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Repetition priming in selective attention: A TVA analysis

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ABSTRACT

Current behavior is influenced by events in the recent past. In visual attention, this is expressed in many variations of priming effects. Here, we investigate color priming in a brief exposure digit-recognition task. Observers performed a masked odd-one-out singleton recognition task where the target-color either repeated or changed between subsequent trials. Performance was measured by recognition accuracy over exposure durations. The purpose of the study was to replicate earlier findings of perceptual priming in brief displays and to model those results based on a Theory of Visual Attention (TVA; Bundesen, 1990). We tested 4 different definitions of a generic TVA-model and assessed their explanatory power. Our hypothesis was that priming effects could be explained by selective mechanisms, and that target-color repetitions would only affect the selectivity parameter (α) of our models. Repeating target colors enhanced performance for all 12 observers. As predicted, this was only true under conditions that required selection of a target among distractors, but not when a target was presented alone. Model fits by TVA were obtained with a trial-by-trial maximum likelihood estimation procedure that estimated 4–15 free parameters, depending on the particular model. We draw two main conclusions. Color priming can be modeled simply as a change in selectivity between conditions of repetition or swap of target color. Depending on the desired resolution of analysis; priming can accurately be modeled by a simple four parameter model, where VSTM capacity and spatial biases of attention are ignored, or more fine-grained by a 10 parameter model that takes these aspects into account.

1. Introduction

Priming occurs when an instance of stimulus presentation influences later responses. Priming effects are ubiquitous in the central nervous system and have been reported in simple neuro-computational processes (e.g. Breitmeyer, Ro, & Singhal, 2004), semantic processes (e.g. Dehaene et al., 1998; Neely, 1977) and even quite complex social situations (e.g. Klein et al., 2014). Repetition priming is a specific kind of priming that has primarily been studied in the context of visual attention (Kristjánsson & Campana, 2010). In such tasks, repetition of a recently important object or object-feature will facilitate target selection. Observers typically search for an object defined by a particular feature; e.g. a color singleton. If this target-defining feature remains the same on consecutive trials, performance will usually improve compared to trials when the feature changes (Maljkovic & Nakayama, 1994).

By some accounts, the priming is feature-based and part of perceptual stimulus processing. These accounts can explain results from a multitude of studies where repeated visual features have been shown to affect performance independently and simultaneously; i.e. that repetition of one feature is not affected by the repetition or alternation of another stimulus feature (e.g. Kristjánsson, 2006; Maljkovic & Nakayama, 1994). Not all studies have observed independent priming of features, however. Huang and Pashler (2005) found, for briefly displayed search arrays, that observers' performance (measured by localization accuracy) did not improve when a target feature was repeated, unless repetitions were expected due to non-random presentation contingencies. Therefore, they proposed a perceptual account of priming, specific to conditions where expectancy was heightened for feature repetitions, but concluded that feature priming in regular visual search arrays (specifically Maljkovic & Nakayama, 1994) reflected post-perceptual effects (Huang & Pashler, 2005, pp. 157).

In contrast, Yashar and Lamy (2010; see also Sigurdardottir, Kristjánsson & Driver, 2008) reported feature (shape) priming in briefly presented stimulus arrays, but only when the task required focused attention. They presented observers with identical stimulus arrays in two different conditions. In one, observers had to focus attention on fine details of a stimulus, but in the other they only had to judge whether a feature singleton was presented on the right or left side of a stimulus array. Priming effects were only observed in the former task. Ásgeirsson et al. (2014) generalized this result further by presenting observers with brief arrays of colored letters, where they were to report an odd-one-out letter among distractors. There were clear priming effects for both color

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and positions, and these were independent of each other, a finding at odds with some studies of priming in standard visual search (Campana & Casco, 2009; Pratt & Castel, 2001), and with the episodic retrieval view of priming.

Hillstrom (2000) also proposed that episodic representations are the unit of priming; arguing that priming operates on visual short-term representations of earlier trials. In another study, Huang, Holcombe, and Pashler (2004) demonstrated that stimulus features did not prime independently of each other but collectively, as an episode of feature and response repetition or alternation. The authors accounted for their result with a post-perceptual account, where the priming mechanism was hypothesized to exert its influence at a decision-making, rather than perceptual, stage of processing. They concluded that when all target features are repeated, along with the previous response, the decision about target identity is faster.

Ásgeirsson and Kristjansson (2011) made slight adjustments to the task used by Huang et al. (2004), and found that their episodic priming effects were contingent on task difficulty. When a target-defining feature was sufficiently salient, priming effects for that feature were independent of other features. When the target-defining feature was not very salient, the priming effect interacted with other features as if it was episode or object-based (see Kristjánsson, Ingvarsdóttir, & Teitsdóttir, 2008, for a study of feature versus object-based priming). Recently, the idea that priming reflects memory traces of episodes has resurfaced. Thomson & Milliken (2011) argued that since priming was affected by a switch in task (presumably a higher level effect), this was evidence for priming of episodes, likening this to the priming of event files (Hommell, 2011).

From the available literature, it seems unlikely that a single mechanism is responsible for all repetition priming. In fact, there are some noteworthy multi-stage theories of priming (Kristjánsson & Campana, 2010; Lamy, Yashar, & Ruderman, 2010), where perceptual and post-perceptual components are assumed. In the current context, it is important that there is an accumulation of priming over sequences of adjacent trials, independent of response demands, response mapping and speeded decision-making. In what follows, we limit our investigation to such effects.

1.1. Modeling priming in TVA

In this study, we investigate priming effects using a Theory of Visual Attention (TVA Bundesen, 1990). The theory treats visual selection and recognition as a problem of making perceptual categorizations of the form "object x has the feature i" where object x is a perceptual object, e.g. an alphanumeric character, and a feature i is a perceptual feature, e.g. a color or shape. Perceptual categorizations are made when a perceptual object enters visual short-term memory. Describing this process are two central equations; the rate equation (Eq. (1)) describes the rate of categorizations (objects/s) and the weight equation (Eq. (2)) describes the relative resources devoted to each visual object. The rate v for object x belonging to category i is given by Eq. (1):

$$v(x,i) = \eta(x,i)\beta_i \frac{\omega_x}{\sum_{z\in S}\omega_z} \qquad (1)$$

where $\eta(x, i)$ is the strength of the sensory evidence that object x belongs to category i, β_i is the perceptual decision bias associated with category i, and w_x and w_z are the attentional weights of objects x and z. S represents the set of all elements in the visual field. The attentional weights in the rate equation are calculated for each visual object according to its pertinence and physical characteristics by Eq. (2):

$$\omega_x = \sum_{j\in R}\eta(x,j)\pi_j \qquad (2)$$

where $\eta(x, j)$ is the strength of the sensory evidence that element x belongs to category j and π_j is the pertinence of category j. A concrete translation of the mathematical terms in the context of the current experiment is such that v (x, i) is the rate of encoding into VSTM where x is a digit between 1 and 9; $\eta(x, i)$ represents the evidence that digit x belongs to one of the categories 1–9; π_j represents the current importance of a feature category, e.g. the color red, while $\eta(x, j)$ is the strength of sensory evidence that digit x is a red element. Finally, the weight w_x represents how resources are distributed to x. This value is only meaningful relative to the weight of other objects in the display. In the current study, the weights of visual objects are primarily interesting in that they form the basis of the selectivity parameter (α), which simply describes the ratio between a distractor and target weight, all other things being equal.

Our primary aim is to test several model definitions and see how repetition priming is best accounted for within TVA (Ásgeirsson et al., 2014). In our earlier paper, we demonstrated independence between color and position priming in a brief exposure selective attention tasks (partial report of a color singleton). We proposed a plausible account for the results by extending simple assumptions from TVA (Bundesen, 1990) to the obtained data, collapsed over all observers. Specifically, we suggested that color and position priming effects were obtained by the modulation of selectivity by increased *pertinence* of the primed attributes, i.e. the implicit importance of a repeated color or spatial position increase by repetition. Here, attempt to replicate and expand on those results by isolating the parameters necessary to describe color priming at an individual trial-by-trial level by fitting TVA-models to each participants data (see also Tseng, Glaser, Caddigan, & Lleras, 2014, for a perceptual decision-making approach to modeling response time benefits from color priming), whereby we may confirm or reject the viability of our earlier hypothesis (Ásgeirsson et al., 2014) by a much more detailed analysis. From earlier work (Goolsby & Suzuki, 2001; Meeter & Olivers, 2006; Yashar & Lamy, 2010) we simply hypothesize that priming can be described as an increase in selectivity for repeated features compared to feature "swaps"; when the target-defining feature is swapped with a distractor-defining feature, and vice versa. Goolsby and Suzuki (2001) demonstrated that color priming effects were virtually eliminated in "pop-out" visual search for an odd-one-out colored singleton when the position of a target was pre-cued, leaving selective attention almost untaxed. Meeter and Olivers (2006) went on to show that color priming effects are eliminated by presenting a target alone, without distractors (experiment 3). Because of these results, we hypothesize that color priming takes place only under circumstances of strong selection pressure (i.e. where multiple visual objects compete for selection) but not when selective pressure is minimal (Goolsby & Suzuki, 2001) or absent (Kristjansson, Saevarsson, & Driver, 2013; Meeter & Olivers, 2006; but see also Rangelov, Müller & Zehetleitner, 2011a,b). In terms of TVA, we may hypothesize the following: when a feature belongs to a target, it increases in pertinence, and, similarly, when a feature appears as a feature of a distractor, it decreases in pertinence. These changes are expressed in the π-values of Eq. (2). Consequently, the weight ratios between a distractor and target (defined as α) decrease and processing resources will be more concentrated on the target stimulus. Other things being equal, the repetition-contingent reduction in α leads to a higher rate of target encoding in the race towards visual categorization and consequently a higher probability of a target being reported. If this assumption holds, an increase in performance on feature repetition trials compared to swap trials should result in significant differences in α estimates between the two conditions (model 1).

Another hypothesis we tested by TVA-modeling was whether priming effects for brief masked displays are spatially contingent. Attention is usually not equally distributed in space and it is, therefore, far from certain whether color priming occurs uniformly in the visual field. There may be no relationship between repetition priming and spatial priorities, leaving the pattern of spatial deployment of attention