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Reply to Letter to the editor

# Reply to Talis Bachmann on object substitution

In reply to the commentary by Talis Bachmann on a recent article by one of us entitled "Object substitution masking and its relation to other forms of masking" (Enns, 2004), we address the following issues.

First, Bachmann's perceptual retouch theory concerns the role of nonspecific thalamic modulation in conscious visual experience. It is a reasonable theory, grounded in neurophysiological evidence, and it is likely relevant to many aspects of perception in which temporal factors play a critical role. But of greatest importance to the current discussion is that it makes no claims about the specific cortical representations that form the contents of consciousness. It simply takes cortical processes of object formation as a given. In contrast, object substitution theory is a framework for studying the emergence of specific cortical representations, but at the same time it stops short of claiming to be a theory of consciousness. As such, these theories should be seen as complementary to one another rather than as in competition.

To illustrate the differences in the two approaches, consider the way in which perceptual-retouch theory accounts for common-onset masking. According to Bachmann, common-onset masking by four dots occurs because "... nonspecific modulation which is evoked by S1 and which is necessary for explicit perception is slow [and thus] reaches the cortex when mainly the specific signals from S2 drive cortical activity". What is overlooked in this account is that when the nonspecific modulation arrives, there are *two* relevant sources of cortical activity: one arising from the initial display containing the target and the distractors and persisting in the neural trace, the other from the four-dot mask that are still on view.

Because the nonspecific modulation is, by definition, nonselective, it should enhance the decaying representation of the target as well as the representation of the mask. It must be emphasized that when the nonspecific modulation arrives, the target-related activity is clearly strong enough to mediate perception, as evidenced by the fact that when the target and the mask offset simultaneously, the target can be perceived without difficulty.

On this reasoning, perceptual retouch theory predicts that what an observer should see is a composite pattern consisting of a relatively strong mask and a weaker, but clearly visible target. Instead, what is seen is *only* the four-dot mask. Indeed, observers report that the empty square region defined by the four dots appears brighter than the background, much as in a Kanizsa figure. What is missing in the perceptual-retouch model is a mechanism of perceptual selectivity that enables the perception of the trailing mask to the exclusion of the target in the leading display. To be clear about this, what is needed is an account explaining why the target is visible when all stimuli terminate simultaneously and why it is suppressed when the mask remains on view. To say that the nonspecific modulation "... reaches the cortex when mainly the specific signals from S2 drive cortical activity..." is not sufficient because, as we noted above, such nonspecific modulation would enhance the ongoing activity of the target as well as the mask, and would mediate the perception of both.

The problem of selectivity is resolved in the object-substitution model by a process of iterative comparisons between high-level candidate perceptual hypotheses and the ongoing activity in the system's input layer. The perceptual hypothesis that correlates most strongly with the prevailing pattern of ongoing activity in the input layer at the time of reentry determines what is perceived. This process of spatiotemporal correlation has been embodied in a computer simulation (CMOS; Di Lollo, Enns, & Rensink, 2000) and has been compared with other quantitative models in its ability to account for various aspects of masking (Di Lollo, von Mühlenen, Enns, & Bridgeman, 2004; Francis, 2000, 2003). Perceptual retouch theory has only recently (June 16, 2004) been added to the testable models on Francis' (2003) website, http://www.psych.purdue.edu/~gfrancis/Publications/BackwardMasking/, and so the feasibility of this

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account may soon also be able to be compared to the other quantitative theories.

In summary, object substitution theory proposes that masking occurs while objects are in the process of being formed and updated. It does not make any claims about the processes of consciousness per se. To put it in Bachmann's own terms (1999, p. 174), object substitution theory says more about how objects materialize on the stage of consciousness than on who raises the curtain or what the audience sees once the curtain is raised. In contrast, Bachmann's theory singles out nonspecific thalamic signals as the "curtain-raiser", but it says nothing about who or what is on stage. As such, our two views may well be complementary, each requiring the other for a complete account of masking at neurophysiological, behavioral, and phenomenological levels.

Second, contrary to Bachmann's claim, not all empirical findings about common-onset masking can be explained by the perceptual-retouch model. These include the findings that masking by object substitution does not occur if the target is the only item in the display, nor the finding that no masking occurs if the four dots terminate with the display items. Masking. emerges only as the number of items in the display is increased and if the four dots remain on view longer than the display items. In his commentary, Bachmann attempts to encompass these critical findings of common-onset masking by claiming that the period of specific activity triggered by the target decreases with the number of items in the display. He proposes that the greater the number of items, the sooner the specific activity associated with the target subsides. Yet, this assumption incorrectly predicts masking in the case where there are a large number of display items and the four dots terminated with them. Clearly a large set size alone is insufficient to predict masking by the four dots.

The assumption that the neural activity regarding the target decays more rapidly as the display size is increased also runs contrary to established principles of visual functioning, starting from the earliest, most peripheral levels. It is well known, for example, that the strength and duration of visual afterimages *increases* directly with the strength and duration of the inducing stimulus (Brown, 1965). There is also no indication in the data on visible persistence that persistence decreases as the number of items in the display is increased (Coltheart, 1980; Di Lollo, 1980). The data Bachmann appeals to in support of this assumption concerns the effect of set size on measures of attention, where visual search and target identification are *delayed* and made more error-prone by the addition of distractor items to a display. Although these effects could in principle be related to the more rapid *decay* of neural activity concerning the target, there are numerous other ways in which they could be implemented at a neural level, including mechanisms of competition, inhibition, and increased neural latencies. Thus, in the absence of independent support for an inverse relationship between stimulus energy and the *decay* of neural activity regarding the target, Bachmann's assumption appears to be a speculative hypothesis worthy of further study rather than a claim based on available evidence.

Third, Bachmann asserts that it is misleading to claim that "Prior to object substitution theory, there has been no reason to suspect that metacontrast masks, pattern masks and four dots are so closely related to one another in the way they interfere with target identification" (Enns, 2004, p. 1329). Bachmann offers instead that "factually similar predictions" can be found in Bachmann and Allik (1976) and in Bachmann (1994). This comes as a surprise to us. We were unable to find any mention of masking by four dots, or of explicit predictions regarding the similarity of metacontrast masking and pattern masking in these publications. What we do find in them is a clear distinction between masking by processes of temporal integration versus masking by processes of object interruption and replacement, discussed in the context of pattern masking. As discussed in these papers, this is very similar in spirit to the distinction made in earlier papers by Spencer and Shuntich (1970) and by Turvey (1973) who were credited with this distinction by Enns (2004).

Hindsight is often said to give us 20–20 vision. When Bachmann refers to the study of Hogben and Di Lollo (1974) as "... implicitly suggesting the possibility of between-object competition." and when he refers to the U-shaped pattern masking functions in the study by Bachmann and Allik (1976) as "... reminiscent of typical metacontrast functions." it is not equivalent to making and testing the explicit prediction that "... all forms of backward masking will have, at a first approximation, an equal effect on target accuracy. This prediction derives directly from the idea that the contents of the mask will replace those of the target if it has not been identified prior to its replacement on the screen by the mask (Enns, 2004, p. 1323)". Although the ideas of separate effects of masking by integration and by interruption have been around for a long time, as noted in Enns (2004), they apparently did not prompt anyone to state that metacontrast masking stimuli and pattern masking stimuli would have identical effects within a predictable time window of visual processing.

Finally, we draw the reader's attention to the fact that Dr. Bachmann's commentary largely ignores the specific empirical data presented in Enns (2004), which were focused on comparisons between different masking stimuli. Instead of addressing these data, he devoted most of his commentary to the preamble of that paper, where four features of visual masking were singled out as presenting problems for the standard feedforward accounts of masking based on processes of integration, interrup-

tion, and competition. With the exception of one of these points (the attenuation of masking by focused spatial attention) these issues were not addressed in Enns (2004).

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