Evidence that the Attention Blink Reflects Categorical Perceptual Dynamics

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Abstract

Among the numerous formal and informal theories of the attentional blink, the common theoretical thread is that the deficit stems from selective attention and working memory processes being tied up in processing the first target (T1) when the second target (T2) appears. Rusconi & Huber (2017) challenged this view by proposing the 'perceptual wink' model of the AB, which posits that for categorical AB tasks (e.g., number/letter) the deficit reflects a failure to perceive that T2 belonged to the target category. The model makes the assumption that perception is 'multi-faceted'; that is, there are separate, independent perceptual representations for an item's identity and its category, and that either representation can be used to drive performance (e.g., trigger attentional encoding) depending on the task demands. To differentiate between attention versus perceptual accounts of the AB, we used a stripped down RSVP task where participants were asked to either report the identity or category of the third item in a sequence of characters. In support of the perceptual account, we found priming for identity or category depending on the task. Furthermore, we found that the category results were analogous to the AB and the spread of sparing even though the first character was not a target and there was no need to selectively filter items into working memory.

Keywords: perception; attention; priming; attentional blink

Introduction

Through the lens of the attention literature, it may appear that the representational contents of perception are rather limited and basic, including low-level properties such as brightness, orientation, contrast, etc. (e.g. Treisman & Gelade, 1980). However, there is long-standing, robust evidence supporting the idea that perception is able to represent higher-level, more abstract stimulus properties that go beyond the mere configuration of parts; that is, properties that are not inherent in the low-level features of stimuli. In the present paper, we take a 'multi-faceted' view of perception, which holds that perception is capable of representing a range of low- and high-level stimulus properties independently, with performance in different tasks depending on the perceptual dynamics of the task-relevant properties.

The work inspiring this multi-faceted view shows that an item's alphanumeric category (a higher-level feature not inherent in the configuration of its parts) can be represented independently of that item's identity (a lower-level feature that is inherent in the configuration of its parts) in a manner that is consistent with perceptual identification. Most notably, Brand (1971) compared search times for (1) within category identity search (e.g., search for the '5' amongst other numbers), (2) between category identity search (e.g., search for the '5' amongst letters), and (3) categorical search (e.g., search for any number amongst letters). Crucially, condition (3) yielded the shortest search times regardless of practice with the task. Brand (1971) concluded that items can be processed categorically and independent of identity, which enables more efficient search. These findings were supported by Egeth et al. (1972), who found no effect of distractor set size on reaction time (RT) when searching for a number target amongst letters. Schneider & Shiffrin (1977a,b) added to this body of work by replicating the above results and showing that such fast, efficient categorical detection can occur for learned categories with sufficient practice. Taken together, these findings support the multi-faceted view by showing that visual displays can be processed in terms of separate, independent perceptual representations: alphanumeric category, or identity.

If perception is multi-faceted, then visual search paradigms involving categorically defined targets and distractors might reflect perceptual dynamics rather than top-down selective attentional processes. Consistent with this idea, Rusconi & Huber (2017) recently argued that categorical AB effects (e.g., search for target letters amongst number distractors) can be explained as perceptual rather than attentional deficits when the multi-faceted view is considered. In the present paper, we introduce the AB as an attentional phenomenon, and then contrast this with Rusconi & Huber (2017)'s 'perceptual wink' explanation. The goal of this paper is to present new empirical evidence testing counterintuitive predictions of this perceptual explanation of the AB by examining whether perception for category produces the same patterns of results as found for AB tasks that require report of identity.

The Attentional Blink

The AB is a robust deficit in the ability to report the identity of a target (T2) if it appears 200-400 milliseconds after another target (T1) in an RSVP stream of distractors. The temporal difference, or 'lag,' between T1 and T2 is manipulated by changing the order of items in the RSVP stream, where items are presented for 100 ms each. In categorical AB tasks, T2 report accuracy is good, and sometimes even improved if T2 appears immediately following T1 (known as lag 1 sparing),

and then falls significantly for lags 2 to 4, until it recovers to some degree by lags 5 or 6. This u-shaped performance curve across lags is the trademark of the AB.

Many formal and informal theories of the AB have been proposed (for review, see Dux & Marois, 2009), but all of these theories assume that the blink occurs when attention is unable to adequately handle the second target. For example, Raymond et al. (1992) posited attentional inhibition of perceptual processing to avoid distractor interference as a cause for the AB, while Chun & Potter (1995) argued that the deficit stemmed from a bottleneck in attentional resources while loading T1 into working memory. In these theories, and most other popular AB theories, the AB deficit is characterized in terms of top-down selective attention; the only difference between theories is the specific attentional mechanism at play. As a result, most AB theories are committed to an object-based characterization of the RSVP task. On this view, a target in the RSVP stream is 'bound' into an object and loaded into working memory in the absence of a blink; awareness of the target and its features is all-or-none in the sense that any information about the target and its features must come from the bound target-object. However, within the blink, the item remains unbound, implying a failure to report all of the properties of the missed target.

The Perceptual Wink

Contrary to this view, the perceptual wink account of Rusconi & Huber (2017) posits that the AB can be explained by ubiquitous perceptual dynamics operating within a multifaceted perceptual system. Specifically, Rusconi & Huber (2017) argue that there are perceptual nodes (i.e., collections of neurons with similar inputs and outputs) that respond selectively to the categorical features of targets and distractors, which Rusconi & Huber (2017) term the target- and distractor-detectors for a specific task. According to this view, the perceptual dynamics of these target- and distractor-detectors drives performance in the AB task. In contrast to object-based attentional theories, this interpretation of the AB leaves some properties of the target intact: while a deficit in the target-detector (i.e., a failure to realize that T2 belonged to the target category) prevents the loading of T2's identity into working memory, the perception of T2's identity (and other features) might be processed without any deficit, but soon forgotten.

The perceptual wink model adopts the perceptual dynamics of the neural Responding Optimally with Unknown Sources of Evidence (nROUSE) model of Huber & O'Reilly (2003). This hierarchical, multi-layer neural network was built to explain the temporal parsing of the continuous stream of visual input. More specifically, nROUSE assumes that perceptual habituation via synaptic depression (Markram & Tsodyks, 1997) reduces unwanted blending between recently viewed items and the current item Huber & O'Reilly (2003). These perceptual dynamics have successfully explained a wide range of tasks that show repetition deficits (Huber, 2008; Tian & Huber, 2010; Rieth & Huber, 2010; Huber, Clark, et al., 2008; Davelaar et al., 2011; Huber, Curran, et al., 2008; Tian & Huber, 2013). As applied to the AB, the perceptual wink model assumes that the AB is just another repetition deficit, only the deficit in this case is for perception of the target category.

According to the perceptual wink model, the perceptual input from T1 sends activation to the target-detector node, triggering attentional encoding of the most active identity into working memory, with the strength of encoding dictated by the magnitude of the target detector's activation (i.e., the extent to which the observer appreciates that T1 is a target). When T2 appears immediately after T1, there is a *positive priming* effect for 'targetness': T2 is encoded because it rides off of the categorical activation from T1, giving rise to lag 1 sparing. However, if a distractor appears between the two targets, there is *categorical interference* from the distractor-detector, compounded with habituation in the target-detector, which prevents the triggering of attentional encoding [1]. Thus, at lags 2 through 4, even though T2 is adequately processed in terms of its identity and features, it is not appreciated as a target, and as a result, goes unreported. Then, recovery from the blink past lag 4 is a result of habituation for the distractor-detector combined with recovery from habituation for the target-detector.

By examining identity priming within an AB task defined by letter-case, key predictions of the perceptual wink model were confirmed, using perceptual dynamics determined from previously reported perceptual priming results. In addition, model simulations showed that the model readily handled a wide range of effects in the AB literature, including the 'spread of sparing' (the lag 2 deficit disappears when the intervening item is also a target Di Lollo et al., 2005), and the subsequent reversal of this effect when a blank screen is inserted Chen & Zhou (2015).

Experiment

Rusconi & Huber (2017) established the perceptual wink model as a viable alternative to object-based attentional theories of the AB. However, the main argument for preferring the perceptual wink model was parsimony: use of the same dynamics that previously explained perceptual effects also explained the AB and priming within the AB. The current study sought to take this a step farther by directly testing the perceptual wink's core assumption that in the midst of the blink, independent of top-down selective attention, there is a deficit in category perception, but identity perception is unaltered. Thus, we aimed to test whether there are separate, distinct perceptual dynamics governing category- and identity-based versions of the same RSVP task that operate independently of top-down attentional selection, and if so, whether these categorical perceptual dynamics mirror traditional AB findings

[1] Importantly, the model is able to explain the persistence of a reduced AB without distractors entirely through habituation in the target-detector and its subsequent recovery (modeled in Rusconi & Huber (2017)); distractor interference is not necessary for the AB, it simply deepens the deficit.

(i.e., the deficit, lag 1 sparing, and the spread of sparing). This was examined with a task that did not require selective attention to items from a target category but rather simple forced choice decisions about the category or identity (manipulated between subjects) of a third and final character. With just three characters, this was well within the capacity of working memory. Furthermore, the first two characters were represented at the time of test to reduce the need to maintain them in an attempt to disambiguate sequential order. Using this design, we were able to test boiled down, three-character analogs of the lag 2 AB deficit, lag 1 sparing, and the spread of sparing that required no top-down selective attentional filtering into working memory, and to compare performance in category and identity groups across six identical priming conditions designed to differentially affect identity and category perception.

Design and Methods

An example trial and more detailed information about the experimental design is presented in Figure 1. On each trial of the experiment, participants were shown two characters in RSVP sequence for 100 milliseconds each, and then shown a third character at perceptual identification threshold (determined for each subject with a calibration block that employed a staircase method), presented either immediately after the second character, or after a 400 millisecond blank screen. This difference in blank screen duration is meant to mirror lags 2 and 6 of the AB. Then, participants were asked to complete a two-alternative forced-choice task (2AFC), with one group (identity group) making a choice between the third character (the target) versus a different character drawn from the same category (the foil), while another group (category group) made a number/letter categorical choice regarding the target, without needing to indicate it's identity. While making their choice, participants were shown the first two characters of the sequence to reduce any tendency to hold those items in working memory.

There were six possible trial types, created by crossing three identity priming conditions with two category priming conditions. It may be helpful to follow along with the trial examples and figure description in Figure 2 to best understand how these conditions differ. Identity priming was manipulated through the identity of the first character (the second character never reappeared as the target or the foil), while category priming was manipulated through the category of the second character (analogous to the intervening item between targets in the AB). This design choice was necessary to cross identity and category priming conditions in a compact way. The three trial types for identity priming were target-primed, where the identity of the first item matched that of the target, foil-primed, where the identity of the first item matched that of the incorrect answer, and neither-primed, where the category (and thus identity) of the first item differed from that of the third item. In prior work, it was established that with immediate repetition priming and no intervening distractor, brief repetition primes produce a target-primed advantage and a foil-primed deficit, in comparison to the neither-primed condition (Huber, 2008). The two trial types for category priming were target-primed, where the category of the second item matched the category of the target, and foil-primed, where the category of the second item did not match that of the target. Put another way, there were two versions of the three typical identity priming conditions: one version where the category of the intervening item matched the target, and one where it did not. To ensure that identity was not predictive of the correct answer in any way, there were twice as many identity neither-primed conditions than identity target- or foil-primed conditions. Both identity and category groups received the same sequences and distribution of trial types.

Importantly, these trial types mirror critical conditions of the AB task. The three foil-primed conditions for category map onto the traditional AB, where two items of the same category are separated by an item of a different category. In addition, the three target-primed conditions for category mirror the spread of sparing when all three items belong to the same category (target- and foil-primed conditions for iden-

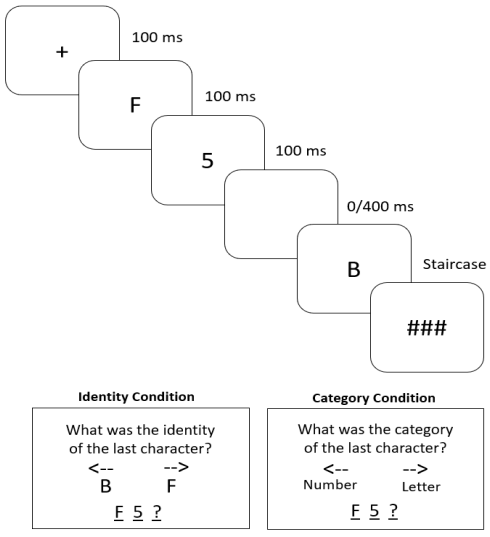

Figure 1: An example trial of the experiment. Participants used the left and right arrow keys to make their decisions and were given feedback. For the identity group, this trial is considered foil-primed, because the prime ('F') is given as the foil (incorrect) response option. For the category group, this trial is also considered foil-primed because the intervening category does not match that of the target. This condition mirrors lag 2 of traditional AB paradigms. Participants completed a training block, and then a calibration block that modulated the presentation time of the 3rd character to keep accuracy between 62.5 and 82.5 percent. After, participants completed two 160-trial experimental blocks. There were six trial types crossed with two blank screen conditions, but there were twice as many neither-primed identity conditions. This means that there were 20 trials per condition per subject across both blocks for all conditions, other than the neither-primed identity conditions, which had 40 trials each.

tity), and lag 1 sparing when the first item differs in category from the others (neither-primed condition for identity).

The results of these conditions are crucial for differentiating between attentional and perceptual accounts of the AB. Because there is no need for attentional selection or loading of the first two items in the sequence, attentional accounts predict that these characters will have no effect on the ability to report the target; that is, attentional accounts predict no difference between target- and foil-primed category conditions, and no effect of blank screen duration (other than a possible main effect where longer durations yield better performance due to less perceptual masking). On the other hand, the perceptual account predicts deficits in the categorical foil-primed conditions and relative benefits in the categorical target-primed conditions when there is no blank screen, and recovery to a relatively equal baseline for all conditions with a 400 ms blank screen when the effects of perceptual habituation and interference have subsided.

Another important divergence in predictions between these accounts comes from the difference between the identity and category groups. According to attentional accounts, there should be no difference between these conditions because in both cases the target must be bound into an object representation and loaded into working memory to ensure accurate report. However, the multi-faceted perceptual view predicts that these groups should show priming effects for the task-relevant perceptual attribute: the categorical condition should show priming for category but not for identity, and the identity condition should show priming for identity but not category.

Results and Discussion

All p-values reported here were taken from a 2x2x6 (group x blank screen duration x trial type) mixed ANOVA and post-hoc t-tests based on of the ANOVA results (all main effects and interactions for the ANOVA had $p < 0.01$). 30 undergraduates from UMass Amherst were run in the identity group, and 31 were run in the category group. The staircase method of altering the presentation time of the third character resulted in a mean of 5 frames (at 8.33 ms per frame) for the identity group, and a mean of 6 frames for the category group. Proportion correct scores across all possible conditions of the experiment (6 priming trial types and 2 blank screen durations) are shown in Figure 2. A quick scan of this table shows that despite seeing identical sequences, the identity and category groups showed huge differences in performance. The main effect underlying this difference is that performance in the identity group was unaffected by the category of the intervening item (2nd character), while the category group was, as predicted by the multi-faceted account. Thus, to make these data more readable and clear, we collapsed across the 6 trial types for the identity and category groups to form corresponding priming conditions, depicted in Figure 3. Specifically, for the identity group, there was no significant difference between conditions 1 and 4, 2 and 5, and 3 and 6 (all $p > 0.05$), so these were collapsed into their 3 corresponding priming conditions: target-primed, foil-primed, and neither-primed. Likewise, for the category group, the identity of the first character did not affect performance. Specifically, there was no difference between conditions 1-3 ($p > 0.05$), or conditions 4-6 ($p > 0.05$), so they were collapsed into their corresponding priming conditions: foil-primed and target-primed.

For the priming-collapsed identity group conditions, a significant deficit was found for the foil-primed condition ($p < 0.001$; difference of means = 0.12), but there was no significant difference between the target- and neither-primed conditions ($p = 0.13$; difference of means = 0.03). At 400 ms, there was no significant difference between any of these three conditions (all $p > 0.05$). For the priming-collapsed category group conditions, there was a large difference between target- and foil-primed conditions with no blank screen ($p < 0.001$; difference of means = 0.27). More specifically, when the intervening character was from the opposite category (i.e., foil-primed), as is the case for the AB, category forced choice decisions were not statistically different from chance (50 percent). In other words, in this case, observers completely failed to perceive the category of the target.

Proportion Correct Across Conditions				
Priming Condition	Trial Example	Blank Screen Duration (s)	Identity Condition (H or L)	Category Condition (Number or Letter)
1	H - 4 - H	0	0.67	0.48
		0.4	0.78	0.84
2	H - 4 - L	0	0.54	0.51
		0.4	0.78	0.87
3	6 - 4 - L	0	0.63	0.52
		0.4	0.79	0.86
4	H - B - H	0	0.67	0.78
		0.4	0.74	0.86
5	H - B - L	0	0.56	0.82
		0.4	0.80	0.92
6	6 - B - L	0	0.65	0.72
		0.4	0.78	0.89

Figure 2: Mean performance (proportion correct) across all possible conditions (6 trial types crossed with 2 blank screen durations) in the experiment for both the identity and category groups. The 'Trial Example' column gives an example of the three characters that could be displayed in a given trial type, with the last character being the target. The exact numbers and letters chosen for these examples are arbitrary. The parentheses in each condition column heading refer to the response option that participants were given at the end of the trial. For example, the '(H or L)' in the 'Identity Condition' column refers to the choice that would be given for the sequences in the 'Trial Example' column.

In contrast, this category deficit greatly diminished with a 400 ms blank screen ($p = 0.2$; difference of means = 0.03), and category perception was near ceiling, regardless of whether the intervening character was the same or different from the target. Critically, chance performance for the category group at 0 ms occurred even though the very same displays produced well above chance performance for the identity group neither-primed condition. Thus, for sequences corresponding to lag 2 AB deficits, we observed profound category deficits compared to identity perception. In contrast, at 400 ms, corresponding to lag 6 recovery in an AB task, category perception was nearly perfect, better than the identity neither-primed condition. This supports the claim that displays like the AB produce category perception deficits but not identity perception deficits.

In addition to the basic blink and recovery despite preserved identity perception, particular comparisons highlight other typical AB effects. Lag 1 sparing occurs when there are back-to-back items from the target category, and is realized by comparing condition 6 to condition 3 (refer to Figure 2) of the category group in the 0 ms condition. The spread of sparing occurs with three back-to-back items from the target category, and is realized by comparing condition 5 to condition 2 of the category group in the 0 ms condition. Thus, despite the lack of selective attention to the first two characters in the stream, results corresponding to the canonical AB deficit and recovery, lag 1 sparing, and the spread of sparing were found, with this occurring for the same displays that failed to produce identity deficits (but succeed in producing identity repetition priming, with the same recovery temporal profile as recovery from categorical deficits).

Conclusion

While Rusconi & Huber (2017) established the perceptual wink model as a viable and more parsimonious account of the AB, there were no concrete empirical reasons to prefer it over competing attentional accounts. The present experiment was designed to test differential predictions of the perceptual wink as compared to attentional theories. The category group revealed a pattern of results that mirrored all of the basic AB effects, with lag 1 sparing, a lag 2 deficit, recovery after a 400 ms intervening blank, and the spread of sparing if the intervening character was also from the same category as the target. If these results reflected attentional filtering, despite our efforts to obviate the need for such filtering by re-presenting the first two characters (and by only testing the third character), then object-based attentional theories would predict similar deficits for the identity group because the displays were the same for both groups. In support of the multifaceted view of perception, and as predicted by the perceptual wink model, the results for the identity group were radically different, revealing identity priming effects that disappeared with a 400 ms delay, and, more importantly, a lack of identity deficits for conditions that produced profound category perception deficits.

At first blush, these results may seem to contradict the results of Raymond et al. (1992) and Chun (1997), where the AB was eliminated when participants were asked to ignore T1 and focus on reporting T2 only. Many studies have cited these results as evidence that the AB is not perceptual. However, in Raymond et al. (1992), the first target was always a

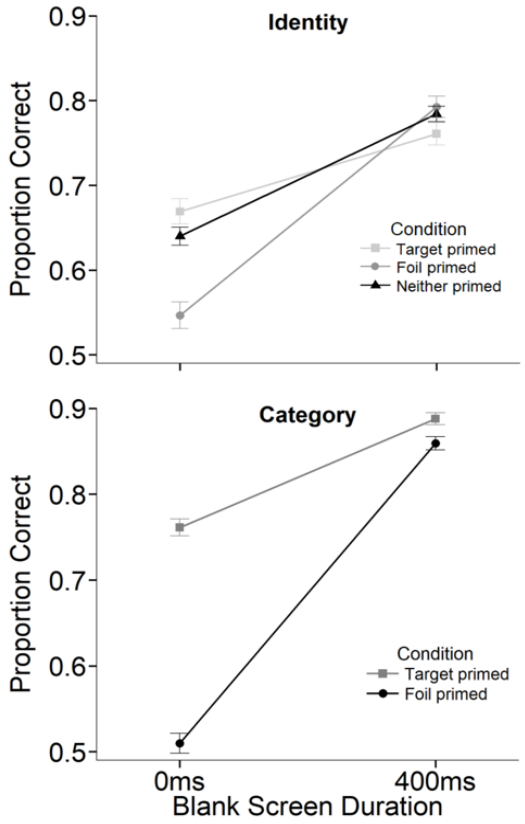

Figure 3: Proportion correct for the collapsed priming conditions as a function of blank screen duration. The error bars show one standard error in both directions. For the identity condition, the target-primed data was collapsed across the two conditions where the first character matched the identity of the target (conditions 1 and 4 of previous figure), the foil-primed data was collapsed across the two conditions where the first character matched the foil option (conditions 2 and 5 of previous figure), and the neither-primed data was collapsed across the two conditions where the first character was a different category (and thus identity) than the target (conditions 3 and 6 of previous figure). The second character never matched the identity of the target. For the category condition, the target-primed data was collapsed across the three conditions where the category of the second character matched that of the target (conditions 1-3 of previous figure), and the foiled-primed data was collapsed across the three conditions where the category of the second character did not match that of the target (conditions 4-6 of previous figure).

white letter, and the second target was always a black 'X'. Completing such a task requires a sort of task-switch rather than categorical detection (there is no shared target defining perceptual attribute between these two targets), so it does not fall under the scope of the perceptual wink model. Instead, this deficit may reflect attentional switching dynamics, in which case it is unsurprising that there was no deficit in the absence of a first task. In Chun (1997), targets were always colored differently, and the color of T2 was always given at the start of each trial. Again, participants could rely on a target-detector sensitive to the color of T2 but not T1, so there is no reason to think that habituation or categorical interference would play a role in such a task. As a thought experiment, one could imagine a true categorical AB task in which participants were asked to ignore the first target but only report the second (e.g., report the identity of the second letter in an RSVP stream with two letters and number distractors). According to the perceptual wink model, such a task should produce a blink. However, in this thought experiment, the counter argument would be that the first target required attention so as to know that the second target was indeed second. Thus, the only way to properly address this question is with a task that did not require any reference to the first target as being a target in any manner. That is what the current experiment has done, finding profound category perception deficits that correspond to typical AB results.

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