Illusory Conjunctions Die Hard:
A Reply to Prinzmetal, Diedrichsen, and Ivry (2001)

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M. Donk (1999) showed that various data patterns that have been considered as evidence for the existence of illusory conjunctions may be due to errors of target–nontarget confusion, an account that challenges the mere existence of illusory conjunction. In a reply, W. Prinzmetal, J. Diedrichsen, and R. B. Ivry (2001) argued against this conclusion, claiming that some earlier findings can be explained only when one assumes that illusory conjunctions exist. The current article shows that Prinzmetal et al.'s claims cannot refute any of Donk's earlier conclusions, suggesting indeed that one can only conclude that "illusory conjunctions are an illusion."

Since the original work of Treisman and Gelade (1980), a variety of studies have addressed how the visual system assembles individual features into object percepts (e.g., Ashby, Prinzmetal, Ivry, & Maddox, 1996; Baylis, Driver, & McLeod, 1992; Cohen & Ivry, 1989; Gallant & Garner, 1988; Ivry & Prinzmetal, 1991; Treisman & Gormican, 1988; Treisman & Sato, 1990; Treisman & Schmidt, 1982). Among these studies, a substantial number have been concerned with determining under what circumstances observers make "illusory conjunctions": percepts in which visual features are correctly identified but incorrectly combined (Ashby et al., 1996; Baylis et al., 1992; Cohen & Ivry, 1989; Gallant & Garner, 1988; Ivry & Prinzmetal, 1991; Treisman & Schmidt, 1982). Identifying the conditions under which illusory conjunctions occur should provide information about how the visual system combines primitive features.

It should be noted that illusory conjunctions as such cannot be directly observed; instead, they are inferred on the basis of error rates. In a typical experiment investigating illusory conjunctions, participants report the color and identity of a target element that is presented simultaneously with a colored nontarget element. As a result of short exposure durations, eccentric presentation of the stimulus array, the presence of another visual task, or the presence of masking flankers, participants generally make a substantial number of errors (e.g., Cohen & Ivry, 1989; Ivry & Prinzmetal, 1991; Prinzmetal & Millis-Wright, 1984; Treisman & Schmidt, 1982). When participants report incorrect combinations of features present in the visual field, these errors are considered to be conjunction errors (e.g., reporting a green T if a red T and a green C have been presented). When features are reported that are not present in the visual field, the errors are treated as feature errors (e.g., reporting a blue T if a red T and a green C have been presented).

To obtain an estimation of the rate of illusory conjunctions, originally researchers compared the number of conjunction errors with the number of feature errors. If the number of conjunction errors exceeded the number of feature errors, the excess was considered evidence of the rate of illusory conjunctions (Gallant & Garner, 1988). In this way, the rate of illusory conjunctions was found to be affected by a variety of factors, including the extent to which features group into objects (Prinzmetal & Keysar, 1989), familiarity (Prinzmetal & Millis-Wright, 1984), and common fate (Baylis et al., 1992; see Prinzmetal, Diedrichsen, & Ivry, 2001).

Ashby et al. (1996) pointed out that findings of previous studies on illusory conjunctions might have been falsely interpreted on the basis of overly simple probabilistic considerations. Comparing number of conjunction errors with number of feature errors does not necessarily provide a good estimation of the rate of illusory conjunctions. Instead, the estimated value of the rate of illusory conjunctions might have included other instances such as those in which participants failed to perceive the identities of the elements while perceiving the colors. Consequently, in these previous studies the rate of illusory conjunctions might have been an overestimation.

These considerations led Ashby et al. (1996) to develop a formal approach to feature binding that makes it possible to disentangle the probability of correctly perceiving individual features from the probability that an illusory conjunction will occur. They constructed several multinomial models representing alternative theoretical accounts of imperfect feature binding and perfect feature binding. Imperfect feature binding models are models that allow correctly identified features to be incorrectly combined, a notion consistent with the idea that illusory conjunctions exist. Perfect feature binding models do not allow the possibility of incorrectly combining identified features. Applying this approach to new and earlier-obtained data, Ashby et al. (1996) demonstrated that a model that assumes imperfect binding provided the best fit to the data. Consequently, they concluded that illusory conjunctions exist and that the occurrence of illusory conjunctions depends on various factors, including interitem distance and target eccentricity.

Even though it is recognized that Ashby et al.'s (1996) approach is a substantial improvement over previous methods, Donk (1999) showed that the Ashby et al. approach fails to account for possible

effects of target–nontarget confusion. Target–nontarget confusion occurs when nontargets are misperceived as targets, or vice versa. Given the results of previous studies on letter perception (Appelman & Mayzner, 1982; Bouma, 1970, 1971; Jacobs, Nazir, & Heller, 1989; Krumhansl & Thomas, 1977), such errors are quite likely in typical experiments on illusory conjunctions. In the six experiments of Donk (1999), it was shown that data patterns suggesting the existence of illusory conjunctions are likely to be due to errors of target–nontarget confusion and not to imperfect feature binding. Consequently, Donk concluded that illusory conjunctions are most likely an artifact instead of a true psychological phenomenon.

Recently, Prinzmetal et al. (2001) argued that Donk's conclusion is invalid. The authors made four arguments to substantiate this claim. First, they argued that Donk's (1999) Experiment 5 was incompatible with the claim that conjunction errors are the result of target–nontarget confusion errors. Second, they claimed that the method used by Donk (1999) in Experiments 1–4 was problematic. Third, throughout the article, they suggested that there exists a "plethora of findings" that cannot be accounted for by the confusion model. Finally, they cited results of a previous experiment on illusory conjunctions (Prinzmetal, Henderson, & Ivry, 1995, Experiment 1) that showed a data pattern assumed to be opposite to what would have been expected if conjunction reports were the result of target–nontarget confusion errors. On the basis of these arguments, the authors concluded that even though possible confusions between target and nontarget items may indeed lead to responses that are erroneously attributed to illusory conjunctions, Donk's confusion hypothesis cannot account for all previous findings of illusory conjunctions.

For each of these points raised by Prinzmetal et al. (2001), there are several counterarguments. First, Prinzmetal et al. argued that one particular condition of one particular experiment out of a series of six may not be compatible with the confusion hypothesis. They claimed that the results from the letter condition of Donk's Experiment 5 are incompatible with the confusion hypothesis. In this experiment, participants were simultaneously presented with one of two possible target identities and one of two possible nontarget identities. Participants reported the identity and color of the target. In the letter condition, identities consisted of letters; in the rectangle condition, identities consisted of rectangles.

The results of Experiment 5 are depicted in Table 1. According to Prinzmetal et al. (2001), a confusion model would predict the number of color conjunction errors with concurrent correct identity reports (CRs) to be equal to the number of color conjunction–identity feature errors (LFCRs). They argued that if observers misperceive the nontarget identity as one of the target identities, these observers should be just as likely to report a correct as an incorrect target identity. In other words, the proportion of CRs should be equal to the proportion of LFCRs. In the case of illusory conjunctions, the CRs should outnumber the LFCRs.

In the letter condition of Experiment 5, there were indeed more CRs than LFCRs, $F(1, 5) = 22.83, p < .01$. However, for the data to be incompatible with the confusion hypothesis, the number of CRs should outnumber the sum of LFCRs and color feature errors with concurrent correct identity reports (CFs).[1] A reanalysis of the data of Experiment 5 shows that this was not the case in the letter condition, $F(1, 5) = 5.73, p > .06$, or in the rectangle condition, $F(1, 5) = 0.34$. In the rectangle condition, the number of CRs did

Table 1

Mean Proportions of Responses as a Function of Condition: Experiment 5

	Condition	
Response	Letter	Rectangle
C	.68	.52
CR	.13	.17
CF	.03	.03
LF	.09	.12
LFCR	.06	.14
CLF	.01	.02

Note. From "Illusory Conjunctions Are an Illusion: The Effects of Target–Nontarget Similarity on Conjunction and Feature Errors," by M. Donk, 1999, *Journal of Experimental Psychology: Human Perception and Performance, 25,* p. 1225. Copyright 1999 by the American Psychological Association. Columns may not sum to 1 as a result of rounding errors. C = correct response; CR = color conjunction error, identity correct; CF = color feature error, identity correct; LF = color correct, identity feature error; LFCR = color conjunction error, identity feature error; CLF = color feature error, identity feature error.

not even outnumber the number of LFCRs only, $F(1, 5) = 6.27, p > .05$. Basically, the results are fully compatible with a confusion model.

Note that the results of Experiment 5 are also compatible with an illusory conjunction account, at least if one assumes that illusory conjunctions occur with some stimuli and not with others. Indeed, this is what Prinzmetal et al. claimed. According to their view, illusory conjunctions occurred in the letter condition of Experiment 5 because target and nontarget were highly distinct from each other. Only when target and nontarget were confusable, as they claimed was the case in Donk's rectangle condition, could the confusion hypothesis account for the occurrence of conjunction responses. Obviously, the claim that illusory conjunctions occur with some stimuli and not with others, as argued by Prinzmetal et al., is hard to reconcile with the notion that perception of identity and location occurs in a statistically independent way, an assumption made by every account of illusory conjunctions (Ashby et al., 1996).

More important, however, is that Prinzmetal et al.'s account regarding the results of Experiment 5 cannot explain by any means the results of Experiment 6. Indeed, the aim of Experiment 6 was to determine to what extent target–nontarget similarity would affect performance when a typical illusory conjunction setup was used. According to Prinzmetal et al., low target–nontarget similarity (i.e., if targets and nontargets are highly distinct from each other) should lead to data patterns compatible with an illusory conjunction account, whereas high target–nontarget similarity (i.e., with highly confusable targets and nontargets) should result in data

[1] As noted by Prinzmetal et al. (2001), according to a confusion hypothesis, CRs might occur not only when target and nontarget are confused but also when they are not confused and the target letter is correctly identified, whereas the target color is not. Such instances contribute to the number of CRs as well as the number of CFs. Consequently, in accordance with a confusion hypothesis, the number of CRs might be larger than the number of LFCRs but should never be larger than the sum of the number of LFCRs and CFs.

patterns in line with the confusion hypothesis. The results of Experiment 6 were completely opposite to this; the results showed that the perfect binding model outperformed the imperfect binding model in the low-similarity condition and showed the reverse in the high-similarity condition. Note that these results as a whole are compatible with the confusion hypothesis but not by any means compatible with a view that assumes the existence of illusory conjunctions.

Another point raised by Prinzmetal et al. (2001) concerns Donk's (1999) Experiments 1–4. Prinzmetal et al. claimed that the method adopted by Donk in Experiments 1–4 was problematic. The argument was that the paradigm used by Donk excluded the possibility of obtaining a proper indication of feature error rates because these rates were achieved on the basis of trials in which the to-be-reported feature was present in both the target and the nontarget (identical trials). To elucidate their argument, Prinzmetal et al. cited two studies of Bamber (Bamber, 1969; Bamber, Herder, & Tidd, 1975) in which it was shown that when observers view two sequentially presented letter strings, "the response 'same' is often faster than the response 'different' " (Bamber et al., 1975, p. 321). It is unclear why these studies of Bamber et al. were cited, because they involved a completely different paradigm, one that seems to be irrelevant for a discussion of illusory conjunctions.

Indeed, in Donk's Experiments 1–4, observers never had to detect any difference between sequentially presented features as in the Bamber et al. study; as in many illusory conjunction experiments, however, they had to indicate the color or identity of one element while another nontarget element was simultaneously present. To support their claim that the method used in Donk's Experiments 1–4 was problematic, Prinzmetal et al. suggested that various parameter estimates were unstable. Although it is true that the parameter estimates in Experiments 1–4 showed variation, this does not necessarily imply that these estimates were unstable. The reason for variation in the estimated parameters across individuals is not related to "unstableness" but is due to the fact that exposure duration was not adjusted for each individual participant. In other words, all participants had an exposure duration of 50 ms. In typical studies on illusory conjunctions, individual performance levels are controlled by implementing adjustments in exposure duration (e.g., Ashby et al., 1996) or target eccentricity (Prinzmetal et al., 1995). Because this procedure was not used in Donk's study, there were individual differences in the absolute values of the parameter estimates. It should be noted, however, that even though these individual differences were present, participants all showed a similar data pattern.

It is true that the method used in Donk's Experiments 1–4 is quite different from the one used in previous studies on illusory conjunctions. However, the very reason to use such a well-controlled paradigm with only two values on each dimension, each matched with respect to luminance and numbers of pixels, was precisely to ensure that feature processing of one dimension was not dependent on the value of the other dimension. Furthermore, the paradigm excluded the possibility that participants take advantage of sophisticated guessing strategies that may contaminate the data. To date, most studies on interdimensional illusory conjunctions (i.e., illusory conjunctions between two values of two different dimensions such as color and shape) have used as stimuli letters that were neither matched for luminance nor matched for numbers of pixels. This lack of control in combination with the

paradigms used may have led to data patterns that suggested the existence of illusory conjunctions, whereas instead feature binding might have been perfect.

For example, unmatched stimuli may substantially differ in their relative visibility. If stimuli differ in visibility and stimulus identification is very difficult (as in typical illusory conjunction experiments), participants may begin to use a strategy of naming the least detectable alternative when nothing is detected (Johnston & Pashler, 1990). This can result in data patterns in which the number of conjunction errors is larger than expected on the basis of a perfect binding model. Consider, for example, a typical experiment in which observers have to report the identity and color of a target element that is briefly presented concurrently with a nontarget element. Suppose there are three possible colors wherein one has a relatively high luminance value and the other two have relatively low luminance values. If participants are presented with the two colors of low luminance, chances might be relatively high that neither color is perceived. If this occurs, an optimal strategy would be to guess one of the least visible colors, resulting in either a correct response or a conjunction error. In this way, failures of identification inevitably result in many conjunction errors and correct responses at the cost of feature errors. The observed conjunction error rate will be higher than expected on the basis of a perfect binding model. However, this higher value may not be due to imperfect binding. Instead, participants may have used a very sophisticated guessing strategy. Considerations such as these resulted in the use of a limited set of matched stimuli in an altered paradigm in Experiments 1–4.

A third argument of Prinzmetal et al. concerns the assertion that, in general, Donk's confusion hypothesis cannot account for results obtained in previous studies on illusory conjunctions. At this point, it should be remarked that Donk never claimed that all conjunction errors derive from target–nontarget confusion. Instead, it was argued that interdimensional illusory conjunctions do not exist and that part of the variance in conjunction errors probably derives from target–nontarget confusion. Other parts may derive from feature misperceptions (Ashby et al., 1996), postperceptual factors (Navon & Ehrlich, 1995), or possible guessing strategies (Johnston & Pashler, 1990). As mentioned before, previous studies on illusory conjunctions have failed to properly control for errors of misperception (Ashby et al., 1996) or advanced guessing strategies, rendering earlier conclusions with respect to feature binding more or less invalid.

For example, in one cited study (Baylis et al., 1992), observers had to indicate the color and shape of a postcued item that was concurrently presented with two other items. Each time, two items were moving in one direction and another item was moving in another direction. The main result was that the excess of conjunction errors (labeled "on-errors" by Baylis et al., 1992) over feature errors (labeled "off-errors" by Baylis et al.) was larger between features that moved in the same direction than between features that moved in opposite directions. It was concluded that illusory conjunctions were more likely between features that moved in the same direction than between features that moved in opposite directions. Obviously, given these findings, this conclusion seems valid. However, an illusory conjunction account is not a necessary inference. It is likely that, on some trials, observers perceived the colors of the items without perceiving their identities.

Furthermore, the likelihood of correctly perceiving the colors of the elements might have been related to whether or not elements moved in the same direction. As a consequence, data patterns might have emerged that suggested that illusory conjunctions occurred and that their occurrence is related to the extent to which features have a common fate. One might also argue that these data patterns are related to feature misperceptions because in this study there was no adequate way to control for feature misperceptions. In a similar vein, Prinzmetal and Keysar (1989) demonstrated in their Experiment 1 that observers make more color conjunction errors between elements within one row or column than between elements in different rows or columns. One might argue that these results are caused by feature migrations, which would be in accordance with an illusory conjunction account. Alternatively, one might argue that the likelihood of correctly perceiving the colors of the elements might have been related to whether or not elements were in the same perceptual unit.[2] As in the study of Baylis et al. (1992), it is not possible to formally decide between these two options. In fact, the same line of reasoning applies to the other studies cited as well.

In summary, almost all arguments of Prinzmetal et al. (2001) that disagree with Donk do not hold. The interpretation of Prinzmetal et al. of Donk's results, as well as the claim that there exists a wide variety of factors that affect feature binding, is invalid. What is left is their point related to a result previously obtained in one experiment by Prinzmetal et al. (1995). According to the authors, the finding of more CRs than LFCRs in Experiment 1 of Prinzmetal et al. (1995) is incompatible with the confusion hypothesis of Donk (1999) and can be explained only if one assumes the existence of illusory conjunctions. Indeed, it appears that this finding is hard to reconcile with the idea that conjunction errors derive from target–nontarget confusion. However, it should be noted that these results were obtained under very unusual conditions in which stimuli were presented under extremely difficult viewing conditions. Elements were presented at large eccentricities of 7.2° to 8.2° of visual angle and were very close to each other (an interitem distance of about 0.14° of visual angle). In addition, elements were flanked by white Os with very high luminances of 120 cd/m^2, probably inducing considerable masking effects. Finally, characters were not matched with respect to luminance or with respect to numbers of pixels.

In addition to these peculiar stimulus characteristics, unusually long exposure durations of 1.5 s were used. In spite of these long exposure durations, observers still made many errors. Because of the conditions used, it is unlikely that we are dealing here with illusory conjunctions. Instead, it seems that, as a result of the difficult viewing conditions, participants obtained only scarce information about the individual features of the stimuli presented. As a consequence, they may have used different advanced guessing strategies, possibly resulting in a large excess of CRs over LFCRs. Of course, the results of this single and unusual experiment are not in line with an account assuming that all conjunction errors derive from target–nontarget confusion. However, given the very unusual conditions, if anything, this experiment only shows that under extreme viewing conditions, observers cannot perceive much and probably use unknown guessing strategies. Therefore, it is hard to maintain the claim that these findings reflect the existence of illusory conjunctions.

In summary, Prinzmetal et al. (2001) attempted to convince us that illusory conjunctions are alive and well. The current article shows that their belief is based on experiments that do not allow adequate control for target–nontarget confusability, guessing strategies, and feature misperceptions. If the adequate experiments are performed, the only conclusion that is left is that "illusory conjunctions are an illusion."

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[2] Because the colors of the items within one row or column were always identical to each other, it is, in addition, likely that if observers did not perceive the target color, they used a guessing strategy in which they reported the color that was perceived to occur in two adjacent items. Objectively, such a guessing strategy would increase the likelihood of a correct response relative to plain guessing but would concurrently result in more conjunction errors within one perceptual unit than between units.

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