Cognition 250 (2024) 105864

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

A dissociation between the effects of expectations and attention in selective visual processing

Alon Zivony [a,*], Martin Eimer [b]

[a] Department of Psychology, University of Shefeld, Portobello, Shefeld S1 4DP, United Kingdom
[b] Department of Psychological Sciences, Birkbeck College, University of London, Malet Street, London WC1E 7HX, United Kingdom

ARTICLE INFO

Keywords:
Expectations
Prediction
Attention
Attentional engagement
Working memory
Encoding

ABSTRACT

It is often claimed that probabilistic expectations affect visual perception directly, without mediation by selective attention. However, these claims have been disputed, as effects of expectation and attention are notoriously hard to dissociate experimentally. In this study, we used a new approach to separate expectations from attention. In four experiments ($N = 60$), participants searched for a target in a rapid serial visual presentation (RSVP) stream and had to identify a digit or a letter defined by a low-level cue (colour or shape). Expectations about the target's alphanumeric category were probabilistically manipulated. Since category membership is a high-level feature and since the target was embedded among many distractors that shared its category, targets from the expected category should not attract attention more than targets from the unexpected category. In the first experiment, these targets were more likely to be identified relative to targets from the unexpected category. Importantly, in the following experiments, we also included behavioural and electrophysiological indices of attentional guidance and engagement. This allowed us to examine whether expectations also modulated these or earlier attentional processes. Results showed that category-based expectations had no modulatory effects on attention, and only affected processing at later encoding-related stages. Alternative interpretation of expectation effects in terms of repetition priming or response bias were also ruled out. These observations provide new evidence for direct attention-independent expectation effects on perception. We suggest that expectations can adjust the threshold required for encoding expectations-congruent information, thereby affecting the speed with which target objects are encoded in working memory.

For humans to navigate the world, our perceptual system needs to perform an amazing feat. It has to take sensory information from an abundant, complex, ambiguous, and dynamic environment and transform it into manageable events that can flexibly guide our behaviour. One way the perceptual system achieves this feat is by relying on foreknowledge about the world and about whatever task is at hand. For example, when searching for our keys in a cluttered apartment, knowing the colour of the attached keychain allows us to focus only on specific objects and ignore others. This is an illustration of how top-down knowledge can help guide our attention, a topic of voluminous amount of research (see e.g., Luck et al., 2021 for review). Recently, there has been growing in how predictions about probable world states affect the decoding of ambiguous information from the environment. Specifically, it has been suggested that probabilistic expectations constrain interpretation of events, such that expected events are identified more readily (Summerfield & Egner, 2009). For example, according to this view, our keys are more likely to be recognized when they are where we usually leave them (e.g., near the door) than when they are in an unexpected location (e.g., on the floor).

A major challenge in studying the effects of expectations on perception is separating them from selective attentional effects. In many cases, expectation effects are (at least partially) mediated by attention. For example, foreknowledge about where our keys are likely to be found allows us to prioritize and focus spatial attention on these locations, thereby increasing the chance of a successful search. Another illustration for such mediation by attention is the well-studied phenomenon of inattentional blindness (IB; e.g., Simons & Chabris, 1999; Rock et al., 1992). In IB, unexpected but easily noticeable objects escape awareness when observers engage in a demanding primary task. According to the most common interpretation of IB, the reason that the unexpected object is rendered invisible is because it is unattended (Jensen et al., 2011). Once you know what to expect, the same object will attract attention,

* Corresponding author at: Department of Psychology, University of Shefeld, Portobello, Shefeld S1 4DP, United Kingdom.
E-mail address: a.zivony@sheffield.ac.uk (A. Zivony).

https://doi.org/10.1016/j.cognition.2024.105864
Received 29 July 2023; Received in revised form 31 May 2024; Accepted 13 June 2024
Available online 20 June 2024

making it nearly impossible to miss. Thus, the effects of attention and expectation on visual perception are hard to distinguish, especially when they produce similar outcomes, such as improving the detectability of visual objects. One possibility is that attentional effects and expectation effects on perception cannot be dissociated at all, because effects of expectation are *always* mediated by selective attention. Alternatively, it is possible that there are situations where expectation affects perception directly, without any involvement of attention.

To test these two alternatives experimentally, methods are required that allow for the separation of expectation and attention effects on visual perception. According to one commonly used approach (Summerfield & Egner, 2009, 2016), expectations should be operationalized by manipulating the probability of visual objects within a given task context. In contrast, attention should be operationalized by manipulating the relevance of these objects for this task. If these two factors can be manipulated orthogonally, it should be possible to reveal expectation effects that are independent from attention. For example, in Kok et al. (2012), participants were presented sequentially with two gratings and had to make a judgement about their orientation or their contrast. The two gratings were more likely to be tilted to one side, making the expected orientation relevant for one task but irrelevant for the other. The results suggested that expectations about the stimuli's orientation improved their representation in the visual cortex, as revealed by decoding methods. Importantly, this effect was not modulated by object relevance, which the authors took to indicate that it was independent of attention.

While this general approach has become widely used, it has also faced important criticisms. Empirically, there are some studies that showed expectation effects emerging independently from the relevance manipulation (Wyart et al., 2012; Yon et al., 2018; Zuanazzi & Noppeney, 2019). Conversely, others found that processing differences between expected and unexpected features are amplified for relevant stimuli (Jiang et al., 2013; Smout et al., 2019; Zhou et al., 2022), indicating that some expectation effects are mediated by attention. Such variability in outcomes suggests that there are multiple pathways through which expectations can affect perception. However, this variability does not provide strong evidence in favour of the claim that expectation effects are *necessarily* mediated by attention. Importantly, there are also conceptual issues that cast serious doubt on the ability of orthogonal manipulations of probability and relevance to dissociate the effects of attention and expectation even in cases where relevance and probability produce independent effects. First, while relevance is obviously an important factor in determining what is attended, it is well known that objects with salient features can capture attention even when they are entirely irrelevant to the task at hand (e.g., Gaspelin et al., 2016; Zivony & Lamy, 2018). Thus, attentional selection processes are not always driven exclusively by relevance. This is important for the study of expectation-attention links, as the manipulation of the probability of target-defining features may also change their saliency (Alink & Blank, 2021). If this is the case, some expectation-induced modulations of perception may actually be mediated indirectly by saliency-driven attentional capture. Second, changing the probability of objects may also affect attention directly, by modulating their relevance (Rungratsameetaweemana & Serences, 2019). This would also challenge previous attempts to manipulate these factors orthogonally. If likely and therefore expected objects are considered to be more relevant to the task at hand, this can result in preferential attentional guidance towards them. Such modulations would not necessarily be the result of any conscious strategies. Instead, they may reflect stronger activation of expected relative to unexpected features in the observers' search template, which controls the allocation of attention during visual search. Some evidence in favour of this last claim comes from a study by Rungratsameetaweemana et al. (2018), who found that when expectations provide no task-relevant information, they only affected late decision-making processes, but not earlier visual processing.

The goal of the present study was to introduce a new approach and use new procedures to reveal the presence of direct attention-independent expectation effects on visual perception. To reduce the possibility of indirect attention-mediated expectation effects (i.e., when changes in the probability of target-defining features change their salience or relevance), it is useful to manipulate the probability of features that are less likely to attract attention, and to employ procedures where these features cannot be used to distinguish target and non-target objects. To ascertain whether an expectation effect is mediated by attention (i.e., through expectations changing the relevance or salience of particular objects), it is important to include independent measurements of known indices of attentional processing. We adopted both approaches in the present experiments.

1. The current study

So far, most studies of links between expectation and perception have varied expectations regarding low-level features, such as the colour, orientation, or spatial location of visual objects. This approach is reasonable from a neuroscientific perspective as the processing of these features is more easily decodable from neural signals. However, this method is vulnerable to the problems noted earlier: manipulating the probability of such low-level features may also affect their bottom-up saliency or their relevance, thereby resulting in an increased tendency for attention to be guided towards them. One way to tackle this issue is to create an experimental context where the expected features exert no control over attentional allocation.

It is well established in attention research that not all features are equally effective in guiding attention, even when their task relevance is the same. Observers are highly efficient in tuning their attention to low-level features, but not to complex (high-level) features (Wolfe & Horowitz, 2017). For example, when searching for a grey digit, both the low-level feature "grey" and the high-level feature "digit" are equally relevant in defining the target, but they are not equally likely to attract attention. This is illustrated in Fig. 1, where search for a grey digit is easy when the target colour is unique (in this case, the target "pops out"), but much harder when its category is unique. Meanwhile, an irrelevant letter ("L") in Fig. 1B is detected immediately when it is surrounded by a salient-yet-irrelevant shape. Thus, the problem that differences in the probability of particular features can modulate their salience or relevance and thus their ability to attract attention should be less severe when probability is manipulated with regards to high-level features, such as alphanumerical category. However, even though high-probability high-level features may be *less* likely to attract attention, they may still do so to some degree. Previous work has demonstrated effective attentional guidance and attentional capture by a relevant alphanumeric category (Baier & Ansorge, 2019; Nako et al., 2014). Many RSVP studies (e.g., Potter et al., 1998) have also shown that observers are remarkably efficient in detecting and identifying target objects defined by an alphanumeric category (e.g., a digit among a series of letters). Importantly, in all of these studies, the selection of targets had to be guided by their category, since the category was the sole attribute that distinguished targets from nontarget objects.

In the present study, we therefore manipulated the probability of the alphanumeric category of target objects (letters versus digits) but ensured that observers can't use this feature to guide their attention to the target. First, we used a design where targets were defined by a different, low-level, feature. Participants were presented with rapid serial visual presentation (RSVP) streams including letters and digits and had to report target objects that were defined by an outline circle surrounding the target (see Fig. 3). In any given block of trials, the target was more likely to be a letter than a digit, or vice versa. Because targets were defined by the easily detectable outline shape, there was no longer any need to rely on the target's category to guide attention, in contrast to previous studies that have demonstrated category-based attentional guidance (e.g., Baier & Ansorge, 2019; Nako et al., 2014; Potter et al., 1998). Second, and importantly, the distractors that preceded the target

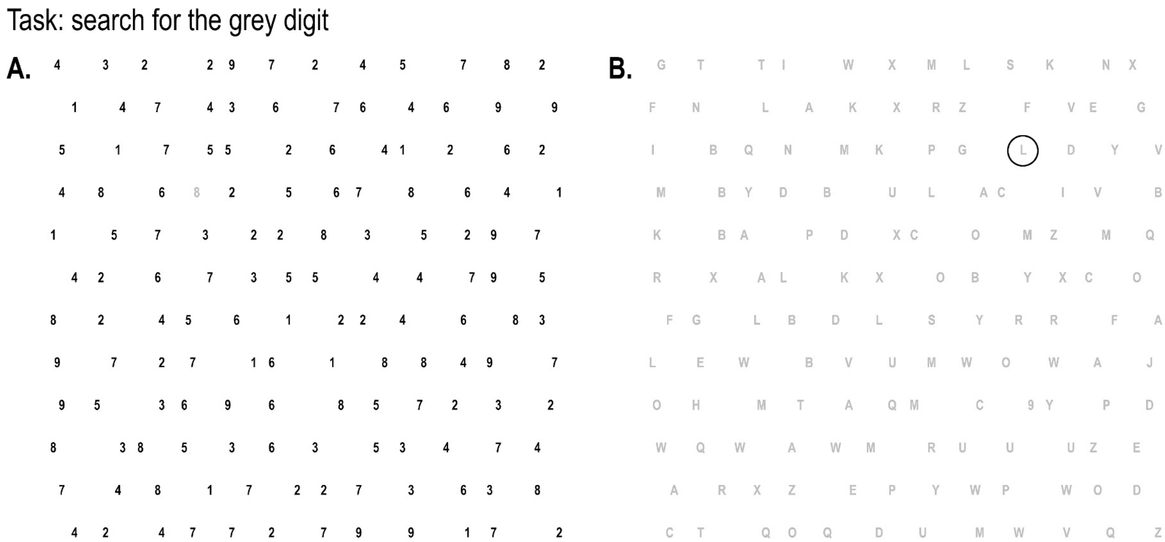

Fig. 1. Illustration of two visual search tasks for a grey digit, differing in search difficulty, demonstrating the limitation of equating attention and relevance. The target appears in the upper-left quadrant of search A (8) and lower-right quadrant of search B (9). Search A is easy because the target differs from distractors based on a low-level feature (colour). Search B is difficult because the target differs from distractors based on a high-level feature (alphanumeric category). Meanwhile, the salient shape in search B (a black circle) captures attention even though it is irrelevant.

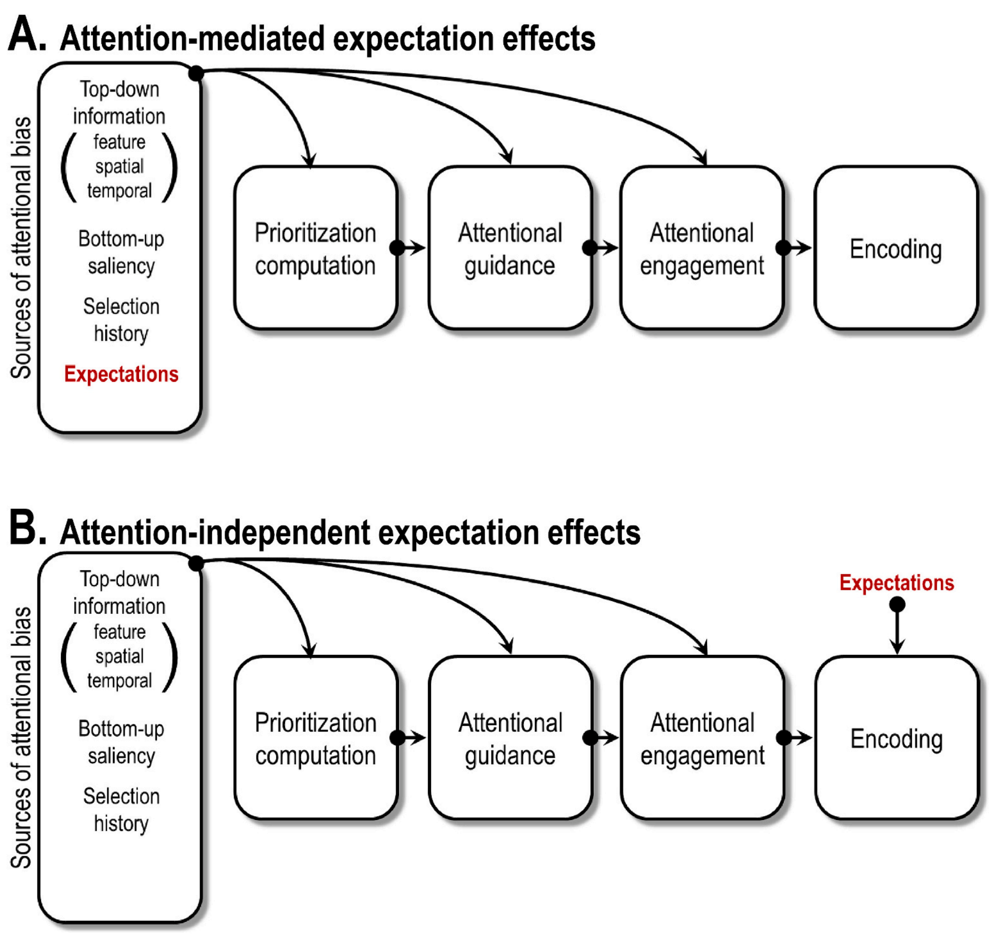

Fig. 2. Architecture of parallel and serial attention mechanisms and the potential role of expectations. Early mechanisms of attention operate in parallel to bias prioritization computations. These mechanisms affect later serial attentional mechanisms (guidance and engagement), which eventually result in the encoding of specific objects. According to one hypothesis (A), expectations affect perception indirectly, by biasing these attentional mechanisms. In contrast, it is possible that under certain conditions, expectations may also affect encoding directly, that is, independently of attention (B).

were equally likely to be digits or letters, regardless of whether targets were more likely to be digits or letters, and irrespective of the actual target category on a particular trial. As a result, the target's category was no longer helpful to distinguish targets from distractors, and should therefore play no role in the guidance of attention. Therefore, we reasoned that even if expected features are more relevant or salient in an abstract sense, they are nevertheless unlikely to automatically capture attention.

The second key feature of the current study is the inclusion of direct measures of attentional processing, which allowed us to empirically test whether our expectation manipulation affected attention. Such measures should be affected by the expectation manipulation if observed expectation effects on perception are attention-mediated. However, the question remains which direct measures of attentional processing should be employed to demonstrate this. The term 'attention' does not refer to a unitary mechanism, but to a diverse set of processes that result in the selective modulation of visual processing (e.g., Petersen & Posner, 2012), and this provides a conceptual challenge for the study of links between attention and expectation. Demonstrating the independence of expectation from one type of attentional mechanism (e.g., feature-based attention, exogenous attention) does not imply independence from other types of attention (e.g., spatial attention, endogenous attention). This problem can be resolved by drawing on the well-established architecture of the attentional selection process (Fig. 2). According to contemporary models of attention, early attentional processes that result in the guidance of attention towards particular objects can operate in parallel, whereas later attentional processes that result in the identification and encoding of these objects emerge sequentially (Eimer, 2014; Itti & Koch, 2001; Treisman, 2014; Wolfe, 2021; Wyble et al., 2011). Attentional guidance is determined by an object's priority that is computed based on (top-down) relevance, (bottom-up) salience, and/or previous selection history (Luck et al., 2021). Once attention is guided towards the location of a prioritized object, a period of *attentional engagement* substantially increases the likelihood that objects and object features at this location will be encoded into working memory (Zivony & Lamy, 2018). Critically, because attentional guidance and engagement reflect the tail end of attentional processing prior to encoding (Fig. 2), any manipulation that affects early attentional mechanisms or attentional priority should also have a measurable effect on guidance and engagement. Coupling manipulations of expectation with independent measurements of attentional guidance and engagement should therefore be able to reveal whether expectation effects are mediated by attention in a given experimental setting. If expectations affect an object's prioritization, whether endogenously or exogenously, whether by modulating its salience or relevance, this should be reflected by expectation-induced effects on guidance and engagement. It follows then that a reliable demonstration of the absence of such effects indicates that expectation effects on perception can emerge without a corresponding modulation of either early or late attentional processes.

Following this rationale, we present experiments where expectation effects on encoding are accompanied by measurement of different indices of attentional guidance (Experiment 2) and engagement (Experiment 3 and 4). If expectation effects are mediated by attention (Fig. 2A), these measures should be affected by the expectation manipulation. In contrast, if these measures remain unaffected by the expectation manipulation, this suggests that expectations can affect encoding independently of attention, at a late stage that follows guidance and engagement (Fig. 2B).

In Experiment 1, we examined whether alphanumerical expectations affect identification accuracy in an RSVP task. We previously demonstrated the existence of such effects in an IB-like paradigm, where the main measure was accuracy on a single surprise trial (Zivony and Eimer, 2022a). Here, our goal was to obtain independent markers of attention that need to be measured across multiple trials, thus ruling out such a single-trial design. Therefore, expectations regarding the targets' alphanumeric category were manipulated probabilistically in the current study, and the goal of Experiment 1 was to demonstrate that such a manipulation would still produce reliable behavioural effects. In Experiments 2–4, we employed similar RSVP procedures and probability manipulations as in Experiment 1, except that we now presented the target among two or three RSVP streams. In Experiment 2, the target location was unpredictable, so that spatial attention needed to be newly allocated to the target object on each trial. This allowed us to test whether expectations effects on perception are dependent on prior shifts of spatial attention, and whether attentional capture triggered by salient (yet completely task-irrelevant) spatial cues are modulated by category-based expectations. In Experiment 3, we tested whether these expectations have any effect on attentional engagement (as reflected by the attentional blink). In Experiment 4, we also measured electrophysiological markers of engagement (the N2pc component) and the subsequent encoding of target objects in working memory.

To preview the results, targets from the more likely (expected) alphanumeric category were identified more successfully than targets from the unexpected category in all four experiments, demonstrating robust effects of category-level expectations on visual perception. In marked contrast, behavioural markers of spatial attention shifts and attentional engagement, as well as event-related potential (ERP) markers of engagement, were entirely unaffected by these expectations. At the same time, the ERP results of Experiment 4 revealed the clear link between expectations and working memory encoding.

2. Experiment 1

In Experiment 1, procedures were similar to our earlier study (Zivony and Eimer, 2022a). Observers reported the identity of a target letter or digit that was indicated by a shape cue (a circle) within an RSVP stream of other letters and digits (Fig. 3A). In our earlier study, the target category repeated for 19 trials and switched only on the 20th trial. This makes it possible that the repeated exposure to multiple targets of the same alphanumerical category might have resulted in a residual attentional bias towards this category. In contrast, in the current experiment, targets on a given block were either more likely to be letters than digits (75% versus 25%), or vice versa. The critical question was whether this probabilistic manipulation of expectation would result in differential effects on target report accuracy.

Stimuli were drawn from a set of 24 letters and 8 digits. Thus, in blocks where letter targets were more frequent, the probability that any individual letter will be the target on a given trial was equal to the probability that any individual digit will be the target. This fact allowed us to confirm that any expectation-related effects were indeed related to an entire alphanumeric category, or were instead associated with individual exemplars within each category. If expectations were exemplar-based, any differential effects should only emerge in expect-digits block, and not the expect-letters block. If they were category-based, they should be present in both types of blocks.

2.1. Method

All methods used in this experiment, and subsequent experiments, were approved by the institution's departmental ethical guidelines committee at Birkbeck, University of London.

2.1.1. Sample size selection

Because this is the first study that compared between the effect of expected target's alphanumeric category on average accuracy, we could not conduct a power analysis based on previous results from similar experiments to justify our sample size. Therefore, we treated Experiment 1 as an exploratory study. The results of this study were then used to determine the appropriate sample size for the following experiments. In line with previous experiments in our lab using similar paradigms, we selected a sample size of $N = 15$, which is sufficient for detecting an effect size of $d_z = 0.7$ with 80% power in a repeated measures design.

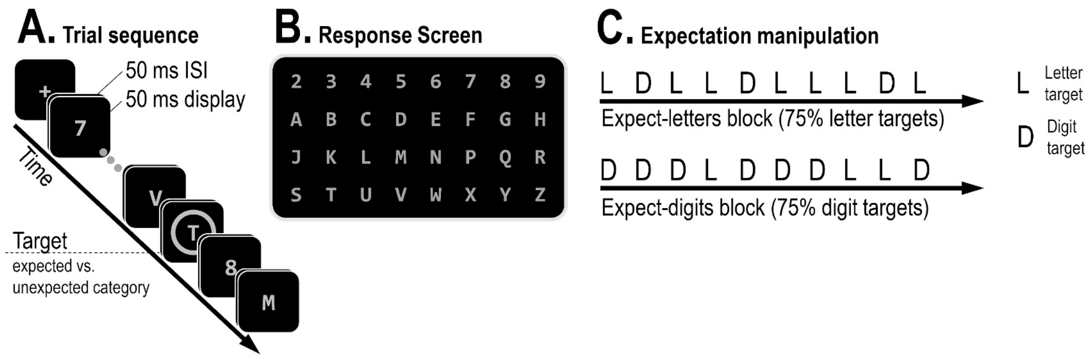

Fig. 3. Illustration of the experimental paradigm used in Experiment 1. Participants had to find a target character inside a circle (A), embedded in an RSVP stream of grey digits and letters, and report its identity (B). The target was either a letter or a digit. Expectations about the target's category were manipulated between blocks (C). On expect-letters blocks, the target was a letter on 75% of the trials and a digit on the rest. On expect-digits block this ratio was reversed.

2.2. Participants

Participants were 15 (9 women) volunteers (*Mage* = 26.8, *SD* = 6.6) who participated for £5 or course credits. All reported normal or corrected-to-normal visual acuity and normal colour vision. Participants were given the option to report gender identities other than woman or man. In this experiment and all subsequent experiments, these options were not selected. No other demographic information was collected.

2.2.1. Apparatus

Stimuli were presented on a 24-in. BenQ LED monitor (120 Hz; 1920 × 1080 screen resolution) attached to a SilverStone PC, with participant viewing distance at approximately 80 cm. Manual responses were registered via a standard mouse.

2.3. Design

Participants had to report as accurately as possible the identity of an alphanumeric character that appeared inside a (0.8° radius) circle cue (selection feature). These targets were presented unpredictably in an RSVP stream that appeared in the centre of the screen. Manual responses were executed without time pressure at the end of each trial. The sequence of events is illustrated in Fig. 3. Each trial began with the presentation of a fixation display (a grey 0.2° × 0.2° "+" sign at the centre of the screen). Then, after 500 ms, the RSVP stream appeared. Each frame appeared for 50 ms, followed by an ISI of 50 ms. The target appeared with equal probability and unpredictably in the 6th, 8th, 10th, or 12th frame within the RSVP stream and was followed by two additional distractors. Therefore, the length of the RSVP was between 8 and 14 frames. All characters in the RSVP streams were randomly selected without replacement from a 24-letter set (all English alphabet letters, excluding I and O) and a set of 8 digits (2–9), with the restriction that letters and digits appeared equally often.

The response screen included all the possible responses (all alphanumeric characters except for "0", "1", "I", and "O") organized in four rows and eight columns (see Fig. 3B). The centre-to-centre distance between characters was 2.4° horizontally and 3.2° vertically. Participants used the mouse to select one of the characters, by pressing on an area within an invisible 0.8° × 1.0° rectangle around a character. Once pressed, a (0.8° radius) circle appeared for 200 ms around the selected character to provide participants with visual feedback that their response was registered. Following feedback, a blank screen appeared for 800 ms before a new trial started.

The experiment included 10 practice trials followed by 360 experimental trials, divided into 60-trial blocks. The critical manipulation concerned the frequency of digit targets and letter targets in any given block. In Expect-digits blocks, the target was a digit on 75% of the trials and a letter on 25% of the trials. In Expect-letters blocks, the target was a letter on 75% of the trials and a digit on 25% of the trials. Given the set size of possible digits and letters used in this experiment (8 digits, 24 letters), this meant that the likelihood that a specific digit (e.g., "8") would be the target on a given trial was 9.375% in Expect-digits blocks and 3.125% in Expect-letters blocks. The likelihood that a specific letter (e.g., "Z") would be the target on a given trial was 3.125% in Expect-letters blocks and 1.04% in Expect-digits blocks. Participants were told whether the target was more likely to be a digit or a letter in a given block, but were not informed about the exact proportion of these two types of trials. In all blocks, digit targets and letter targets were presented in random order. For half of the participants, the first 3 blocks were Expect-digits blocks, and the rest were Expect-letters blocks. For the rest of the participants this order was reversed.

2.3.1. Stimuli

All stimuli in the RSVP streams were grey (CIE colour coordinates: 0.309/0.332, luminance 46.6 cd/m^2). Alphanumeric characters were all 1.3° in height. The selection cue was 0.8° in radius and 4-pixel in line width.

2.3.2. Open data

All the data and materials necessary to reproduce the experiment and analyses are available online at: https://doi.org/10.6084/m9.figshare.21805989. None of the study's analyses were preregistered.

2.4. Results

Preliminary analysis revealed that in this and the following experiments, expectation effects were not modulated by whether participants were first introduced to expect-digits blocks or expect-letters blocks. Therefore, all data was collapsed across this factor and was not included in any of the analyses reported here.

Accuracy was higher when the target was from the expected category relative to the unexpected category (Fig. 4A), and this was true for both alphanumeric categories. The expectation effect was nevertheless larger when the target was a digit than when the target was a letter ($\overline{d} = 16.1\%$ vs. $\overline{d} = 8.2\%$). These observations were all confirmed by entering accuracy rates to an ANOVA with target condition (expected vs. unexpected) and alphanumeric category as factors. The two main effects were significant, both $ps < 0.01$, and so was the interaction between the two factors, $F(1,14) = 4.69$, $p = .048$, $\eta_p^2 = 0.25$. Importantly, the effect of expectation was significant for both digit targets, $F(1,14) = 19.37$, $p < .001$, $\eta_p^2 = 0.58$, and letter targets, $F(1,14) = 12.26$, $p = .004$, $\eta_p^2 = 0.47$.

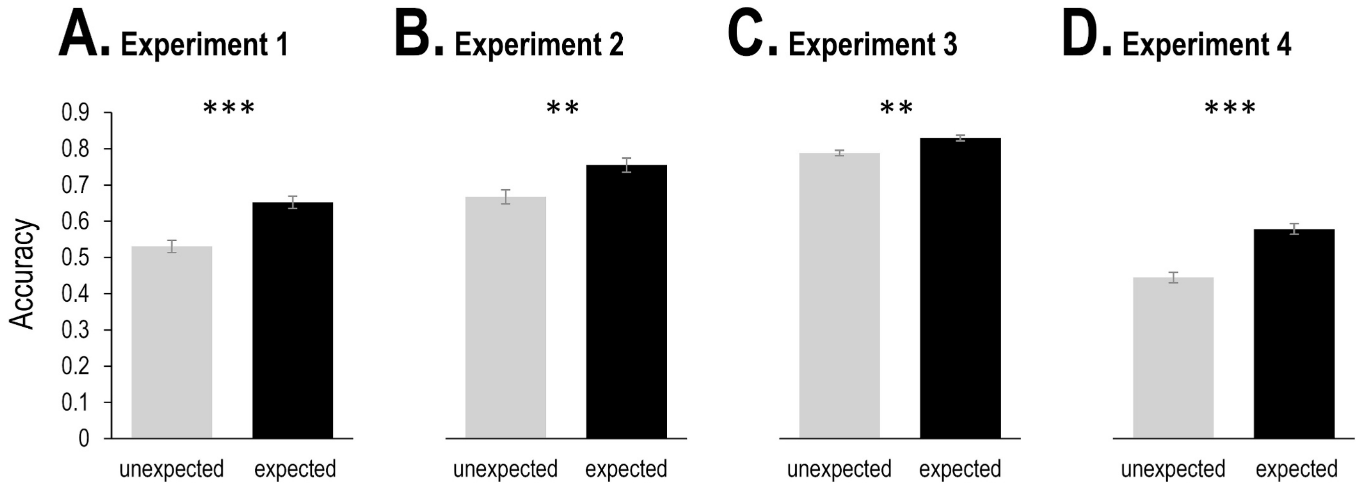

Fig. 4. Mean accuracy in Experiments 1–4 as a function of target category condition (expected vs. unexpected). Error bars reflect one within-subject standard error. *Note.* ** $p < .01$, *** $p < .001$.

2.5. Discussion

A target from an expected category was more likely to be correctly reported than a target from an unexpected category. This demonstrates that this expectation effect is not restricted to situations where the unexpected target category is encountered for the first time after a long series of trials with targets in the other category (Zivony and Eimer, 2022a), but also when exemplars from the less likely category are encountered regularly throughout each block. Importantly, this expectation effect was observed both in expect-letters and in expect-digits blocks (Table 1), a pattern that emerged in all the following experiments as well (see Supplementary Analysis 1). This result shows that participants' expectation was indeed defined at the category level rather than linked to the probability of individual exemplars within each category. However, the observation that this effect was larger for digits suggests that some exemplar-based expectations may also have affected performance to some degree.

It should be noted that due to probabilistic manipulation of target categories employed in Experiment 1, alternative interpretations of these results in terms of differential repetition priming or differential response bias cannot be ruled out entirely. This will be addressed in the General Discussion, based on additional analyses of data collected across all four experiments (as reported in the Supplementary File).

3. Experiment 2

The results observed in Experiment 1 (and in Zivony and Eimer, 2022a) suggest that expectations can affect perception. However, due to the absence of a separate measure of attention in these experiments, it remains unclear whether these expectation effects emerge independently from attention or whether they are mediated by attention. In Experiment 2, we included such a measure, based on a classic procedure to exogenously manipulate the focus of spatial attention (spatial cueing; Posner, 1980). The task was similar to Experiment 1, except that letter or digit targets now appeared unpredictably in one of two lateralised RSVP streams and was indicated by their colour (red). The probability of letter versus digit targets in each block was manipulated in the same way as in Experiment 1. Importantly, in the frame prior to the target, an irrelevant and spatially non-informative cue (a grey circle) appeared in one of the two streams (Fig. 5A). This allowed us to compute whether the target was more likely to be detected and identified when it appeared in the cued position relative to the uncued position (a location benefit).

While it is often assumed that location benefits in spatial cueing paradigms always reflect an effect of spatial attention on visual perception, it has also been suggested that spatial cueing may also affect the speed of post-perceptual decision-related processes (Eckstein et al., 2013). Therefore, we examined how cueing affects report accuracy (and not reaction times) in Experiment 2, in order to unambiguously measure modulations of target perception and encoding. As cues were spatially non-informative regarding the target's location, any location benefits observed for these cues could not reflect an expectation-based effect (unlike predictive/informative cues, see, e.g., Rungratsameetaweemana & Serences, 2019), but instead can only reflect attentional capture.

The critical question was whether this cueing effect would interact with the effect of category-based expectation (i.e., higher accuracy for targets in the expected category). This should be the case if expectation effects are mediated by attention. If target objects in the expected category attract attention, then triggering an exogenous shift of attention to the target location prior to the presentation of this target should reduce (or even eliminate) the benefit produced by expected targets (relative to when attention is focused on the target's location). As a result, expectation effect should be smaller for cued targets as compared to uncued targets. In contrast, if expectation effects are independent of the deployment of spatial attention, no such interaction should be observed. Instead, the effects of expectation and exogeneous attentional capture should be fully additive.

Finally, we also examined whether the spatial cuing effect is modulated by the type of distractor character that appears inside the spatial cue. We reasoned that if objects from the expected alphanumeric category are prioritized, whether due to bottom-up saliency or top-down relevance, this priority signal will add to the bottom-up priority signal produced by the irrelevant cue (Lamy et al., 2004; Luck et al., 2021). As a result, the likelihood for attentional capture (and therefore the size of the cueing effect) by a cue containing a distractor from the expected alphanumeric category should be greater than capture by a cue containing a distractor from the unexpected category. In contrast, if the

Table 1
Accuracy Target category, and Expectation (target category expected versus unexpected) in all four experiments.

Experiment	Target Category	Expected	Unexpected
1	Digit	62.5%	46.3%
	Letter	67.9%	59.7%
2	Digit	76.5%	67.6%
	Letter	74.5%	65.9%
3	Digit	85.3%	80.0%
	Letter	80.6%	77.7%
4	Digit	53.5%	39.2%
	Letter	59.5%	51.4%

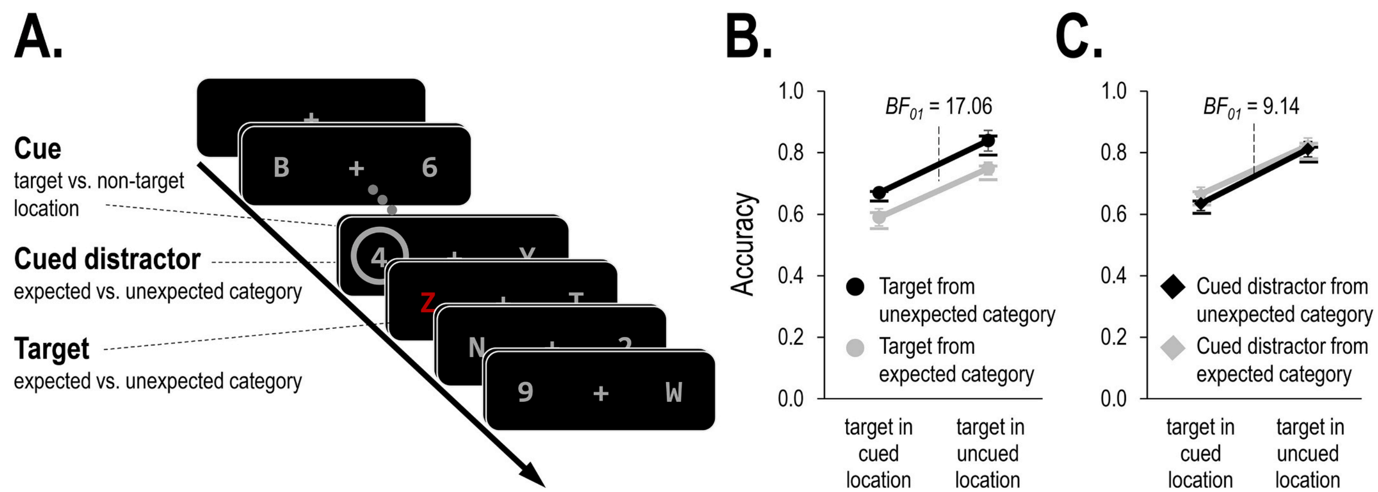

Fig. 5. Illustration of the experimental paradigm used in Experiment 2 (A) and the resulting accuracy data (B & C). A: Participants had to identify the red character, which was preceded by an irrelevant circle that appeared in the target's location (cued condition) or the non-target location (uncued condition). B: Mean accuracy as a function of target category (expected vs. unexpected) and target location relative to the cue (cued location vs. uncued location). The results indicate that the expectation effect was not modulated by cueing. C: Mean accuracy as a function of the category of the distractor inside the cue and target location relative to the cue. The results indicate that the cuing effect was not modulated by the distractor's category. BFs refer to the Bayes Factor associated with the interaction term. Error bars reflect one within-subject standard error. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

alphanumeric category affects perception directly without modulating attention, then no difference should emerge between the two conditions.

3.1. Method

3.1.1. Sample size selection

We used a power analysis to determine the sample size required to replicate the expectation effect observed in Experiment 1. To do so, we input the effect size of the expectation effect across alphanumeric category ($d_z = 1.28$) and calculated the required sample to achieve 80% power using G*power (Faul et al., 2013). This analysis suggested that a sample size of 6 participants is required. Nevertheless, given the changes to Experiment 2 and to allow for a better comparison between the two experiments, we once again used a sample size of $N = 15$ which allowed for the detection of smaller effect sizes.

3.2. Participants

Participants were 15 (7 women) volunteers ($Mage = 37.0$, $SD = 12.2$) who participated for £8. All reported normal or corrected-to-normal visual acuity and normal colour vision.

3.2.1. Apparatus, design, and stimuli

The apparatus, design, and stimuli were all identical to Experiment 1, except for the following changes (Fig. 5A). The target was defined as the red (CIE colour coordinates: 0. 629/0.333, luminance 47.2 cd/m^2) alphanumeric character. It was embedded among two RSVP streams that appeared 4.5° to the left and right of fixation. The target was equally likely to appear in the left or right RSVP stream, and all other items in the streams were grey. Each RSVP stream contained an equal number of letters and digits that were randomly selected with replacement from the stimulus set described in Experiment 1. The sole restriction was that the same stimulus could not appear on both RSVP streams on the same frame. The frame immediately prior to the target always included a grey circle cue (0.8° radius) that was equally likely to appear in the left or right RSVP stream and was equally likely to appear in the same location as the target or in the alternative location. Participants were informed about the possible appearance of the cue and that it was unpredictive of target location (and could therefore be ignored).

3.3. Statistical analysis

Some tests reported in this experiment and the following experiments includes the interpretation of null results. Therefore, statistical tests with theoretically important non-significant results were supplemented with a corresponding calculation of a Bayes Factor in favour of the null hypothesis (BF_{01}). All tests were conducted using the anovaBF and lmBF functions from the BayesFactor package in R (Morey et al., 2018). As recommended by van Doorn et al. (2023), we used the "maximal" model (i.e., the model that both participant intercepts and effect slopes as random effects) to evaluate our effects, although all the results were comparable when only participant intercepts were included as random factors. Bayes Factors associated with a two-way interaction were calculated by dividing two Bayes Factors: (*i*) the Bayes Factor associated with the full model, and (*ii*) the Bayes Factor associated with the model that includes only the two main effects. Since we had no a-priori expectations regarding these effects, we used the default medium prior ($r = 0.50$), yet in all experiments, we obtained similar results with wider priors ($r = 0.707$ or $r = 1.0$). We consider a BF_{01} to provide evidence for the null hypothesis if it is larger than 3 (i.e., $BF_{10} < 0.33$) and substantial evidence if it is larger than 10. These measures mean that given the data, we should update our belief (relative to our prior belief) in favour of the null hypothesis by a factor of 3 or 10, respectively.

3.4. Results

Preliminary analysis revealed that in this and all following experiments, the alphanumeric category of the target did not modulate attention indices, nor did it modulate any interactions between the expectation manipulation and attention indices (all $ps > 0.20$). Therefore, for sake of brevity, we collapsed all the analyses across these conditions.

Accuracy was higher for expected targets than unexpected targets ($M = 75.4\%$ vs. $M = 66.9\%$; Fig. 3B) and for targets that appeared in the cued location relative to targets that appeared in the uncued location ($M = 79.4\%$ vs. $M = 63.0\%$). Importantly, as can be seen from Fig. 5B, the two effects were completely additive. To test these observations, we entered accuracy rates to an ANOVA with target condition (expected vs. unexpected) and the target's location relative to the cue (cued vs. uncued location) as factors. The two main effects were significant, $F(1,14) = 9.67$, $p = .008$, $\eta_p^2 = 0.41$, and $F(1,14) = 26.24$, $p < .001$, $\eta_p^2 = 0.65$, respectively. In contrast, the interaction between the two factors was not significant, $F < 1$, $BF_{01} = 17.06$.

Next, we examined whether spatial cuing was dependent on the type of distractor that was inside the cue. For this analysis we collapsed the data across target category. Cuing effects were observed whether the distractor inside the cue was from the expected or unexpected alphanumeric category. Importantly, as can be seen from Fig. 5C, the distractor's category did not modulate the cuing effect. To test this observation, we entered accuracy rates to an ANOVA with cued distractor condition (expected category vs. unexpected category) and the target's location relative to the cue (cued vs. uncued location) as factors. The interaction between the two factors was not significant, $F < 1$, $BF_{01} = 9.14$.

3.5. Discussion

In Experiment 2, an irrelevant cue presented prior to the target display captured attention exogenously, as reflected by better performance for targets at cued as compared to uncued locations. The critical question was whether cuing would modulate the expectation effect on perception, as would be predicted if expectation effects were mediated by attention (e.g., by improved attentional guidance). The results demonstrated that this was not the case, as the spatial cuing effect and the expectation effect were entirely additive. Moreover, we examined whether the category of the distractor that appeared inside the cue would modulate the likelihood that it will capture attention, which would indicate that expected categories were attentionally prioritized (either due to modulation of relevance or salience). Here too we found evidence against this possibility. These finding provide strong support for the hypothesis that expectation-induced modulations of perceptual processing are not linked to changes in guidance or the deployment of spatial attention. Instead, they suggest that the expectations regarding the target's category in our experimental paradigm do not increase the attentional priority of objects from the expected category.

Nevertheless, one explanation was not conclusively addressed by Experiment 2. It is possible that while categorical expectations did not modulate attentional guidance, they did modulate the speed or efficiency of attentional engagement. Guidance and engagement are closely associated processes, but they are not one and the same, and can be dissociated in various ways. For example, when the target is defined using a specific feature, abrupt onsets that are entirely irrelevant to the task at hand are thought to guide attention but not engage attention (Maxwell et al., 2021; Zivony & Lamy, 2018). Moreover, some manipulations that affect attentional engagement do not affect attentional guidance (Zivony et al., 2018). Therefore, in Experiment 3, we examined whether categorical expectations modulate a well-known measure of attentional engagement: the attentional blink.

4. Experiment 3

The attentional blink (AB) refers to the well-established phenomenon whereby the identification of the second of two targets in an RSVP is disrupted when they appear in close succession (between 200 and 500 ms) relative to when they appear farther apart (>600 ms). While the standard AB task (e.g., Raymond et al., 1992) requires the report of two targets, AB effects can also be produced when the first target is replaced by an attention-grabbing distractor (Folk et al., 2002; Leblanc et al., 2008; Maki & Mebane, 2006; Zivony & Lamy, 2014). That is, attention-grabbing distractors produce a disruption to the processing of a target that follow the same temporal trajectory as the standard AB, even when the distractors appear in an entirely irrelevant location. However, a shift of spatial attention alone is insufficient to produce an AB effect by a distractor (Ophir et al., 2020). Thus, an AB effect following peripheral distractors is taken to indicate that these distractors both captured and engaged attention.

In Experiment 3, we used a variant of the distractor-based AB task. Participants searched for a red target in the middle of three RSVP streams (Fig. 6A). Prior to the target frame, two red distractors appeared simultaneously in the two lateral streams. We predicted that these distractors would capture attention and produce an AB effect. That is, accuracy in identifying the target will be lower when the target appeared during the blink period (200 ms, distractor-target lag 2) relative to when at appeared outside the blink period (700 ms, distractor-target lag 7). This allowed us to provide converging evidence that our expectation manipulation did not increase the likelihood of attentional capture by expected targets. Previous studies have showed that salient and attention-grabbing targets are also more likely to escape the AB's deleterious effect (Chua, 2005; Lagroix et al., 2016). Therefore, if targets from the expected category are more salient and more likely to capture attention, then they should be less vulnerable to the AB relative to unexpected targets, resulting in a smaller AB effect. Alternatively, if categorical expectations do not affect the targets' ability to capture attention, then expected and unexpected targets should be equally vulnerable to the AB.

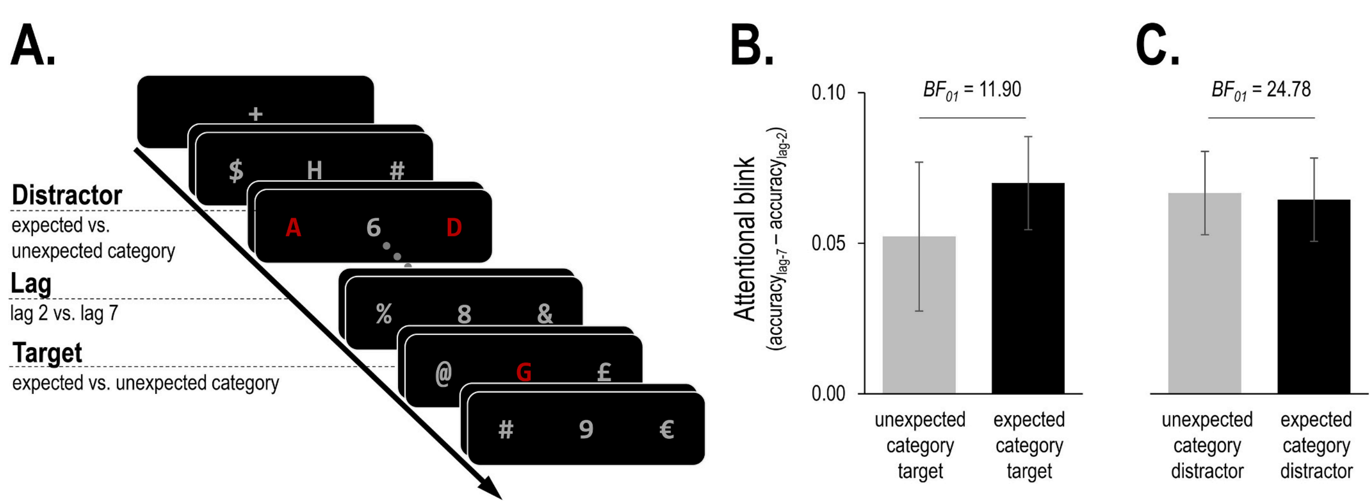

Fig. 6. Illustration of the experimental paradigm used in Experiment 3 (A) and resulting attentional blink effects calculated based on accuracy data (B and C). A: Participants had to identify the red target in the central stream and ignore the two lateral streams. Two distractors from the same category appeared either 200 ms (lag 2) or 700 ms (lag 7) before the target. B and C: Mean attentional blink effects, calculated as the difference between accuracy at distractor-target lag 7 minus accuracy at distractor-target lag 2, as function of the category (expected versus unexpected) of (B) the target and (C) the lateral distractors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The main question, however, was whether the distractors' category would have any effect on the size of the AB effect. Previous studies have showed that both the salience of a distractor and its match with top-down task sets increases the magnitude of a distractor-based AB (Folk et al., 2002; Leblanc et al., 2008; Maki & Mebane, 2006). Here, our goal was to examine whether expectations about the target's alphanumeric category modulate the AB produced by different distractors, either via salience-based or feature-based mechanisms. A similar task was previously used by Leblanc et al. (2008), Experiment 2). In this study, participants searched for a target digit defined by a particular colour (e.g., red) among heterogeneously coloured digits. They found that peripheral distractors that shared the target's colour captured attention and produced an AB effect. However, the target's alphanumeric category also played a part: distractor digits produced a more substantial disruption to target identification than letters and produced larger electrophysiological markers of attentional engagement. Leblanc et al. (2008) interpreted this finding to indicate that while the defining feature captured attention, the relevance of the response category modulated attentional engagement. In contrast to LeBlanc et al.'s study, targets in the current study could be either digits or letters, making both alphanumeric categories relevant to the task. What is yet unclear is whether distractors from the expected target category are more likely to engage attention, corresponding with a larger AB effect relative to distractors from an unexpected (but still task-relevant) category. A difference in the size of the AB effect would indicate that expected categories result in more efficient attentional engagement. This could be the case, for example, if participants did not merely search for the target's colour, but rather search for a conjunction between the target's colour and the expected target category. In contrast, if categorical expectations effects are not mediated by changes to attentional engagement, then the AB effect produced by lateral distractors should be of equal size regardless of their category.

4.1. Method

4.1.1. Sample size selection

We used the effect size of the main effect for target condition in Experiment 2 ($\eta_p^2 = 0.41$) and calculated the required sample to replicate this effect with 80% power. This analysis suggested that a sample size of 15 participants is required.

4.2. Participants

Participants were 15 (8 women) volunteers (*Mage* = 30.3, *SD* = 6.4) who participated for £8 or course credit. All reported normal or corrected-to-normal visual acuity.

4.2.1. Apparatus, design, and stimuli

The apparatus, design, and stimuli were all identical to Experiment 1, except for the following changes (Fig. 6A). Participants were presented with three RSVP stream, one presented centrally, and two that appeared 2.5° to the left and right of fixation. The target could only appear on the central stream, and (like Experiment 2) was defined as the red (CIE colour coordinates: 0. 629/0.333, luminance 47.2 cd/m^2) alphanumeric character. The target appeared randomly in the 9th, 11th or 13th frame. The two lateral streams included mostly grey symbols, drawn randomly from a set of seven symbols (£, $, %, &,?, #, @, €), with the sole restriction that the same symbol could not appear in the two streams at the same frame or on the same stream in two subsequent frames. On one frame (the distractor frame), the two lateral frames included two red alphanumeric characters. These alphanumeric characters were always drawn from the same category, which was equally likely to be a digit or a letter. The distractor frame appeared either two or seven frames before the target (lag 2 versus lag 7). Participants were told to search for the target only in the central stream; they were also notified that irrelevant red distractors will appear in the periphery, and that they should ignore these distractors. The experiment included 10 practice trials followed by 480 experimental trials, divided into 60-trial blocks. One participant completed only 320 trials due to a technical error.

4.3. Results

Accuracy was higher for expected targets than unexpected targets ($M = 83.0\%$ vs. $M = 78.8\%$) and for targets that appeared at lag 7 from the peripheral distractor relative to targets that appeared at lag 2 ($M = 84.0\%$ vs. $M = 77.9\%$). Importantly, this latter effect was unaffected by whether the target (Fig. 6B) or the peripheral distractors (Fig. 6C) were from the expected or unexpected category. To test these observations, we entered accuracy rates to an ANOVA with target condition (expected category vs. unexpected category), the distractors to target lag (lag 2 vs. lag 7), and the distractors' category (expected category vs. unexpected category) as factors. The only significant effects were the main effects of the target condition and distractors to target lag, $F(1,14) = 9.67$, $p = .008$, $\eta_p^2 = 0.41$, and, $F(1,14) = 26.24$, $p < .001$, $\eta_p^2 = 0.65$, respectively. Importantly, there was no interaction between lag and the target's category, $F(1,14) = 1.70$, $p = .21$, $\eta_p^2 = 0.11$, $BF_{01} = 11.90$, or the distractors' category, $F < 1$, $BF_{01} = 24.78$.

4.4. Discussion

In Experiment 3, peripheral distractors that shared the target's colour captured and engaged participants' attention, thereby producing an AB effect that disrupted the target's identification. While targets from the expected category were more likely to be reported than targets from the unexpected category, they were not less vulnerable to the AB. As salient targets are less affected by the AB (Chua, 2005; Lagroix et al., 2016), this finding provides further evidence that the expectation effects observed here were not caused due to modulation of saliency or attentional capture. Furthermore, we examined whether the distractors' category (i.e., whether they matched the target's expected category) would modulate the AB effect. Such an observation would suggest that expectation effects are mediated by attention mechanisms that precede and affect attentional engagement. We found evidence against this prediction: the AB effect was of equal size whether the distractors were from the expected or unexpected category. This finding further suggests that the categorical expectation manipulation employed in the current study did not modulate either attentional guidance or attentional engagement. As such, the results of Experiment 3 provide support to the view that expectation effects on perception are not always mediated by attention.

An important aspect of the current experiment makes it especially beneficial for future attempts to study expectations separately from attention. In most experiments that gauge attention and expectations, both factors improve performance of detecting and identifying target objects, making it harder to differentiate between the two processes. In the current experiment, attention and expectations produce opposite effects on performance. While expectations improve the identification of probable items, attentional engagement to distractors that share these features result in worse performance (i.e., an AB effect). Therefore, this method can be used and modified in future studies that rely on a clear differentiation between attention and expectations.

5. Experiment 4

In Experiment 4, we aimed to further corroborate and refine the conclusions from the previous experiments, by employing an additional electrophysiological marker of selective attentional processing. To do so, we recorded event-related potentials (ERPs) during task performance. Specifically, we measured the N2pc component, a well-known marker of attentional object selection and engagement (Eimer, 1996;

Woodman & Luck, 1999). The N2pc reflects selective attention processes following attentional guidance. This conclusion is supported by two lines of research: (*i*) the N2pc emerges even when attention is shifted in advance to the target's location and no further shifts of attention are needed (Kiss et al., 2008), and (*ii*) the N2pc is modulated by factors that affect attentional engagement but not attentional shifting (Zivony et al., 2018). The N2pc can be triggered in response to distractors that share the target's defining feature, or as a result of attentional guidance towards targets (e.g., Kiss et al., 2008). Importantly, the N2pc is also affected by earlier attentional mechanisms that affect attentional engagement, such as stimulus saliency (Forschack et al., 2023), selection history (Eimer et al., 2010), feature-based attention (Eimer & Grubert, 2014), spatial attention (Foster et al., 2020), and temporal attention (Seibold & Rolke, 2014). This makes it an ideal measure for testing whether expectation effects are mediated by (early or late) attention.

Previous studies have shown that manipulating the probability of target features modulates the N2pc, indicating that expectations can affect attentional engagement under certain circumstances (Berggren & Eimer, 2019; Wei & Ji, 2021; Zivony & Eimer, 2021b). For example, Berggren and Eimer (2019), compared N2pcs to targets in a likely (expected) or unlikely (unexpected) colour, and found earlier and larger N2pc components for expected-colour targets. These findings suggest that expectations associated with a low-level visual feature can indeed affect attentional selection mechanisms, as discussed earlier. In contrast, Experiment 4 again manipulated expectations with respect to the alphanumeric category of target objects, in an experimental paradigm where such features cannot distinguish between the target and distractors. If this type of expectation does not affect attentional mechanisms, there should be no differences between N2pc components to expected versus unexpected targets. In contrast, if expectations affect attentional engagement, either directly or via modulation of earlier attentional mechanisms (see Fig. 2A), N2pcs should be larger and/or emerge earlier for targets in the expected category.

In addition to the N2pc, we also measured P3 components (a positive deflection with a typical peak latency between 300 and 500 ms post-stimulus) to expected versus unexpected targets, in order to assess the presence of expectation-induced effects at processing stages beyond attentional selection. There is still an ongoing debate regarding the exact processes reflected by the P3 (e.g., WM updating, conscious perception, inhibition of extraneous cortical processing; see Polich, 2007, for a review), However, there is wide agreement that this component emerges after information has been encoded to WM, but prior to response selection. In line with this view, P3 components measured in RSVP tasks are either substantially diminished or entirely absent on trials where the target is missed (e.g., Sergent et al., 2005; Verleger et al., 2011). Since the P3 in RSVP tasks is sensitive to the likelihood that a target will be encoded in WM, but not to subsequent response selection processes (e.g., differences in response bias), it allowed us to test whether category-based expectations facilitate WM encoding or merely result in an increased readiness to report expected targets. In the former case, P3 amplitudes should be larger for expected as compared to unexpected targets. In the latter case, there should be no systematic P3 differences between these two types of target objects.

5.1. Method

5.1.1. Sample size selection

We once again used Experiment 2, which was most similar to the current experiment, as our basis of our sample size calculation. Therefore, we once again used a sample size of 15 participants.

5.2. Participants

Participants were 15 (8 women) volunteers ($Mage = 30.9$, $SD = 6.8$) who participated for £25. All reported normal or corrected-to-normal visual acuity.

5.2.1. Apparatus, design, and stimuli

The apparatus, design, and stimuli were all identical to Experiment 2, except for the following changes (Fig. 7A). The target frame included two coloured characters, one yellow (CIE colour coordinates: 0. 461/0.488, luminance 47.2 cd/m^2) and one green (0.306/0.615, 47.3 cd/m^2). Each participant was assigned one target colour that remained constant throughout the experiment. The target was not preceded by a cue.

5.2.2. EEG recording

Electroencephalogram (EEG) was recorded with a BrainAmps DC amplifier. EEG was DC-recorded from 27 scalp electrodes, mounted on an elastic cap at sites Fpz, F7, F8, F3, F4, Fz, FC5, FC6, T7, T8, C3, C4, Cz, CP5, CP6, P9, P10, P7, P8, P3, P4, Pz, PO7, PO8, PO9, PO10, and Oz. A 500-Hz sampling rate with a 40 Hz low-pass filter was applied. Due to the COVID-19 pandemic, we adopted a protocol that reduced the contact time between experimenter and participant in the experiment room. Therefore, electrode impedance in all electrodes was kept <10 kO (instead of <5 kO, which is standard in our lab, see also Zivony and

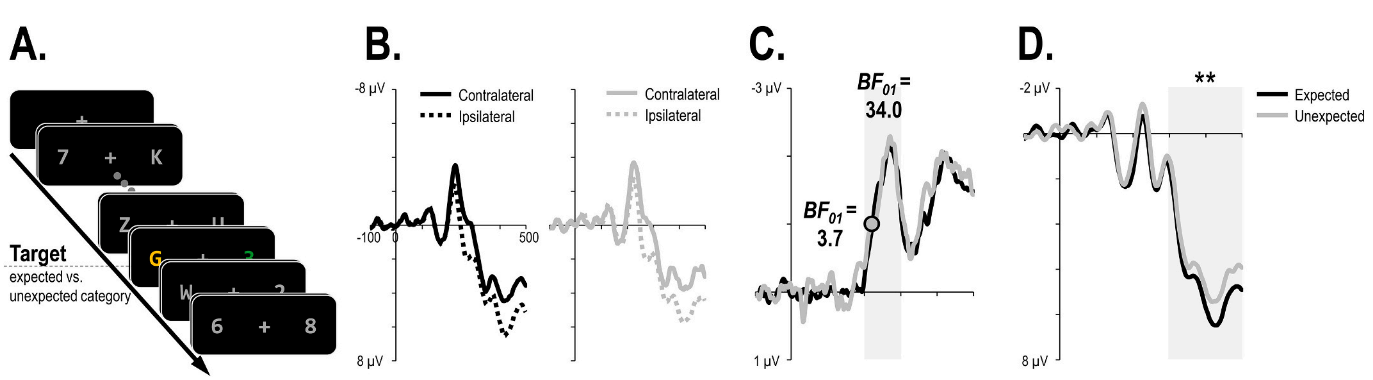

Fig. 7. Illustration of the experimental paradigm used in Experiment 4 (A) and resulting grand-average event-related potentials (ERPs) waveforms elicited in Experiment 4 by target frames (B—D), shown separately for expected target trials (black lines) and unexpected target trials (grey lines). A: Participants had to identify a target in a prespecified colour (e.g., orange). B: Waveforms recorded at electrodes PO7/8 contralateral and ipsilateral to the target. C: Difference waveforms obtained by subtracting ipsilateral from contralateral ERPs at electrodes PO7/8. The N2pc component was calculated as the mean amplitude in the 200–300 ms time window. The latency of the N2pc was defined as the point when the waveform crossed −1 µV. The two latencies, represented as a grey dot surrounded by a black line, were too close together to be represented separately. D: Waveforms recorded at electrode Pz. The P3 component was calculated as the mean amplitude in the 300–500 ms time window.
Note. ** $p < .01$.

Eimer, 2021a; 2021b).

Channels were referenced online to a left-earlobe electrode, and re-referenced offline to an average of both earlobes. No other filters were applied after EEG acquisition. Trials with eye blinks (exceeding ±60 μV at Fpz), horizontal eye movements (exceeding ±30 μV in the HEOG channels), and muscle movement artifacts (exceeding ±80 μV at all other channels) were removed as artifacts. EEG was segmented into epochs from 100 ms before to 500 ms after the onset of the target frame, relative to a 100 ms pre-stimulus baseline. ERPs were computed separately for trials where the target was from the expected category and for trials where the target was from the unexpected category. All trials were included in the calculation of these waveforms, regardless of the participants' response. The reason for this is that the N2pc and P3 components often correlate with accuracy. As accuracy rates differed substantially between trials with expected and unexpected targets, including only trials with correct responses might distort the corresponding ERPs.

5.2.3. ERP analysis

N2pc analysis. Averaged ERP waveforms were computed for trials with a target in the left or right RSVP stream. N2pc components triggered by the target frame were computed by comparing ERPs at electrodes PO7/PO8 contralateral and ipsilateral to the location of the target, and measured in a single 100 ms time window, between 200 and 300 ms after the target, as is common in our lab and others (e.g., Berggren & Eimer, 2019; Callahan-Flintoft et al., 2018; Kiss et al., 2008; Luck, 2014; Zivony & Eimer, 2020). We also analysed the latency of the N2pc components, an index of the speed of attentional engagement (Zivony and Eimer, 2021a). To do so, we used the contralateral-ipsilateral difference waveforms, following an application of a 10 Hz low pass filter. We employed the jackknife procedure described by Miller, Patterson, & Ulrich (1998), with the N2pc onset criterion defined as the point where the difference waveform reached 50% of the average N2pc peak amplitude (averaged across trials with expected and unexpected targets, and measured within a 150–300 ms post-target interval). We used a relative onset criterion, 50% of the peak amplitude (−1 μV), to avoid any distortions due to N2pc amplitude differences (Zivony and Eimer, 2021a; see also Grubert & Eimer, 2015; Grubert, Krummenacher, & Eimer, 2011, for similar procedures). In statistical analyses of N2pc onset latency differences, *F* scores were corrected according to the formula provided by Ulrich and Miller (2001).

For the Bayesian analysis of the N2pc amplitude, the average difference between the contralateral and ipsilateral electrodes in the 200–300 window was extracted for every trial. These data were then entered as the dependent variable in a maximal mixed Bayesian model with expectations as the independent variable, and with subject intercepts and slopes as random factors. Unfortunately, we could not conduct this kind of analysis for the N2pc latency, as the latency calculation relies on the jackknifing procedure, which produces a single average score per participant (rather than a single score per trial). Therefore, differences in N2pc latencies were analysed with a Bayesian *t*-test, using JASP (0.16.3). Since Ulrich and Miller (2001) correction for jackknifed N2pc onset latency data only applies to frequentist statistics, we applied the adjustment described by Smulders (2010) to retrieve an estimate of individual N2pc onset latencies from jackknifed ERPs, and used these data for the Bayesian t-test. Note that relative to a mixed-model, this analysis considerably underestimates the size of the Bayes Factor, as it does not take into account the amount of data or the variability in the underlying data on which the averages are based on (van Doorn et al., 2023).

P3 analysis. The P3 components evoked by the target was measured in averages from the Pz electrode in the 300–500 ms time window, as is common in similar RSVP studies (e.g., Verleger et al., 2011; Vogel et al., 1998).

Residual eye movement *analysis*. While our exclusion criteria for eye movements ensured that no large saccades affected our results, it is possible that small but consistent eye movements in the direction of a target may have been left in the data (Lins et al., 1993). To check whether residual eye movements could have created any systematic differences between ERPs on expected and unexpected target trials, we analysed data from the two HEOG electrodes ipsilateral and contralateral to the visual field where the target appeared. We calculated the difference wave between the ipsilateral and contralateral HEOG traces, such that a positive deflection indicates a tendency for a small deviation of eye gaze towards the target. We then examined whether averaged HEOG difference waves differed between trials with expected and unexpected targets. This analysis, reported in the Supplementary File (Analysis 4), suggested that any residual eye gaze deviations remaining in the data were very small, and did not contribute to any differences between the different target conditions.

5.3. Results

Preliminary analysis revealed that the target's colour (green vs. orange) did not modulate the expectation effects on behavioural results or ERP results. Therefore, we collapsed all data across this factor for all the following analyses.

5.3.1. Behavioural results

As can be seen from Fig. 3D, mean accuracy was once again higher for targets from the expected category relative to the unexpected category ($M = 56.5\%$ vs. $M = 45.3\%$), $t(14) = 5.44$, $p < .001$, $d_z = 1.40$.

5.3.2. Electrophysiological results

The average general EEG data loss due to artifacts was 9.1% ($SD = 10.5\%$).

N2pc. Fig. 7B shows the ERP waveforms triggered by the target frame at electrodes PO7 and PO8 contralateral and ipsilateral to the target, for trials where the target was from the expected category and the unexpected category. The corresponding difference waves obtained by subtracting ipsilateral from contralateral ERPs are shown in Fig. 7C. As can be seen from this figure, both expected and unexpected targets produced clear N2pcs ($M = -1.50$ μV and $M = -1.53$ μV respectively). Single sample *t*-tests confirmed that the amplitude of both components was significantly different from 0 (both $ps < 0.001$). Importantly, there was no difference between the N2pc triggered by these targets $t < 1$, $BF_{01} = 33.89$. Similarly, there was little difference in the latency of the two N2pc components. If anything, the latency of the N2pc was slightly later on trials with expected targets than unexpected target ($M = 220.1$ ms vs. $M = 217.2$ ms), but this difference was not significant, $t < 1$, $BF_{01} = 3.72$ (note that the strength of the evidence in favour of the null for this analysis was expected to be weak given the reasons detailed above; see van Doorn et al., 2023).

P3. Fig. 7D shows the ERP waveforms triggered by the target frame at electrode Pz for trials where the target was from the expected category and the unexpected category. As can be seen from this figure, both expected and unexpected targets produced clear P3 components in the 300–500 ms time window ($M = 6.54$ μV and $M = 5.76$ μV respectively, both $ps < 0.001$). Unlike the N2pc components, however, targets from the expected category produced a substantially larger P3 component than targets from the unexpected category, $t(14) = 3.50$, $p = .004$, $d_z = 0.90$.

5.4. Discussion

Targets from expected categories produced larger P3 components but not larger or earlier N2pc components relative to unexpected targets. The absence of any N2pc differences between these two types of targets provides new evidence that expectations do not necessarily modulate attention-related stages of visual processing, including attentional engagement. They strongly suggest that the expectation effects on performance observed in these experiments (as well as in Zivony and

Eimer, 2022a) are not mediated by attentional mechanisms.

The P3 results obtained in Experiment 4 provide additional evidence regarding the processes that are modulated by expectations. P3 amplitudes were larger for expected relative to unexpected targets, indicating that expectations modulate the probability that a target will be encoded in WM (see Fig. 1B). If expectation effects had been entirely produced at subsequent response-related stages (e.g., differential response bias), there should not have been any expectation-related P3 differences, as the P3 is associated with processes prior to response selection (see above). It is also notable that the P3 modulation observed in Experiment 4 (larger P3 amplitudes for expected targets) contrasts with the standard finding that P3 amplitudes are inversely related to stimulus probability (e.g., Polich, 1990). Indeed, it was suggested that the P3 is associated with prediction errors (Cavanagh, 2015) which are assumed to be larger for unexpected objects. Our results are not necessarily inconsistent with this hypothesis, since the P3 amplitude modulations observed here may be specific to RSVP experiments, where stimuli are presented near the threshold of consciousness (see Bowman et al., 2023). It is also possible that a standard P3 probability effect was also present in Experiment 4, but was counteracted by an even larger P3 modulation associated with an expectation-induced bias that facilitated WM encoding. In this case, the observed P3 amplitude enhancement for expected-category target would reflect an underestimation of the real effect. Overall, the ERP results of Experiment 4 strongly suggest that targets from the expected category are more likely to be encoded, even though they are not more likely to be attended.

6. General discussion

Foreknowledge about predictable information in our environment plays an important role in shaping our perception, especially if such information is beneficial for our immediate goals. While many studies have shown that probabilistic expectations can affect the likelihood that an object will be encoded in working memory, perceived, and reported correctly, it is yet unknown what are the cognitive mechanisms that underlie such expectation-based effects on visual perception. One possibility is that these effects are always mediated by selective attention, and are therefore primarily attentional rather than exclusively expectation-related phenomena. The purpose of the current study was to show that this is not the case, and that there are expectation effects that are not dependent on mediating attentional mechanisms.

It has been suggested that previous studies could not conclusively dissociate expectations and attention because expectations may affect an object's salience (Alink & Blank, 2021) or its relevance to the task at hand (Rungratsameetaweemana & Serences, 2019), and thus affect attentional processing either indirectly or directly. Here, our goal was to avoid this problem by coupling expectation manipulations with measurements of established markers of attentional guidance or engagement. The presence of attention-mediated expectation effects should be reflected by corresponding modulations of such markers, such as the N2pc component (e.g., Berggren & Eimer, 2019). To reduce the likelihood of attentional capture by expected stimuli, we manipulated the probability of a high-level feature of target objects—their alphanumeric category—and presented targets in RSVP streams among multiple distractor items that shared this category.

In all four experiments, targets from the expected category were more likely to be reported, demonstrating robust effects of probabilistic category-related expectations. Experiment 1 demonstrated that the expectation-induced modulations of perceptual reports observed in our previous study on surprise trials (Zivony and Eimer, 2022a) can also be observed when expectations are instead manipulated probabilistically. Importantly, we also measured independent indices of spatial attentional guidance (Experiment 2: spatial cuing effects) and attentional engagement (Experiment 3: the attentional blink; Experiment 4: the N2pc component) that could reveal whether these specific attentional mechanisms were influenced by the probability manipulation. The presence of expectation-related effects on these measures would suggest that any subsequent differences in the accuracy of perceptual reporting expected versus unexpected target objects are at least partially mediated by these mechanisms. In contrast with this possibility, results consistently showed that these mechanisms operated independently of expectations related to the target category. However, and importantly, the ERP results of Experiment 4 provided new evidence that these expectations did indeed affect the visual processing of target objects, but only at the stage where these objects were encoded into working memory.

One may argue that the absence of expectation-induced modulations of attentional guidance and engagement does not rule out the possibility that other types of attentional processes (operating during earlier stages of visual processing) may have been affected by the probability manipulation. Our argument against this alternative account relies on the well-established sequential nature of selective attention (see Fig. 2). Attentional guidance and engagement are believed to take place at the end of the attentional selection process, and to reflect the outcome of preceding space-based or feature-based attentional biases (e.g., Desimone & Duncan, 1995; Eimer, 2014; Itti & Koch, 2001; Treisman, 2014; Wolfe, 2021; Wyble et al., 2011; Zivony & Eimer, 2022b; see also Luck et al., 2021). As such, any modulation of hypothetical earlier attentional mechanisms should also have resulted in downstream modulations of guidance and engagement, which was not the case in the present study. Thus, the absence of any expectation-related behavioural and electrophysiological effects on stages of visual processing that are typically modulated by attention, and the fact that such effects were only observed at the level of the P3 component (Experiment 4), provides new and clear evidence that expectation effects on perceptual reports can emerge without being mediated by attentional processes.

Two other accounts of our results can be readily ruled out by additional analyses of the current data (as reported the Supplementary File). One possibility is that the behavioural expectation effects observed here merely reflect repetition priming. Accuracy may have been better for the high-probability category simply because repetitions of the target category from the previous trial to the current trial were more frequent for this category than for the low-probability category. For example, on expect-digits blocks, the sequence of a digit target (on trial N-1) followed by a digit target (on trial N) was more frequent than the sequence of a letter target followed by a letter target. If target category repetitions increase accuracy, then this can explain the observed effect. To test this possibility, we assessed the effects of such repetition effects across all four experiments (see Supplementary Analysis 2) and found that expectation effects were observed even when the target on the preceding trial belonged to the unexpected category. A second possibility is that the expectation effects observed here merely reflect response bias. Because participants may often encode both the target and a distractor that is temporally adjacent to the target (e.g., Vul et al., 2009; Zivony & Eimer, 2020), they may generally choose to report an item from the expected category. Thus, when the target is from the unexpected category, participants will produce more incorrect reports (i.e., they will report an adjacent distractor), even though the target was also encoded. An assessment of expectation effects as a function of the category of adjacent distractors (see Supplementary Analysis 3) showed that these effects emerged even when the adjacent distractors shared their category with the target, thus ruling out this response bias account.

6.1. *Accounting for attention-mediated and attention-independent expectation effects within a diachronic framework of visual selectivity*

Prominent theories that highlight the central role of prediction in shaping perception (e.g., Friston, 2005) rarely consider the possible mediating role of attentional processes. Conversely, theories of selective attention do not take into account prediction-induced modulations of selective visual processing, unless such selective effects are mediated by attentional mechanisms (e.g., Luck et al., 2021; Wolfe, 2021). Such limitations in the scope and perspective of research conducted within each of these two camps have contributed to the current situation where we still lack an integrative conceptual framework that can account for attention-mediated as well as attention-independent effects of expectations on visual processing. We believe that the current study can help bridge the gap between the two fields to some degree. To do so, we present a modified version of the "diachronic" account of attentional selectivity (Zivony & Eimer, 2022b). This account will allow us to explain and accommodate the finding that expectations can, in some cases, affect both attention and WM encoding, whereas in other cases (as demonstrated in the current study), they only affect the latter but not the prior.

In the diachronic account, visual perception is viewed as a temporally extended process of evidence accumulation that is shaped by attentional modulations unfolding in tandem with perceptual processing (see Fig. 8). Before a fragile sensory representation can be consolidated to a stable WM representation, it must cross an activation threshold (encoding threshold). In RSVP experiments, most items fail to cross this threshold because forward and backward masking from temporally adjacent distractors interrupts evidence accumulation. Known target objects are more likely to be encoded because they contain target-defining features that, once detected, trigger attentional guidance towards their location, thereby increasing their activation levels and thus the probability that they engage attention (i.e., reach an engagement threshold). In this case, an attentional episode is triggered, when evidence accumulation is substantially amplifies for a short amount of time. This strongly increases the probability that a target crosses the encoding threshold, is encoded in working memory, and subsequently successfully identified. When this does not happen, other items in the RSVP stream such as the item following the target may be misidentified as the target (a distractor intrusion).

From this perspective, expectations can affect perception in a variety of ways. In many cases, expectations result in stronger attentional modulations. For example, expectations can increase feature-based attentional guidance towards expected features, resulting in increased activation of these features. In addition, they could lower the engagement threshold associated with these features or increase the efficiency of enhancement during the attentional episode (Fig. 8A). As a result, evidence accumulation is sped up for targets that contain an expected feature, increasing the likelihood that these objects will cross the encoding threshold. Such attention-mediated expectation effects are most likely to be observed when expectations are associated with low-level selection features (e.g., Berggren & Eimer, 2019).

However, even in cases where expectations do not modulate these attentional mechanisms, they can still affect the likelihood of working memory encoding and quality of perceptual reports by affecting encoding thresholds directly (Fig. 8B). It is plausible to assume that these thresholds can be adjustable in line with task demands and expectations, as this would be a highly functional mechanism, especially in crowded visual environments where multiple simultaneous or successively presented objects compete for access to working memory (Zivony & Eimer, 2021b, 2022a). Specifically, expectations can activate the representations of expectation-congruent exemplars that are stored in long-term memory. Once activated, such long-term memory representations may reduce the threshold of activation required for a sensory representation to be consolidated into WM (Oberauer et al., 2017). This process is compatible with the view that expectations improve encoding

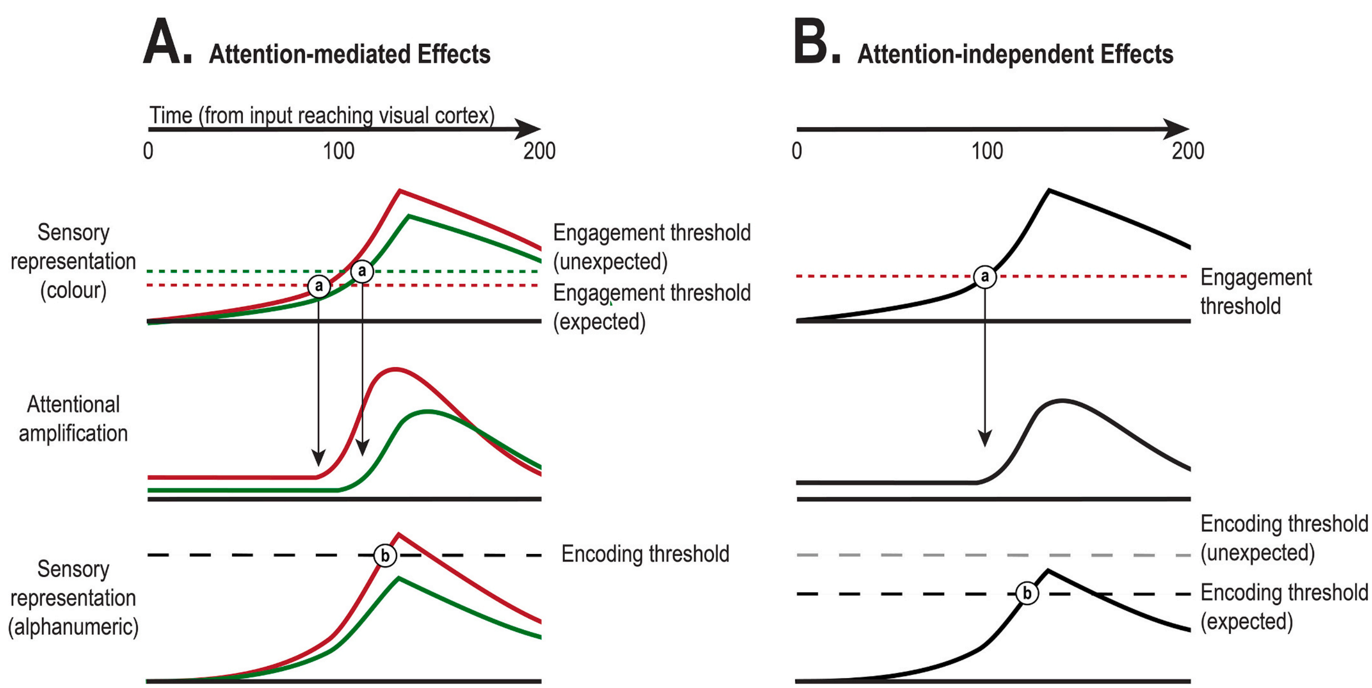

Fig. 8. Illustration of the relationship between expectations and the likelihood that an object will be encoded in WM in an RSVP experiment. The x-axis reflects time relative to the moment when the target input reaches the visual cortex (around 50–80 ms from the target's appearance). In this example, the target is defined by its colour and participants have to report its alphanumeric identity. The strength of the sensory representation of the different target features (colour and identity, first and third rows) gradually rise, but then fall when the masking item reaches the visual cortex (around 100 ms later). When evidence accumulation about the target's defining feature reaches the engagement threshold (a) a transient attentional episode is triggered, amplifying the sensory representation for a short amount of time. If amplified enough, the target's identity reaches the threshold necessary for encoding (b). Expectations can affect perception in one of two ways. If expectations are about a low-level feature that can be used to identify the target (A), these expectations can affect feature-based attention, evidence accumulation about the target's defining feature, and the speed and amplitude of the attentional episode. In this case, expected targets are more likely to be encoded than unexpected targets (red line versus green line) because their sensory representation is more strongly activated, even if the encoding threshold about their identity is unaffected. In contrast, if expectations are about a high-level feature that is ineffective in guiding attention (B), expectations can still affect the encoding threshold. In this case, expected targets are not more likely to be encoded because they are more strongly activated. Rather, given a sensory representation of a certain strength, they are more likely to reach the lowered encoding threshold (black dashed line versus grey dashed line) before they are masked. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

by constraining the interpretation of sensory inputs (Summerfield & Egner, 2009). In RSVP tasks where targets are quickly masked by preceding and subsequent distractors, this results in superior WM encoding and increased accuracy (and increased P3 amplitude). In other tasks, the same modulations may be reflected only as shorter RTs.

6.2. A new perspective on the relationship between expectation and attention

The modified diachronic account may also explain why expectation effects are not entirely independent from manipulations of relevance (e.g., Jiang et al., 2013; Richter & de Lange, 2019; Smout et al., 2019; Zhou et al., 2022). Instead, our account suggests that expectation effects on encoding of attended and on unattended objects may not always be symmetrical, and that this asymmetry might depend on the level of noise in the visual field. In highly dynamic visual environments (as represented for example by RSVP experiments), objects that are not rapidly encoded are overridden by other masking objects. In such environments, expectation effects should be greater for attended than unattended objects, as the latter are highly unlikely to reach sufficient activation to be encoded, even if their encoding threshold is selectively lowered due to expectations. In relatively static environments, this asymmetry may be reversed. Focally attended objects will usually have a strong sensory representation, which could imply that any additional benefit due to expectation-related lowering of encoding thresholds might be minor. In contrast, expectations might have pronounced benefits for unattended objects, which will typically not gain access to working memory, unless encoding thresholds are selectively lowered. That is, in this case, expectation effects should be stronger for unattended objects. In summary, expectation effects on encoding should be more pronounced for "liminal" (i.e., on the cusp of conscious perception) objects whose activation level is close to the encoding threshold. This will be determined by both attentional allocation and the level of perceptual noise in the environment.

However, even features of attended objects in static displays may fail to gain access to working memory when they are unexpected. This is illustrated by Attribute Amnesia (AA), a phenomenon where participants fail to report a feature (e.g., identity, colour) of an attended object when they expected to report a different feature (e.g., location). In the standard AA experiment (Chen & Wyble, 2015), the target is defined as a digit among letters, so that identity is relevant for target detection. However, when observers have to consistently report the location of these targets, they often fail to report their identity in a surprise trial when the response attribute is changed unexpectedly. AA is not caused by forgetting stored identity information following the surprise question, but rather due to a failure to consolidate the target-defining information because it is expected to be irrelevant for perceptual reports (Wyble & Chen, 2017). While AA is counterintuitive for models of attention which assume that focally attended objects should always be encoded (e.g., Wolfe, 2021), it is readily explained by our proposed modified diachronic account. AA occurs when the representation of the identity of a target object is sufficiently activated to cross the threshold for attentional engagement, but not strongly enough to cross the encoding threshold for this feature, which is selectively elevated as a result of the identity being expected to be irrelevant for perceptual report.

The hypothesis of an adjustable encoding threshold that is specifically sensitive to expectations may also explain other findings from the attention literature, and produce new predictions. For example, despite the robustness of the attentional blink, there are individuals who entirely and consistently fail to show such an effect (Martens et al., 2006). It is possible that these "non-blinkers" are able to selectively lower their encoding thresholds for known target objects in a sustained fashion, which may allow them to encode and report both targets, even when the second target is only weakly activated. It would be interesting to study whether blinkers and non-blinkers also differ with respect to attribute amnesia, or the attention-independent expectation effects reported in the present study. An association observed across a variety of different tasks may indicate that encoding thresholds is an important yet relatively unexplored aspect of individual differences in selective visual processing with a particular relevance to the study of expectations.

It is important to note that our proposal that expectations can specifically affect the likelihood that an object will be encoded, independently of any prior attentional mechanisms, does not imply that this is the only way in which expectations affect perception. The variability of neural correlates of expectations (e.g., Esterman & Yantis, 2010; Hesselmann et al., 2008; Kok et al., 2012) suggests that multiple mechanisms may be involved, and that this depends on the specific demands of an experimental task and the particular ways in which expectations are manipulated. This is also exemplified by the remarkable variability of results observed in studies that independently manipulated relevance and expectations (Jiang et al., 2013; Kok et al., 2012; Smout et al., 2019; Zhou et al., 2022).

Likewise, we do not claim that the methods used in the current study are the only valid ways of dissociating attention and expectations. Various experimental methods can and should be used. For example, the method of independently manipulating relevance and expectations is often very useful to assess how expectations shape perception, in particular with respect to unattended events (Summerfield & Egner, 2009, 2016). We nevertheless suggest that including direct measures of attentional guidance and engagement should be beneficial for future research that relies on this strategy, as this can reduce uncertainty about the mechanisms responsible for a specific pattern of effects. Measures of attentional guidance and engagement can substantiate the general but often untested assumption that only the relevance of features and objects drives attentional selectivity. Moreover, and importantly, the inclusion of such measures can also provide more conclusive insights into whether and under which conditions manipulations of expectations will modulate relevance (Rungratsameetaweemana & Serences, 2019) or salience (Alink & Blank, 2021).

Our experiments also demonstrate the importance of careful experimental design choices when investigating expectation/attention links. By using a certain set of targets and distractors, one can reduce or eliminate possible confounds that may have affected previous research. This however does not imply that expectations about high-level features are unique in their ability to produce attention-independent effects on perception. We expect that our results will be generalizable to other types of stimuli, but this will need to be demonstrated in future research.

7. Summary

To summarize, the current study provides clear and novel evidence that there are conditions where expectations have substantial effects on visual perception that are not mediated by attention. These results demonstrate that the roles of attention and expectation for selectivity in visual processing can be successfully dissociated, and open the door to new research on the interactions between expectation and attention and on the neural mechanisms that underlie these interactions.

Author's note

Both authors (A.Z. and M.E.) were responsible for conceptualization, experiment design, and writing. A.Z. programmed the experiments, collected the data, conducted the statistical analyses, and wrote the original draft.

For the purpose of open access, the authors have applied a creative commons attribution (CC BY) licence to any author accepted manuscript version arising. This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 896192 to Alon Zivony and from ESRC Grant No. ES/V002708/1 to Martin Eimer.

CRediT authorship contribution statement

Alon Zivony: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Martin Eimer:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Data availability

All the data and materials necessary to reproduce the experiment and analyses are available online at: https://doi.org/10.6084/m9.figshare.21805989. None of the study's analyses were preregistered.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2024.105864.

References

Alink, A., & Blank, H. (2021). Can expectation suppression be explained by reduced attention to predictable stimuli? *NeuroImage, 231*, Article 117824.
Baier, D., & Ansorge, U. (2019). Contingent capture during search for alphanumerical characters: A case of feature-based capture or of conceptual category membership? *Vision Research, 160*, 43–51.
Berggren, N., & Eimer, M. (2019). The roles of relevance and expectation for the control of attention in visual search. *Journal of Experimental Psychology: Human Perception and Performance, 45*(9), 1191–1205.
Bowman, H., Collins, D. J., Nayak, A. K., & Cruse, D. (2023). Is predictive coding falsifiable? *Neuroscience & Biobehavioral Reviews, 105404*.
Callahan-Flintoft, C., Chen, H., & Wyble, B. (2018). A hierarchical model of visual processing simulates neural mechanisms underlying reflexive attention. *Journal of Experimental Psychology: General, 147*(9), 1273–1294.
Cavanagh, J. F. (2015). Cortical delta activity reflects reward prediction error and related behavioral adjustments, but at different times. *NeuroImage, 110*, 205–216.
Chen, H., & Wyble, B. (2015). Amnesia for object attributes: Failure to report attended information that had just reached conscious awareness. *Psychological Science, 26*(2), 203–210.
Chua, F. K. (2005). The effect of target contrast on the attentional blink. *Perception & Psychophysics, 67*, 770–788.
Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*(1), 193–222.
van Doorn, J., Aust, F., Haaf, J. M., Stefan, A., & Wagenmakers, E. J. (2023). Bayes factors for mixed models. *Computational Brain & Behavior, 6*, 1–13.
Eckstein, M. P., Mack, S. C., Liston, D. B., Bogush, L., Menzel, R., & Krauzlis, R. J. (2013). Rethinking human visual attention: Spatial cueing effects and optimality of decisions by honeybees, monkeys and humans. *Vision Research, 85*, 5–19.
Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*(3), 225–234.
Eimer, M. (2014). The neural basis of attentional control in visual search. *Trends in Cognitive Sciences, 18*(10), 526–535.
Eimer, M., & Grubert, A. (2014). The gradual emergence of spatially selective target processing in visual search: From feature-specific to object-based attentional control. *Journal of Experimental Psychology: Human Perception and Performance, 40*(5), 1819–1831.
Eimer, M., Kiss, M., & Cheung, T. (2010). Priming of pop-out modulates attentional target selection in visual search: Behavioural and electrophysiological evidence. *Vision Research, 50*(14), 1353–1361.
Esterman, M., & Yantis, S. (2010). Perceptual expectation evokes category-selective cortical activity. *Cerebral Cortex, 20*(5), 1245–1253.
Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2013). *G*Power (Version 3.1.7) [Computer software]*. University of Kiel.
Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics, 64*(5), 741–753.
Forschack, N., Gundlach, C., Hillyard, S., & Müller, M. M. (2023). Attentional capture is modulated by stimulus saliency in visual search as evidenced by event-related potentials and alpha oscillations. *Attention, Perception, & Psychophysics, 85*(3), 685–704.
Foster, J. J., Bsales, E. M., & Awh, E. (2020). Covert spatial attention speeds target individuation. *Journal of Neuroscience, 40*(13), 2717–2726.
Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society, B: Biological Sciences, 360*(1456), 815–836.
Gaspelin, N., Ruthruff, E., & Lien, M. C. (2016). The problem of latent attentional capture: Easy visual search conceals capture by task-irrelevant abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 42*(8), 1104–1120.
Grubert, A., & Eimer, M. (2015). Rapid parallel attentional target selection in single-color and multiple-color visual search. *Journal of Experimental Psychology: Human Perception and Performance, 41*(1), 86–101.
Grubert, A., Krummenacher, J., & Eimer, M. (2011). Redundancy gains in pop-out visual search are determined by top-down task set: Behavioral and electrophysiological evidence. *Journal of Vision, 11*(14), 1–10.
Hesselmann, G., Kell, C. A., Eger, E., & Kleinschmidt, A. (2008). Spontaneous local variations in ongoing neural activity bias perceptual decisions. *Proceedings of the National Academy of Sciences, 105*(31), 10984–10989.
Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience, 2*(3), 194–203.
Jensen, M. S., Yao, R., Street, W. N., & Simons, D. J. (2011). Change blindness and inattentional blindness. *Wiley Interdisciplinary Reviews: Cognitive Science, 2*(5), 529–546.
Jiang, J., Summerfield, C., & Egner, T. (2013). Attention sharpens the distinction between expected and unexpected percepts in the visual brain. *Journal of Neuroscience, 33*(47), 18438–18447.
Kiss, M., Van Velzen, J., & Eimer, M. (2008). The N2pc component and its links to attention shifts and spatially selective visual processing. *Psychophysiology, 45*(2), 240–249.
Kok, P., Jehee, J. F., & De Lange, F. P. (2012). Less is more: Expectation sharpens representations in the primary visual cortex. *Neuron, 75*(2), 265–270.
Lagroix, H. E., Patten, J. W., Di Lollo, V., & Spalek, T. M. (2016). Perception of temporal order during the attentional blink: Using stimulus salience to modulate prior entry. *Attention, Perception, & Psychophysics, 78*, 1064–1073.
Lamy, D., Leber, A., & Egeth, H. E. (2004). Effects of task relevance and stimulus-driven salience in feature-search mode. *Journal of Experimental Psychology: Human Perception and Performance, 30*(6), 1019.
Leblanc, E., Prime, D. J., & Jolicoeur, P. (2008). Tracking the location of visuospatial attention in a contingent capture paradigm. *Journal of Cognitive Neuroscience, 20*(4), 657–671.
Lins, O. G., Picton, T. W., Berg, P., & Scherg, M. (1993). Ocular artifacts in EEG and event-related potentials. I: Scalp topography. *Brain Topography, 6*(1), 51–63.
Luck, S. J. (2014). *An introduction to the event-related potential technique*. MIT Press.
Luck, S. J., Gaspelin, N., Folk, C. L., Remington, R. W., & Theeuwes, J. (2021). Progress toward resolving the attentional capture debate. *Visual Cognition, 29*(1), 1–21.
Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin & Review, 13*, 125–131.
Martens, S., Munneke, J., Smid, H., & Johnson, A. (2006). Quick minds don't blink: Electrophysiological correlates of individual differences in attentional selection. *Journal of Cognitive Neuroscience, 18*(9), 1423–1438.
Maxwell, J. W., Gaspelin, N., & Ruthruff, E. (2021). No identification of abrupt onsets that capture attention: Evidence against a unified model of spatial attention. *Psychological Research, 85*, 2119–2135.
Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology, 35*(1), 99–115.
Morey, R. D., Rouder, J. N., Jamil, T., Urbanek, S., Forner, K., & Ly, A. (2018). Package 'BayesFactor'. Available at https://cran.r-project.org/web/packages/BayesFactor/BayesFactor.pdf.
Nako, R., Wu, R., & Eimer, M. (2014). Rapid guidance of visual search by object categories. *Journal of Experimental Psychology: Human Perception and Performance, 40*(1), 50–60.
Oberauer, K., Awh, E., & Sutterer, D. W. (2017). The role of long-term memory in a test of visual working memory: Proactive facilitation but no proactive interference. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43*(1), 1–22.
Ophir, E., Sherman, E., & Lamy, D. (2020). An attentional blink in the absence of spatial attention: A cost of awareness? *Psychological Research, 84*(4), 1039–1055.
Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73–89.
Polich, J. (1990). P300, probability, and interstimulus interval. *Psychophysiology, 27*(4), 396–403.
Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology, 118*(10), 2128–2148.
Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3–25.
Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The visual attentional blink and an amodal task-switch deficit. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*(4), 979–992.
Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*(3), 849–860.
Richter, D., & de Lange, F. P. (2019). Statistical learning attenuates visual activity only for attended stimuli. *elife, 8*, Article e47869.
Rock, I., Linnett, C. M., Grant, P., & Mack, A. (1992). Perception without attention: Results of a new method. *Cognitive Psychology, 24*(4), 502–534.
Rungratsameetaweemana, N., Itthipuripat, S., Salazar, A., & Serences, J. T. (2018). Expectations do not alter early sensory processing during perceptual decision-making. *Journal of Neuroscience, 38*(24), 5632–5648.
Rungratsameetaweemana, N., & Serences, J. T. (2019). Dissociating the impact of attention and expectation on early sensory processing. *Current Opinion in Psychology, 29*, 181–186.
Seibold, V. C., & Rolke, B. (2014). Does temporal preparation speed up visual processing? Evidence from the N2pc. *Psychophysiology, 51*(6), 529–538.

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature Neuroscience, 8*(10), 1391–1400.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception, 28*(9), 1059–1074.

Smout, C. A., Tang, M. F., Garrido, M. I., & Mattingley, J. B. (2019). Attention promotes the neural encoding of prediction errors. *PLoS Biology, 17*(2), Article e2006812.

Smulders, F. T. (2010). Simplifying jackknifing of ERPs and getting more out of it: Retrieving estimates of participants' latencies. *Psychophysiology, 47*(2), 387–392.

Summerfield, C., & Egner, T. (2009). Expectation (and attention) in visual cognition. *Trends in Cognitive Sciences, 13*(9), 403–409.

Summerfield, C., & Egner, T. (2016). Feature-based attention and feature-based expectation. *Trends in Cognitive Sciences, 20*(6), 401–404.

Treisman, A. (2014). The psychological reality of levels of processing. *Levels of Processing in Human Memory*, 301–330.

Ulrich, R., & Miller, J. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology, 38*(5), 816–827.

Verleger, R., Śmigasiewicz, K., & Möller, F. (2011). Mechanisms underlying the left visual-field advantage in the dual stream RSVP task: Evidence from N2pc, P3, and distractor-evoked VEPs. *Psychophysiology, 48*(8), 1096–1106.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 24*(6), 1656–1674.

Vul, E., Hanus, D., & Kanwisher, N. (2009). Attention as inference: Selection is probabilistic; responses are all-or-none samples. *Journal of Experimental Psychology: General, 138*(4), 546–560.

Wei, P., & Ji, L. (2021). Reward expectation modulates N2pc for target selection: Electrophysiological evidence. *Psychophysiology, 58*(8), Article e13837.

Wolfe, J. M. (2021). Guided search 6.0: An updated model of visual search. *Psychonomic Bulletin & Review, 28*(4), 1060–1092.

Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. *Nature Human Behaviour, 1*(3), 1–8.

Woodman, G. F., & Luck, S. J. (1999). Electrophysiological measurement of rapid shifts of attention during visual search. *Nature, 400*(6747), 867–869.

Wyart, V., Nobre, A. C., & Summerfield, C. (2012). Dissociable prior influences of signal probability and relevance on visual contrast sensitivity. *Proceedings of the National Academy of Sciences, 109*(9), 3593–3598.

Wyble, B., & Chen, H. (2017). Memory consolidation of attended information is optional: Comment on Jiang et al. (2016). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43*(6), 997–1000.

Wyble, B., Potter, M. C., Bowman, H., & Nieuwenstein, M. (2011). Attentional episodes in visual perception. *Journal of Experimental Psychology: General, 140*(3), 488–505.

Yon, D., Gilbert, S. J., de Lange, F. P., & Press, C. (2018). Action sharpens sensory representations of expected outcomes. *Nature Communications, 9*(1), 1–8.

Zhou, Z., Chen, Y., & Fu, S. (2022). The effects of expectation on attention are dependent on whether expectation is on the target or on the distractor. *Acta Psychologica Sinica, 54*(3), 221–235.

Zivony, A., Allon, A. S., Luria, R., & Lamy, D. (2018). Dissociating between the N2pc and attentional shifting: An attentional blink study. *Neuropsychologia, 121*, 153–163.

Zivony, A., & Eimer, M. (2020). Perceptual competition between targets and distractors determines working memory access and produces intrusion errors in rapid serial visual presentation (RSVP) tasks. *Journal of Experimental Psychology: Human Perception and Performance, 46*(12), 1490–1510.

Zivony, A., & Eimer, M. (2021a). Distractor intrusions are the result of delayed attentional engagement: A new temporal variability account of attentional selectivity in dynamic visual tasks. *Journal of Experimental Psychology: General, 150*(1), 23–41.

Zivony, A., & Eimer, M. (2021b). The number of expected targets modulates access to working memory: A new unified account of lag-1 sparing and distractor intrusions. *Journal of Experimental Psychology: Human Perception and Performance, 47*(11), 1543–1560.

Zivony, A., & Eimer, M. (2022a). Expectation-based blindness: Predictions about object categories gate awareness of focally attended objects. *Psychonomic Bulletin & Review, 29*(5), 1879–1889.

Zivony, A., & Eimer, M. (2022b). The diachronic account of attentional selectivity. *Psychonomic Bulletin & Review, 29*, 1118–1142.

Zivony, A., & Lamy, D. (2014). Attentional engagement is not sufficient to prevent spatial capture. *Attention, Perception & Psychophysics, 76*(1), 19–31.

Zivony, A., & Lamy, D. (2018). Contingent attentional engagement: Stimulus-and goal-driven capture have qualitatively different consequences. *Psychological Science, 29*(12), 1930–1941.

Zuanazzi, A., & Noppeney, U. (2019). Distinct neural mechanisms of spatial attention and expectation guide perceptual inference in a multisensory world. *Journal of Neuroscience, 39*(12), 2301–2312.