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Illusory Conjunctions are Alive and Well: A Reply to Donk (1999)

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Abstract

When presented with a red T and a green O, observers occasionally make conjunction responses, indicating that they saw a green T. These errors have been interpreted as reflecting separable processing stages of feature detection and integration, with the illusory conjunctions arising from a failure at the integration stage. Recently, Donk (1999) asserted that the phenomenon of illusory conjunctions is an artifact. Conjunction reports are actually the result of confusing a nontarget item (O in the example above) for a target item (the letter T) and (correctly) reporting the color associated with the (incorrectly) selected target. We demonstrate that, although target-nontarget confusion errors are a potential source of conjunction reports, there is a plethora of findings that can not be accounted for by this confusion model. A review of the literature indicates that in many studies, illusory conjunctions do result from a failure to properly integrate features.

Many theories of object recognition emphasize that perception involves an analytic process in which image components are initially extracted and then integrated to form coherent objects. Critical components have been variously described in terms of spatial frequencies (e.g., DeValois & DeValois, 1980), geons (Biederman, 1987), or features (e.g., Selfridge, 1959). Regardless of the components of object recognition, all recognition by component models face a similar problem. Given a complex scene, with many different objects, the visual system must appropriately combine the components. This problem is referred to as the binding problem.

The visual system is apparently very facile in solving the binding problem: In every day life we are not aware of combining image features. Indeed, until the pioneering work of Treisman (e.g., Treisman & Gelade, 1980) and Wolford (1975) the problem of feature binding was generally neglected.. However, the seminal work of Treisman and Schmidt (1982) described several experimental paradigms that made the problem of feature binding manifest and also provided a method for studying how the visual system combines visual features (also see Wolford & Shum, 1980). They described a phenomenon called "illusory conjunctions" or errors in feature binding. For example, when

briefly presented with a multi-character display that contained a red T and green O, observers sometimes reported that the display contained a green T.

In the last two decades, the phenomenon of illusory conjunctions has proven useful for exploring feature binding. Experiments involving illusory conjunctions have been productive in determining the stimulus information that the visual system uses to bind features (see Prinzmetal, 1995, for a review), the roll of attention in feature binding (e.g., Cohen & Ivry, 1989; Kleiss & Lane, 1986; Prinzmetal, Henderson, & Ivry, 1995; Prinzmetal, Presti, & Posner, 1986), cognitive factors in feature binding (e.g., Prinzmetal & Keysar, 1989; Prinzmetal, Treiman, & Rho, 1986; Treisman, 1986) and the neurophysiology of feature binding (e.g., Arguin, Cavanagh, & Joanne, 1994; Cohen & Rafal, 1991; Friedman-Hill, Robertson, & Treisman, 1995). Note that the studies mentioned here are only a small sample of the work using illusory conjunctions to understand feature binding.

One problem encountered in all of this work is how to measure binding errors separately from errors that result from misperceiving features. An experiment by Prinzmetal, Henderson, and Ivry (1995; Experiment 1) illustrates this problem. Observers were presented an array of letters in the periphery for 5 seconds while they simultaneously monitored a string of digits at fixation. The array of letters consisted of a colored target letter that could be either the letter T, X, or L and a colored nontarget letter (the letter O). These two colored

letters were flanked by two white Os. Following the presentation of the letters, the observers were required to report the identity of the target (i.e., T, X, or L) and its color (i.e., red, green, or blue). Consider the situation where the display contained a red T and green O. There are 6 possible response categories, shown in Table 1. For example, observer responded with the correct response (C) on 77% of the trials. Conjunction responses (CR) occur when the observer reports the correct target letter and the color of the nontarget letter. In this experiment, conjunction responses occurred on 17% of the trials.

Not all of the conjunction responses (CR) represent incorrect feature binding. Some proportion of them undoubtedly result from misperceiving either the target color or the target letter and guessing a color and/or letter. To correct for guessing, Prinzmetal et al. used an adaptation of the multinomial processing procedures (Batchelder, Riefer, & Hu, 1994; Batchelder & Riefer, 1999; Riefer & Batchelder, 1988) that had been developed to study illusory conjunctions (Ashby, Prinzmetal, Ivry, & Maddox, 1996). From this method, Prinzmetal et al (1995). estimated the probability of correctly perceiving the target color, target letter, and correctly binding features. The parameter for feature binding, called a , can go from .5 (random feature binding) to 1.0 (no errors in feature binding). The parameter a in Prinzmetal, et al. (1995, Experiment 1) averaged .83 which indicates good, but not perfect binding. This result was typical of the results from the experiments in that paper and other studies reported in the literature.

Donk (1999) recently suggested that illusory conjunctions are an artifact. Rather than result from the incorrect combinations of correctly perceived features, she proposes that they occur because observers' incorrectly perceive the nontarget letter as a target letter. In the example from Prinzmetal et al. (1995), consider a trial in which the target was a red T and the nontarget item a green O. If observers misperceived the O as a T, a conjunction response (CR) would result. Previous studies of illusory conjunctions have not entertained this possibility. A thought experiment readily demonstrates the viability of this hypothesis. Suppose the target and nontarget were both T's, but differed by one pixel. Obviously in this situation, target-nontarget confusions would readily occur and the occurrence of conjunction reports would be quite high. Donk questions an assumption that is made by many researchers, namely that such confusions do not occur because the target and nontarget letters sets are highly distinct (e.g., X and T for the target and O and C for the nontarget).

The Donk (1999) paper thus concludes that the phenomenon of illusory conjunctions is a chimera. This issue is important because illusory conjunctions have been used as a valuable experimental tool to understand how the visual system binds features. Fortunately, it is very easy to demonstrate that the problem suggested by Donk can not explain existing data on feature integration.

Consider as an example the experiment discussed above. What Donk correctly points out is that there is a nonzero probability that the nontarget letter will be erroneously

identified as the target. This possibility is depicted in Figure 1. The parameter s corresponds to the probability of correctly distinguishing the target from the nontarget item. Correspondingly, $1-s$ represents the probability of making a target-nontarget confusion. In this figure, there is a probability, $1-s$, that the nontarget O will be confused with one of the target items (T, L, or X). The consequence of misperceiving the O as a T is a conjunction response (CR). The consequence of misperceiving the O as one of the other target letters is what we label a "letter-feature illusory conjunction" (LFIC, see Table 1). We do not know the confusion matrix of O with T, L, or X, but since the target letter was randomly selected we can assume that over trials and targets, the three outcomes are equally likely. Thus misperceiving the nontarget as a target would result in twice as many responses in the LFIC category as the CR category. However, in that experiment there were many more CRs (17%) than LFICs (3.5%). This pattern is opposite what one would expect if the conjunction reports were actually the result of target-nontarget confusion errors given that there are two paths resulting in LFICs and only one resulting in a CR. Indeed, we know of no previous data that conforms to the predictions of Donk's confusion model.

One might propose that the higher rate of CRs is due to the fact that such errors can occur even when the target letter is correctly identified, whereas LFICs are restricted to situations in which the target letter is not perceived. Observers on some proportion of trials might misperceive the target color (red) as the nontarget

color (green). Or they may correctly identify the target letter, but fail to perceive its color and guess the nontarget color. An important aspect of multinomial models is that they allow one to estimate the contribution of such errors. In most experiments, color feature errors are rare and contribute minimally to the CR category. For example, in Prinzmetal et al. (1995), Experiment 1, color feature errors occurred on about 0.5% of the trials and the estimated probability of correctly perceiving the target color was .97. These results are typical of those in the field.

Donk correctly points out that previous correction for guessing procedures (e.g., Ashby, et al. 1996; Prinzmetal et al. 1995) does not estimate the probability of confusing the nontarget with the target directly.¹ Note however, that for this analysis, it is not necessary to estimate the value of the parameter, s (Figure 1). The relation between CR and LFIC responses is the same regardless of the value of s . Unfortunately, the above analysis can not be applied to the results in Experiments 1-4 of the Donk paper. Only two possible values were used for each dimension and both values on the dimension used to select the target were present on every trial. Thus the necessary response categories do not exist in Donk's Experiments 1 to 4.

It is possible to use nontarget letters that are confusable with the target letter. If the nontarget is confused with the target letter, the confusion model in Figure 1 should predict the relation between CR and LFIC responses. In Experiment 5, Donk used three possible colors, two target shapes, and a nontarget shape. If

conjunction reports result from a confusion between the nontarget shape and the target shape in this situation, then the proportion of CR's should equal the proportion of LFICs., However, if, at least some of the conjunction reports are actual errors in binding, then the proportion of CR's should be greater than the proportion of LFICs. (Note that in Prinzmetal et al, there were 3 possible targets, thus the proportion should be twice as many LFICs as CR, whereas Donk had 2 possible targets).

The results of Experiment 5 are revealing. Donk used two stimulus sets. One stimulus set consisted of colored letters. Similar to many of the previous studies of illusory conjunctions, the target letters, X and T, were not particularly confusable with the nontarget letters, C and S. The proportion of CR's was more than twice the proportion of LFICs (.13 to .06). The other stimulus set consisted of rectangles and the target and nontarget shapes were very similar. The rectangles could be oriented with the long axis either vertical or horizontal. The target rectangle was always 5 x 8 pixels whereas the nontarget rectangle was 4 x 10 pixels. With these stimuli, the proportion of CRs (.17) was much closer to the proportion of LFICs (.14). Thus it would appear that Donk's confusion hypothesis can account for the occurrence of conjunction responses when the target and nontarget are confusable. However, in most experiments by other researchers, the nontargets are chosen to be distinct from the targets. Donk's confusion model can not account for the results of these previous studies.

The method adopted by Donk in Experiments 1-4 turn out to be problematic. In these studies, there were only two values on each dimension, a paradigm that is unfortunate for three reasons. First, as we have mentioned, it precludes the simple analysis described in Figure 1. Second, the probability of misperceiving the target shape or color (feature errors) was estimated from trials on which illusory conjunctions could not occur. These were trials on which the critical feature was repeated (e.g., 2 red objects), referred to as identical trials. The assumption is that the feature errors estimated on the identical trials would provide an estimate of the feature error rate on trials in which the target and nontarget color were different. However, there is evidence suggesting that detecting stimuli with identical features might be different than detecting stimuli with heterogeneous displays (Bamber, Herder, & Tidd, 1975; Bamber, 1969). If Donk had included more than two features on each dimension, the approach taken in previous studies of illusory conjunctions, she would not have had to make the assumption that feature errors on identical and heterogeneous displays were the same. Third, by adding another color and shape to the stimulus set, the number of response categories would be increased from 3 to 6 making it easier to model the data.

The problem of estimating parameters with the procedure in Experiments 1 to 4 is apparent when considering the estimated values for the parameters that relate to confusing the nontarget with the target, *si* and *sc*. These values vary widely across individuals. For example, in

Experiment 1, they varied from 1.0 to 0.01! This range suggests that, in some conditions, some of the observers never confused the nontarget with the target, whereas other observers essentially failed to distinguish between the target and nontarget on any trials which seems unlikely. We suspect that the estimates of these parameters are unstable and reflect the fact that the models need to account for different types of errors. Such instability is not observed for parameters representing the perception of the target features or the binding of these features, both in previous studies that have used multinomial models (Ashby et al., 1996; Prinzmetal et al., 1995) as well as in the studies of Donk (1999).

It is possible that in several of Donk's experiments, observers did not make illusory conjunctions. This observation, by itself, would not be surprising. The visual system is quite adept at integrating features, and our experience has shown us that it can be quite difficult to elicit illusory conjunctions. For example, illusory conjunctions are more likely (1) when the features are aligned horizontally or vertically rather than on an oblique line (Lasaga & Hecht, 1991; Prinzmetal, 1981); (2) when the items are horizontally aligned than vertically aligned (Prinzmetal & Keysar, 1989); (3) when the major axis of symmetry of the display items is aligned (Gallant & Garner, 1988; Lasaga & Hecht, 1991). The conditions favoring the occurrence of illusory conjunctions were only present in Donk's replication of Ashby et al. The failure to obtain illusory conjunctions does not, by itself, add to our knowledge of feature integration. Of course it is

important to consider hypotheses such as Donk's that challenge the existing evidence in support of illusory conjunctions. But, as with all null results, interpretation is difficult. Donk's results convincingly demonstrate that, under some conditions, target-nontarget confusion errors may masquerade as illusory conjunctions, but they do not challenge the evidence that under other conditions, illusory conjunctions do occur.

Donk's confusion account of illusory conjunctions also fails to account for a wide array of other factors shown to influence binding. For example, illusory conjunctions are more likely to occur between features that group into "Gestalt units" or coherent objects (see Logan, 1996; Prinzmetal & Keysar, 1989). Object formation constraints include similarity (Ivry & Prinzmetal, 1991), good continuation (Prinzmetal, 1981), familiarity (Prinzmetal & Millis-Wright, 1984), common fate for moving display (Baylis, Driver, McLeod, 1992), and occlusion cues (Khurana, 1998), as well as such esoteric factors as the linguistic structure of the stimuli (e.g., Prinzmetal, Treiman, & Rho, 1986; Prinzmetal, Hoffman, & Vest, 1991). Identifying the boundary conditions of illusory conjunctions informs us how the visual system correctly combines features. Thus, specifying not only the conditions that produce illusory conjunctions, but also those that preclude such errors help us to understand the binding process.

The picture of feature integration that has emerged over the last 20 years is that feature binding is constrained by a rich set of factors, ensuring that our perception of objects

is generally veridical. However, in normal environments and even more so, under carefully designed conditions, failures of perception can occur. These failures have proven to be an important source of information concerning the processes of feature perception and integration. Donk (1999) has correctly shown that confusions between the target and nontarget items can lead to responses that are erroneously attributed to illusory conjunctions. The much stronger claim, that the confusion hypothesis can account for all previous reports of illusory conjunctions, is not tenable. The phenomenon of illusory conjunctions has taught us much about how the human visual system binds features. They remain alive and well.

Footnotes

1. Ashby, et al. 1996 did estimate the probability of correctly perceiving the nontarget letter in some of their models. From these, an estimate of s can be obtained. The value of s would equal $1-(1-TL)(1-NL)$. However, the estimates of the NL parameter proved to be unstable, and had little impact on the goodness of fit. We expect this is true for two reasons. First, the $(1-TL)(1-NL)$ branch only influences the response outcome on a small percentage of the trials. Second, Ashby et al. did not require the observers to report the nontarget letter. The confusion parameters estimated by Donk (1999), sc and so , appear to behave in a similar unstable manner.

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Response	red T	green T	blue T	red F (or X)	Green F (or X)	blue F (or X)
Response name	Correct C	Conjunction response CR	Color feature error CF	Letter feature error LF	Letter-feature + conj. response LFCR	Color letter feature error CLF
Results	77%	17%	0.5%	2.0%	3.5%	0.1%

Table 1

The response categories from Prinzmetal et al. (1995). There were three possible target letters (X, T, and L) and there were three possible colors. On each trial, one target letter and two colors were present in the display. In this example, the target was a red T and the nontarget item a green O.

Figure Caption

Figure 1. The consequences confusing the nontarget with the target for Prinzmetal et al. 1995 are depicted. The probability of confusing the nontarget with the target is $1-s$.

