiment 1, each trial was split into three segments: pre-exposure, orienting, and probe. However, in contrast to Experiment 1, the orienting displays could take one of two compositions: 4 novel words, or 4 repeated words. Presentation and probing of novel versus repeated word arrays was randomised, with a restriction that each type of array was tested on 50% of the trials. All other details of the experiment were reported as in the present Experiment 1.

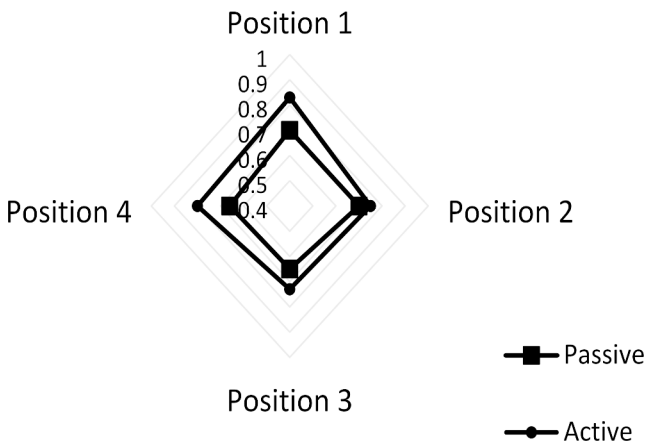
## Results and discussion

The mean proportion (standard deviation) of words localized for the pre-exposure condition (active versus passive), and word type (novel versus familiar), during probe trials are shown in Fig. 3. These data were analysed by a three-factor ANOVA (preexposure condition  $\times$  word type  $\times$  word position). Inspection of the figure reveals superior performance with active over passive pre-exposure,  $F(1,38) = 4.93$ ,  $p = .032$ ,  $\eta_p^2 = 0.114[0.000:309]$ . There was no evidence of a difference in the probability of word localization in the probe trials between the all-novel and all-familiar arrays,  $F < 1$ , and there was no statistically significant interaction between these two factors,  $F(1,38) = 1.82$ ,  $p = .185$ ,  $\eta_p^2 = 0.046[0.000:216]$ .

Thus, the modification in the manner in which words were rendered novel or familiar has eliminated the widely documented all-familiar advantage (e.g., Hawley et al., 1994; Johnston et al., 1990, 1993; Johnston & Schwarting, 1997). The failure to observe this effect is striking. It may be that the pre-exposure trials made these stimuli irrelevant



**Fig. 3** Results from Experiment 2. Mean proportion of correct word localizations, for both novel and familiar words in either an all-novel or all-familiar, for both pre-exposure conditions. Passive=no reading of pre-exposed words. Active=reading pre-exposed words allowed. Error bars = 95% confidence limits



**Fig. 4** Results from Experiment 2. Mean proportion of correct word localizations as a function of word position, and type of pre-exposure condition. Passive = no reading of pre-exposed words. Active = reading pre-exposed words aloud

to the task, and failed to promote efficiency in the development of conceptual-representation. Of course, some caution is needed before accepting this explanation, which is based on a null result. However, as in Experiment 1, an active versus passive effect was noted in this current study, showing it is a procedure capable of producing significant effects. This may be attributable to sampling differences, or the addition of a verbal code, in the active group.

The prediction that all-familiar probe word localization would improve with active pre-exposure was not supported by these results. Although there was a numerical trend towards an interaction between pre-exposure condition and word type, it is the reverse of that which is predicted. If anything, the direction of the effect suggested that all-novel localization performance is inferior with passive pre-exposure, but superior with active pre-exposure. Thus, there was no evidence for the all-familiar over all-novel

word-localization advantage, which would be seen as important, as this advantage is predicted by several models, but appears to be bounded by the precise conditions of the experiment.

Figure 4 displays the mean probability (standard deviation) of word localization during probe trials, at each of the four positions, for passive and active pre-exposure conditions. There was no evidence of positional sampling differences. This conclusion is reflected in the statistical analysis, which revealed that all main effects, and interactions, involving word position were nonsignificant, all  $F_s < 1$ . This finding contrasts with the results of Experiment 1, which illustrated a preferential sampling across the horizontal access for the array for the passive condition. This failure to replicate the effect obtained in Experiment 1 might indicate a non-equivalence of the passive versus active manipulation across the experiments. One possible explanation of this cross-experimental difference is that, in the present study, subjects were tested on two distinct array types, all-novel and all-familiar; in contrast, subjects in Experiment 1 always received the same mixed-array orienting display throughout. Whatever the explanation, it suggests that analysis of positional sampling may not add much to the understanding of this phenomenon given the variability of the results.

### Experiment 3

The previous experiments have replicated the previously questioned within-array novel pop-out effect, but they failed to replicate the all-familiar overall advantage. However, given that each of these findings has only been displayed once, it would seem prudent to replicate both effects within the same study. This would overcome the problem of interpreting a null result, as in the case of the all-familiar versus all-novel procedure (Experiment 2). A further advantage of adopting within-subject demonstration of both effects, would be that it would allow a more direct comparison between the present studies and those reported by Johnston et al. (1990), and Johnston et al. (1993).

Subjects were presented with three different types of arrays in the current study: all-novel, all-familiar, and one-novel. If the current results are replicated, there would be an advantage of the novel item, relative to the familiar items, in the one-novel array, but there would be no difference between localization accuracy in the all-familiar versus all-novel items. However, if the results reported by Johnston et al. (1990, 1993) were replicated, there will be both a within-array novel pop-out effect, and an all-familiar over all-novel advantage.

Two further modifications from the current studies were adopted. As neither Experiments 1 nor 2 showed differences between active and passive exposure, this manipulation was not included, and all displays used a passive exposure. Secondly, two groups of subjects were studied: one group received minimal levels of pre-exposure to the array used, as in the current experiments; a second group received greater levels of pre-exposure, as employed by Johnston et al. (1990). This was conducted to explore whether this manipulation was responsible for the discrepancy between the results reported by Johnston et al. (1990) and the current experiments.

## Method

### Subjects and Apparatus

Subjects were recruited through adverts sent through the Psychology Department subject pool. 40 subjects (29 female; 11 male; 0 nonbinary) were recruited. The subjects were between 18 and 32 years old, all were unpaid volunteers, no subject had served in either Experiment 1 or 2, and they were naive to the purpose of the experiment. The subjects were then randomly allocated to the two groups: Small ( $n=20$ ; 15 female) had a mean age of  $20.58 \pm 2.32$ ; Large group ( $n=20$ ; 14 female) had a mean age of  $19.56 \pm 2.32$ . The stimuli and equipment used were those in Experiment 1. From an expanded pool of word stimuli, which have the same characteristics as those described in Experiment 1, words were randomly allocated to one of five sets: the practise set (Set-P,  $n=48$ ; frequency= $80.36 \pm 78.15$ , imaginability= $5.34 \pm 1.04$ , concreteness =  $4.75 \pm 1.34$ ); the repeating set for the all-familiar array ( $n=384$ ;

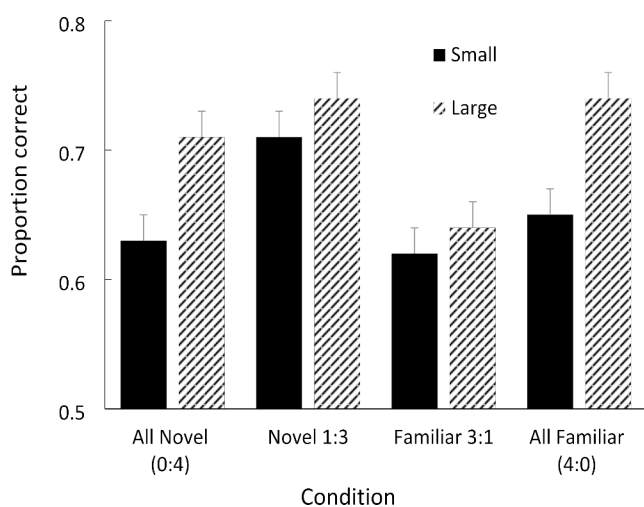
frequency= $81.14 \pm 76.76$ , imaginability= $5.03 \pm 1.01$ , concreteness= $4.98 \pm 1.24$ ); the novel set for the all-novel arrays ( $n=192$ ; frequency= $82.34 \pm 79.98$ , imaginability= $5.49 \pm 1.32$ , concreteness= $4.35 \pm 1.04$ ); the repeating set for the three-familiar array ( $n=192$ ; frequency= $79.95 \pm 84.39$ , imaginability= $5.05 \pm 1.31$ , concreteness= $4.43 \pm 1.12$ ); and the novel set for the one-novel array ( $n=48$ ; frequency= $81.26 \pm 82.43$ , imaginability= $5.54 \pm 1.36$ , concreteness= $4.37 \pm 1.64$ ).

### Procedure

The experimental design was a  $2 \times 4$ , mixed-model design: the between-subject manipulation was level of pre-exposure sampling (small versus large); and the within-subject manipulation was array type (all-novel, all-familiar, 1-novel/3-familiar; and 1-familiar/3-novel). 20 subjects were randomly assigned to the small pre-exposure group, and received between 5 and 8 repetitions of the arrays, as in Experiments 1 and 2; 20 subjects were assigned to the large pre-exposure group, and received between 15 and 20 repetitions of the arrays. All subjects received 6 practise trials, and 148 experimental trials. As in Experiment 1, each trial was split into three segments: preexposure, orienting, and probe. However, orienting displays could take one of three compositions: 4 novel words, 4 repeated words, or 1 novel and 3 repeated words. Presentation and probing of the three types of word arrays was randomised, with a restriction that each type of array was tested in similar proportion to their display. There were: 48 probes of a novel word after all-familiar pre-exposure; 48 probes of a familiar word after all-familiar arrays; 36 probes of a familiar word in the 1-novel/3-familiar condition; and 12 probes of a novel word after a 1-novel/3-familiar condition. All other details of the experiment were reported as in the present Experiment 1.

### Results and discussion

Figure 5 displays the mean (standard deviation) words localized for each group in each condition of pre-exposure condition (small versus large), and word type (novel versus familiar), for the novel and familiar words, during probe trials. These data were analysed by a two-factor, mixed-model ANOVA (pre-exposure condition  $\times$  array type). Inspection of the figure reveals superior performance with large compared to small amounts of pre-exposure,  $F(1,38)=5.68$ ,  $p=.022$ ,  $\eta_p^2=0.130[0.001:326]$ . This finding has not been demonstrated previously, but concurs with the advantage noted when each display is given a longer exposure time (cf. Johnston et al., 1993). There was a difference in the accuracy of localization of the words in the different arrays,  $F(3,114)=11.87$ ,  $p<.001$ ,  $\eta_p^2=0.238[0.100:347]$ . However, this pattern was not entirely consistent across the levels of



**Fig. 5** Results from Experiment 3. Mean proportion of correct word localizations, for both novel and familiar words in either an all-novel, all-familiar, or one-novel and three-familiar array, for both pre-exposure conditions. Small = 5–8 pre-exposures to each array. Large = 15–20 exposures to each array. Error bars = 95% confidence limits

pre-exposure, and there was a statistically significant interaction between the pre-exposure condition and array type,  $F(3,114)=3.15, p=.028, \eta^2_p = 0.077[0.000:169]$ .

To further analyse these data, the effect of array type within each group was analysed separately through a series of planned comparisons. For the group with small amounts of pre-exposure, these planned comparisons revealed no difference between the all-familiar and all-novel displays,  $t < 1$ . However, there was a within-array pop-out effect,  $t(19)=7.66, p < .001, \eta^2_p = 0.755[0.491:846]$ . These effects replicate what was apparent from the cross-experimental comparison of Experiments 1 and 2. The present design also allowed for investigation of the presence of a between-array pop-out effect reported by Johnston et al. (1990, 1993). In this effect there is an advantage for localization of a novel item in a mixed-array, compared to localization of a novel item in an all-novel array,  $t(19)=2.80, p = .011, \eta^2_p = 0.292[0.017:536]$ . However, the presence of the between-array familiar sink-in effect, when localization performance for familiar items in a mixed-array is worse than that in an all-familiar array was not found,  $p > .20$ . This was largely due to the poor performance on the localization of the familiar items in the all-familiar display.

The above pattern of statistical reliability was also found in the group that experienced large amounts of pre-exposure. Planned comparisons revealed no difference between the all-familiar and all-novel displays,  $p > .20$ , and there was a within-array pop-out effect,  $t(19)=7.96, p < .001, \eta^2_p = 0.769[0.516:855]$ . There was a marginal between array pop-out effect,  $t(19)=1.95, p = .066, \eta^2_p = 0.167[0.000:430]$ . However, in this group, there was a between-array familiar sink-in effect,  $t(19)=7.85, p < .001, \eta^2_p = 0.764[0.507:851]$ . Thus, the increase in pre-exposure was sufficient to generate an advantage in localization for familiar items in the all-familiar versus the mixed-array, but was not sufficient to replicate the all-familiar versus all-novel advantage. These data suggest that the latter effect cannot readily be obtained in the present procedure.

The present experiment replicated the results reported in the previous two experiments in the present series. The advantage for novel within-array effect was confirmed, as in Experiment 1. However, as with Experiment 2, there was no evidence for the all-familiar over the all-novel word-localization advantage. This replication was obtained despite using within-subject design, making interpretation of the null result with respect to the all-familiar versus all-novel erase, somewhat easier, given the concurrent positive results with the within-array pop-out effect. There is no evidence that increasing the level of pre-exposure led to the emergence of the all-familiar advantage. Of course, this could be due to inappropriate parameters being used, and it should be noted that Johnston et al. (1990, 1993), employed far greater

levels of pre-exposure than used in the present study. However, the current procedure was particularly long, and pilot studies revealed a rather pronounced drop in attention if the pre-exposure phase was increased much beyond the current values.

## General discussion

The current study explored the robustness of the novel pop-out effect across a number of changes in the methodology compared to the original demonstration (Johnston et al., 1990). These changes were primarily designed to assess the effect of making the items during pre-exposure irrelevant to the test demands, and altering the degree to which they were familiar, as well as addressing procedural issues noted with the original study. Not only would this allow the reliability of the effect to be established with more certainty, but also would allow easier theoretical interpretation of the results. The first experiment noted that decreasing exposure to the initial array prior to test, increased the effect size of the within-array pop-out effect. This may be due to reducing habituation to the stimuli. However, the addition of an active sampling strategy, while improving overall localisation performance, had no impact on the pop-out effect. The second experiment found that decreasing the exposure resulted in the removal of the between-array advantage for localisation after familiar- versus novel-arrays. This was consistent with the suggestion that decreasing the array exposure would pre-exposure would reduce the all-familiar advantage due to reducing the overall conceptual processing of the array. However, as with Experiment 1, although the active sampling strategy improved overall performance, it did not reinstate the pop-out effect. The final study replicated all of these effects using a different procedure for increasing and decreasing familiarity to the array items.

The novel pop-out affecting mixed-arrays, initially observed by Johnston et al. (1990, 1993), was replicated in the present Experiments 1 and 3, and was found to survive a number of methodological changes to the original study. Several of these changes were suggested by critics of the phenomena (e.g., Christie & Klein, 1995); thus, the present design presumably offers a stringent test of the effect. Firstly, the novel pop-out effect was observed with both passive viewing and active naming during pre-exposure. Secondly the pop-out effect can be observed with a small number of prior repetitions (Experiment 1), as well as a somewhat larger number of exposures, (Experiment 3). The repetition of 5–8 presentations used in the present Experiment 1, contrasts with a maximum repetition level of 96 presentations used by Johnston et al. (1990). Finally, the novel pop-out effect was observed using a procedure which did

not require the subject to memorise aspects of the targeted stimuli, such as its location, which may produce confounds in the interpretation of the results (see Christie & Klein, 1995).

Thus, the within array novel pop-out effect appears to be a robust, and replicable, phenomenon. The relative ease in obtaining this effect may reflect that the present experiments adopted procedures designed to minimise the influences that could obscure this pop-out effect. For example, the use of a task irrelevant pre-exposure technique was suggested as a possible way to minimise interference with novelty on orienting trials. Additionally, the use of non-random presentation of arrays would serve to promote familiarity by reducing any disinhibition that random exposure might produce. Although these procedural aspects were not examined experimentally, the fact that the within-array novel pop-out emerged so clearly every time it was examined, in contrast to previous reports weather phenomenon is somewhat elusive, suggests that these manipulations may have been effective.

The results of Experiments 2 and 3 suggested the baseline advantage for all-familiar arrays is not as general as has been previously assumed. This effect was eliminated when the array repetition was irrelevant to the task demands. The attempt to reintroduce relevance through active selection during pre-exposure (Experiment 2) did not prove to be effective. If anything, this manipulation reduced localization for familiar words. An alternative explanation is that there was insufficient repetition to develop the all-familiar advantage noted by Johnston et al. (1990). This was tested in Experiment 3 by increasing the level of pre-exposure, but this manipulation, too, was found to be ineffective in producing the effect. Moreover, it should be noted that a report by Johnston et al. (1993) shows that 6 prior repetitions were sufficient to elevate performance for all-familiar arrays, over that noted with all-novel arrays. In this latter study, each array presentation was probed for a response and, therefore, words were continuously relevant to the task demands. Consequently, the failure to observe an all-familiar advantage in the present Experiments 2 and 3, is still potentially attributable to the irrelevance of the pre-exposure period.

These current findings, although not specifically designed to test a particular theory, do have some theoretical implications. For example, as many of the techniques designed to reduce task relevance during pre-exposure did impact the emergence of the within-array novel pop-out effect, this factor appears important to consider. It may well be that reducing such relevance has two impacts on processing of such stimulus arrays that together or separately could impact the perceived novelty or familiarity of the items. Firstly, it may be that reducing the degree to which dishabituation or habituation occurs to the stimuli by using

non-randomised presentations, and reducing the number of presentations, has an impact on maintaining novelty. Moreover, it could be that reducing relevance prevents the development of filed-representations during pre-exposure (see Davis et al., 2020), which would increase the likelihood of individual items exerting an effect through their novelty or familiarity during test probes.

The potential influence of the task demands during pre-exposure on the emergence of pop-out, suggests that this factor should be taken into account by any model of attention. Any such model could suggest that the current activation of an object field is inhibited by repetition. With repetition, there is an increase in the negative weighting function that dampens activation to an event; the repeated event could become associated with nothing, interfering with subsequent association with something. Thus, when a novel event is presented along with repeated events, in a context where something is to be associated with those events (e.g., a location or a word), the novel event will allow easier association with the salient event, and a larger response will be observed for that novel event relative to the repeated events. Empirically, this is reflected in the superior novel word performance with mixed-arrays.

However, with respect to the all-familiar versus all-novel advantage, performance is only enhanced when the familiar events are relevant to the current task demands. In other words, the development of bias in favour of repeated events depends on whether these events match the current goal state of the subject. Associations from array items to events in the past will only produce large target responses during test, if that previously generated response is consistent with the response required during the test. If the previous repetitions of the item in the array involves some response system not engaged in the test, then this will offer no advantage of test, and may even be detrimental to performance. Thus, when an event is consistently associated with the goal state, there is a development of selection bias. Yet when an event is associated with both goal and non-goal states, little development in selection bias is observed. This proposal is compatible with the latent inhibition literature, and the consistent various effects observed in the automaticity literature (Killcross & Baleine, 1996; Reed 1995; Shiffrin & Schneider, 1977).

Establishing the nature of the novel pop-out effect, as either the result of stimulus-driven (bottom-up), or conceptual and top-down attention processes (see Christie & Klein, 1995; Diliberto et al., 1998; Horstmann, 2005; Johnston & Hawley, 1994; Vatterott & Vecera, 2012), has implications for understanding several areas of practical and real-world importance. In terms of its clinical implications, attentional effects, such as are studied in terms of novel pop-out, or through the conceptually similar latent inhibition paradigm, have been applied to understanding differences in cognitive

mechanisms between those with a clinical conditions, such as schizophrenia (Lubow et al., 1999, 2000) or Parkinson's disease (Leonard et al., 2020). Establishing the reliability of novel pop-out would allow more weight to be placed on the findings from studies with clinical populations, and to help explore the underlying nature of those conditions. In addition, novel pop-out has been suggested as a mechanism that is engaged in searching for objects in real-world environments (Sauter et al., 2020), and have confidence in its reliability can facilitate its use in such environmentally-valid paradigms.

There were a number of limitations to the current study, and associated implications for future research. For example, there was a discrepancy between the localisation performance in Experiments 1 and 2, which was attributed to procedural differences between the active and passive conditions. However, this was not directly tested, and such a finding may have implications for when the novel pop-out effect will be used if stimuli needed to be read are employed. In addition, it would be of interest to explore the use of non-word stimuli in the novel pop-out effect. All stimuli in the current study were words, and the use of pictures, or images not easily verbalised, would be of some interest. This suggestion has relevance in the context of the above mentioned ecologically valid settings, where search in environments is not typically for verbal cues. Moreover, the use of continuous pre-exposure, instead of the current discrete exposures, may also serve to enhance the ecological validity of the paradigm. Finally, a number of additional procedural aspects of the current studies were suggested as important in generating the results, such as the task irrelevant pre-exposure technique, and the use of non-random presentation of arrays. However, none of these were directly experimentally tested. Future studies might usefully address these issues.

## Conclusions

It is clear from the present series of studies that the within-array novel pop-out effect can be obtained, but that the between-array effects may well be sensitive to the task demands of the experimental context.

**Funding** This research received no funding.

**Data Availability** Data are available on request from the corresponding author.

## Compliance with Ethics Statement

**Conflict of interest** The authors have no conflicts of interest.

**Informed consent** Ethical approval was obtained from the University's Psychology Ethics Committee. All participants gave informed

consent for their participation in this study.

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