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Research report

Cortical and subcortical contributions to state- and strength-based perceptual judgments

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ABSTRACT

Perceptual judgments can be made on the basis of different kinds of information: *state-based* access to specific details that differentiate two similar images, or *strength-based* assessments of relational match/mismatch. We explored state- and strength-based perception in eleven right-hemisphere stroke patients, and examined lesion overlap images to gain insight into the neural underpinnings of these different kinds of perceptual judgments. Patients and healthy controls were presented with pairs of scenes that were either identical or differed in that one scene was slightly expanded or contracted relative to the other. Same/different confidence judgments were used to plot receiver-operating characteristics and estimate the contributions of state- and strength-based perception. The patient group showed a significant and selective impairment of strength-based, but not state-based, perception. This finding was not an artifact of reduced levels of overall performance, because matching perceptual discriminability levels between controls and patients revealed a double dissociation, with higher state-based, and lower strength-based, perception in patients vs. controls. We then conducted exploratory follow-up analyses on the patient group, based on the observation of substantial individual differences in state-based perception — differences that were masked in analyses based on the group mean. Patients who were relatively spared in state-based perception (but impaired in strength-based perception) had damage that was primarily in temporo-parietal cortical regions. Patients who were relatively impaired in both state- and strength-based perception had overlapping damage in the thalamus, putamen, and adjacent white matter. These patient groups were not different in any other measure, e.g., presence of spatial neglect symptoms, age, education, lesion volume, or time since stroke. These findings shed light on the different roles of right hemisphere regions in high-level perception, suggesting that the thalamus and basal ganglia play a critical role in state- and strength-based perception, whereas temporo-parietal cortical regions are important for intact strength-based perception.

1. Introduction

How do we detect changes in the environment? Imagine you are shown two photographs of a park and asked whether they are exactly the same or if something about the park was different in the two images. In some cases, you may be able to detect a specific difference—for example, a water fountain that is in one picture but not in the other. Alternatively, you may know that the pictures are different, but are unable to provide details about any specific change.

Thus, there are two kinds of information that can be used for perceptual change detection, which have been referred to as *state-based* and *strength-based* perception (Aly and Yonelinas, 2012; for related distinctions, see Fernandez-Duque and Thornton 2000; Rensink, 2000, 2004), Dehaene et al. (2006), and Howe and Webb (2014)). State- and strength-based perception have been studied by asking individuals to make same/different confidence judgments on pairs of images (e.g., pairs of scenes, faces, fractals, or objects; Aly and Yonelinas, 2012; Aly et al., 2013, 2014). Receiver-operating characteristic (ROC; Green and Swets, 1966; Macmillan and Creelman, 2005) analyses are then used to estimate the contributions of two kinds of perceptual decisions.

State-based perception is associated with high-confidence responses that are rarely in error; it is a discrete state that either occurs or does not, and when it does occur, it is associated with accurate

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awareness of specific details that differentiate two images. The probability of state-based perception is reflected in the upper *x*-intercept of ROCs (Fig. 1). Strength-based perception, on the other hand, is associated with a wider range of confidence responses; it is a continuously-graded signal associated with a feeling that something has changed, with little to no ability to report what that change was. The discriminability afforded by strength-based perception is related to the curvilinearity of ROCs (Fig. 1).

In previous studies, we have found that these two kinds of perception can be doubly dissociated, have different temporal dynamics, and are associated with distinct kinds of conscious experiences (Aly and Yonelinas, 2012; Aly et al., 2013, 2014). For example, state-based perception makes a greater contribution to tasks involving detection of discrete object changes (e.g., a water fountain that is present in one scene but absent in another), is associated with a rapid temporal onset, and subjective experiences are those of consciously perceiving specific, detailed differences. In contrast, strength-based perception makes a greater contribution to tasks involving global or relational change detection (e.g., a subtle manipulation of the distances between component parts of a scene), is associated with a gradual temporal onset, and subjective experiences are those of feeling as if a change has occurred but being unable to pinpoint what that change was (Aly and Yonelinas, 2012; also see Fernandez-Duque and Thornton, 2000; Rensink, 2000, 2004; Dehaene et al., 2006; Galpin et al., 2008; Busch et al., 2009, 2010; Howe and Webb, 2014; but see Simons et al., 2005).

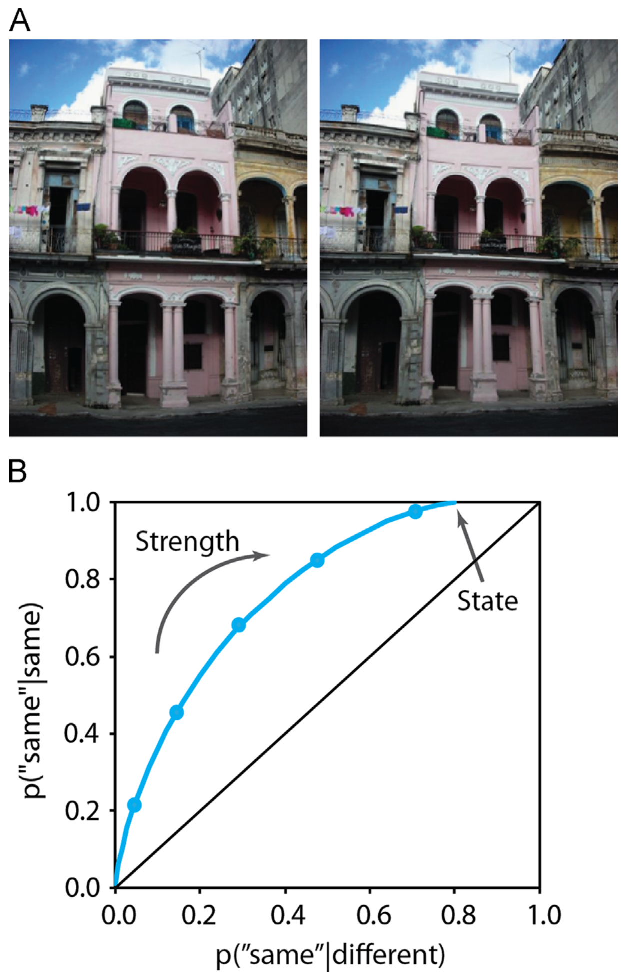

Fig. 1. Assessing state- and strength-based perception. Same/different judgments can be used to estimate the contributions of state- and strength-based perception. For example, participants could be shown pairs of scenes (A) that are either identical or different and asked to make same/different judgments using a confidence scale. In this example, the scenes are different: the image on the left is expanded outward while the image on the right is contracted inward. Same/different confidence ratings are subsequently used to plot receiver-operating characteristics (ROCs). A hypothetical ROC (B), depicting the pattern of results observed in variations of this task in prior studies, is shown here for illustration (Aly and Yonelinas, 2012; Aly et al., 2013, 2014). The left-most point on the ROC reflects the probability of a hit ("same" judgment when images are the same; *y*-axis) and a false alarm ("same" judgment when images are different; *x*-axis) for the most confident "same" response. Subsequent points reflect the cumulative hit and false alarm rates as confidence responses are added on, in order from highest-confidence "same" to highest-confidence "different". The upper *x*-intercept provides an estimate of the probability of state-based perception (further left = higher estimate); this is the point associated with high-confidence, correct "different" responses, with no errors. The degree of curvilinearity of the ROC provides an estimate of strength-based perception (more curved = higher estimate); this reflects the discriminability between equal-variance, signal-detection distributions for same and different items.

Thus, previous behavioral work on state- and strength-based perception has shown that perceptual decisions can be made on the basis of functionally dissociable processes or representations. State- and strength-based perception may reflect differences at early- to mid-level stages of perceptual representation (i.e., what information is represented in visual cortex, depending on the focus of attention) or later stages of decision-making (i.e., what information is used to inform the perceptual decision). While current data do not allow adjudication between these possibilities, it is clear that independent sources of information can be used to guide perceptual judgments.

In a previous neuropsychological study, we investigated the contribution of the hippocampus and surrounding medial temporal lobe (MTL) cortex to state- and strength-based perception (Aly et al., 2013). We tested patients with selective lesions to the hippocampus, bilaterally, and patients with more extensive unilateral MTL lesions that included the hippocampus and surrounding cortex. On each trial, patients and healthy controls were presented with a pair of scenes that were either identical or differed in that the center of one scene was expanded or contracted relative to the other (Fig. 1A). These changes alter the relational or configural information within the scenes without adding or removing any specific objects. Participants made same/different confidence judgments using a 1–6 scale, and these confidence responses were used to plot ROCs (Green and Swets, 1966; Macmillan and Creelman, 2005). The ROCs were in turn used to estimate state- and strength-based perception (see Fig. 1B for hypothetical data). The upper *x*-intercept of an ROC provides the probability that state-based perception has occurred, while the degree of curvilinearity is proportional to the contribution of strength-based perception (Aly and Yonelinas, 2012; see also Yonelinas, 1994).

Using this approach, we found that the patients were selectively impaired in strength-based perception (graded judgments of the overall configural or relational match/mismatch between images) but showed intact state-based perception (related to the ability to identify specific detailed differences between scenes; Aly and Yonelinas, 2012). This was true for patients with selective hippocampal lesions as well as those with more extensive MTL lesions. These data suggested that the hippocampus is critical for detecting configural or relational match/mismatch between complex scenes, but is not needed for state-based judgments based on identification of specific, item-level differences.

The MTL is just one of several regions that are likely to be critical for perceptual judgments on complex scenes. In a previous fMRI study (Aly et al., 2014), we examined whole-brain data to determine whether activity in different brain regions was differentially correlated with state- or strength-based perception. Individuals performed a task similar to that used in the MTL patient study, in which they viewed pairs of images and made same/different confidence judgments. These judgments were made using a scale that allowed individuals to report when state-based perception occurred, or, if it did not occur, to rate the confidence associated with strength-based perception. Activity in the supramarginal gyrus, posterior cingulate cortex, and precuneus was