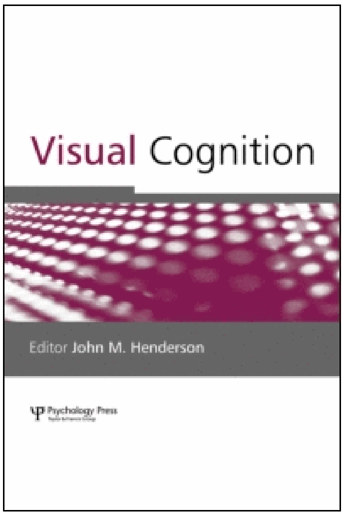

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Selection for Cognition

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Rejoinder to Commentaries by A.H.C. van der Heijden and Frank van der Velde, Claus Bundesen, and Koen Lamberts

Introduction

In our target article, we argued for the importance of considering cognitive constraints on attention, in addition to the constraints imposed by perception and action. To illustrate the kind of constraint we were interested in, we discussed the computational requirements of “propositional representations”. We argued that the ability to think in terms of propositions is the hallmark of human cognition, and the compositionality of propositional representations requires attentional mechanisms and attentional routines beyond those proposed in current theories of attention that focus on selection for perception and selection for action.

We were pleasantly surprised to find that the commentators seemed to accept our basic thesis. Some expanded on it and others criticized some aspects of what we said. In this response, we try to clarify points of contention and amplify points of agreement. We hope that, in the end, this exchange results in a new perspective on attention, new theories of attention with a cognitive flavour, and new empirical investigations of the interfaces between perception, cognition and action. While we have addressed ourselves mainly to students of attention, we hope also that attention will come to figure more prominently in theories of cognition, and that empirical investigations of cognitive phenomena will exploit the impressive advances made in research on attention in the last 40 years.

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Van der Heijden and Van der Velde

Van der Heijden and Van der Velde appear to embrace our general perspective but take exception to some of the things we said about it. For example, they question the details of our analysis of the process of matching conceptual predicates against perceptual representations to establish the truth values of the predicates and thereby create a proposition. Our intention was only to provide a Marr-type computational analysis, not to describe exact algorithms that carry out the computation. We refer readers interested in our perspective on these issues to papers that have dealt with the computation more explicitly and more completely (e.g. Logan, 1994, 1995; Logan & Sadler, 1996). We would like to respond to two points raised by Van der Heijden and Van der Velde: the evolutionary argument and the role of representation in connectionist cognitive science.

Evolution of Perception, Cognition and Action. Van der Velde and Van der Heijden quote Milner and Goodale (1993), who argued that natural selection operates at the level of overt behaviour. In our view, that argument is hard to sustain. From a gene's point of view, natural selection operates at several levels, all of which are designed to replicate and propagate the gene in the gene pool (see Dawkins, 1989). The gene itself cares little whether the vehicle that contains it sees well, thinks well or acts well, as long as it replicates and propagates the gene. We argue that the ability to think propositionally allows the creature endowed with that capacity to make better choices among alternative actions than creatures not so endowed. Animals that make better choices are more likely to replicate and propagate their genes.

From a logical perspective, natural selection operates at several different levels. As Dennett (1978) noted, it operates at the level of species, individual behaviour and private cognition. Darwin and others described its operation at the level of species. Thorndike (1898), in his Law of Effect, and Skinner (e.g. 1981), in his principles of operant conditioning, showed how natural selection modifies the behaviour of single organisms within their lifetimes: Behaviours that are rewarded tend to be reproduced; behaviours that are punished or not rewarded tend not to be reproduced. Newell and Simon (1972), in their notion of means–end analysis, showed how natural selection governed the choice of problem-solving strategies: Subjects simulated various courses of action inside their heads and chose the most advantageous. Effective ideas were reproduced; bad ones fell by the wayside.

We do not wish to make strong arguments about cognitive constraints on the evolution of attention, because they cannot be tested empirically. None of us were there at the time, so none of us knows what really happened. We can only speculate or guess, and Van der Heijden and Van der Velde's guesses are probably as good as ours. Perhaps we should have refrained from evolutionary speculation in the target article.

Connectionism and Cognitive Science. Van der Heijden and Van der Velde take issue with our claim that cognitive science involves assumptions about both representations and process. They argue that there are two cognitive sciences, one based on symbolic representations and one based on connectionism. While we recognize the important distinction between symbolic and connectionist approaches to cognitive science, we do not agree that only the symbolic approach must make assumptions about representation and process.

Our point is illustrated in Figure 1, which depicts a connectionist model. But what is it a model of? There are nodes and connections between them, and we presume that activation flows along the connections and accumulates in the nodes, but it is not clear what the model is a model of without assuming that the nodes represent something. In fact, we abstracted Figure 1 from Van der Heijden's (1992) book, in which it is a very interesting model of the interaction between "what" and "where" systems in vision. In Van der Heijden's (1992) theory, the top right node is for the "what" system and the bottom right node is for the "where" system, and the single node on the left is an early perceptual representation in which "what" and "where" information exist together.

The same model could be viewed quite differently. The top left node could be a phonological route to word reading and the bottom left node could be an orthographic route (e.g. Coltheart, Curtis, Atkins, & Haller, 1993), with subsequent semantic and response nodes left out. There is nothing in Figure 1 to distinguish this interpretation, as a model of reading, from Van der Heijden's interpretation as a model of attention. To make that distinction, it is necessary to assume that the nodes represent something, and that is exactly the kind of

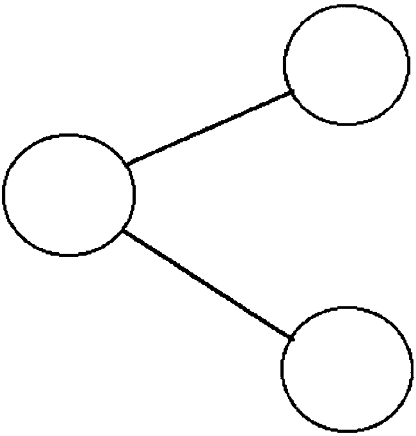

FIG. 1. A localist connectionist model with relatively impoverished representational assumptions.

representational assumption we said theories in cognitive science needed to make.

Other people have made similar points in the recent literature. Kanne, Balota, Spieler and Faust (1998) criticized Cohen, Dunbar and McClelland's (1990) connectionist model of the Stroop task because it would not "scale up". The original model was a "localist" model that had two nodes for two colours, two nodes for two words and two nodes for two responses. When Kanne et al. added nodes for more colours and words, the model no longer behaved as it used to, mispredicting some important effects. The processing assumptions remained the same; connection strengths and the rules for spreading activation were unchanged. What changed were the representational assumptions: nodes representing different colours and words were added (but see Cohen, Usher, & McClelland, 1998). In a similar vein, Cook, Früh and Landis (1995) criticized Kosslyn, Chabris, Marsolek and Koenig's (1992) distributed connectionist model of brain systems underlying "categorical" and "coordinate" spatial relations, arguing that the simulations carried out by Kosslyn et al. did not represent space adequately; rather, they depended on artifactual correlations between input stimuli and responses (but see Kosslyn et al., 1995). More generally, Fodor and Pylyshyn's (1988) arguments about the ability of connectionist models to account for compositional representations and the various rejoinders to it (e.g. Van der Velde, 1995, 1997) suggests that connectionist models do make representational assumptions as well as processing assumptions.

More generally, the choice of architecture in connectionist models amounts to making representational assumptions. Choosing a localist or a distributed representation is clearly a representational assumption. Choosing two layers or three (or more) and choosing which nodes get connected to which are also representational assumptions. Connectionism may blur the distinction between representation and process, but both kinds of assumption need to be made nevertheless.[1] Thus, our claim that representations cannot work without

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[1] Despite the popularity of the claim, it appears to us that the distinction between representation and process is no more blurry in connectionist models than in symbolic models. John Anderson's models are perhaps prototypical of the symbolic branch of cognitive science (e.g. Anderson, 1993), and they involve assumptions about the spread of activation through representations that are very similar to typical connectionist assumptions about spread of activation. The main difference seems to be one of emphasis: Anderson makes explicit representational assumptions that conform to practices in linguistics and artificial intelligence but tends to "hand wire" his connections. Connectionist models are typically more relaxed about representational assumptions and employ learning algorithms to establish connection weights. In practice, however, both kinds of models assume a spread of activation through a set of nodes, so representation and process seem equally blurred.

processes to operate on them and processes cannot work without representations to operate on applies to the connectionist branch of cognitive science as much as to the symbolic branch.

Bundesen

Bundesen takes us to task for rejecting two approaches that have proven useful in the past, saying in essence that we may have thrown the babies out with the bathwater. First, we rejected resource theory and the energy metaphor on which it is based, claiming it was intellectually bankrupt. Bundesen points to the longstanding role of the concept of capacity limitations in theories of attention and to the success of his fixed-capacity independent race model (FIRM) in fitting complex partial report data (Shibuya & Bundesen, 1988), noting that its success depended on the assumption of fixed capacity. Perhaps we were not clear enough about what we were rejecting. We intended primarily to reject resource theory (e.g. Kahneman, 1973; Moray, 1967, Navon & Gopher, 1979), which is distinct from the concept of capacity limitations. Resource theory makes several strong assumptions in addition to the assumption that capacity is limited: It assumes that capacity is fixed, not just limited, that capacity can be allocated in parallel, and that performance improves and degrades smoothly as resources are allocated and withdrawn. To our knowledge, none of these assumptions has been tested adequately in the 30 years since the advent of resource theory (for a more complete discussion, see Logan, 1997).[2]

The assumption that capacity is limited is much less restrictive than the assumption that capacity is both fixed and limited. As Bundesen notes, capacity can be measured objectively in terms of the amount of work done per unit of time, which is a measure of the rate of processing. Capacity is unlimited if the rate at which one process operates does not change when another process operates concurrently; capacity is limited if the rate at which one process operates is slowed down when another process operates concurrently; capacity is limited and fixed if the rate at which one process operates is slowed down when another process operates concurrently *and* the sum of the rates equals a

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[2] Another assumption of early resource theories was that there was only one source of mental energy that limited performance (i.e. central processing capacity; Kahneman, 1973). Research thoughout the 1970s showed convincingly that the assumption was wrong, and single-resource theories were replaced by multiple-resource theories (e.g. Navon & Gopher, 1979). Multiple-resource theories can account for virtually any pattern of data—if two tasks interfere with each other, they share resources; if they do not interfere with each other, they use different resources—and so seem incapable of falsification. In our view, multiple-resource theory is a large part of the reason for the demise of resource theories (also see Logan, 1997).

constant (Townsend & Ashby, 1983). Typical demonstrations of capacity limitations, such as dual-task interference or large display size effects in visual search, allow us to reject the hypothesis that capacity is unlimited, but they do not allow us to distinguish between limited capacity and fixed capacity. Limited capacity is easy to demonstrate; fixed capacity requires careful measures of processing rates and demonstration that the sums of the rates equal a constant across conditions, strategies and tasks. To our knowledge, no-one has ever demonstrated that capacity is fixed as well as limited.

Shibuya's and Bundesen's (1988) FIRM theory assumes fixed capacity and the fits are consistent with that assumption, but it seems to us that the fits do not rule out other alternatives. Indeed, FIRM is a special case of Bundesen's (1990) elegant theory of visual attention which assumes that capacity is limited but it is not fixed. Capacity depends on things like discriminability and perceptability, that can vary from condition to condition and from situation to situation. So capacity is not fixed; rather, it varies from condition to condition and from situation to situation.

Bundesen is right in taking us to task for rejecting capacity limitations, since there is abundant evidence that they exist. We differ from traditional approaches, however, in starting from different first principles. Early theories, like those of Broadbent (1958) and of Kahneman (1973), assumed capacity limitations axiomatically. The theories were built around that axiom, and other properties of attention were deduced from it. Our approach is to take cognitive representations—propositions—as axioms and deduce other properties of attention from that, including capacity limitations. It appears to us that capacity limitations are to be explained rather than assumed. It is as if the early theorists observed capacity limitations in overt performance and internalized the observation, claiming that some parts of the cognitive system were capacity limited and other parts were not. If this is what they did, they were using the phenomenon to explain itself. We would rather explain the phenomenon of limited capacity in terms of other principles. Perhaps this baby should not have been in the bathwater in the first place.

Second, Bundesen takes us to task for summarily dismissing feature list and template approaches to object recognition, arguing that they may be sufficient for simple perceptual categorizations, such as those in the attention experiments that the theory of visual attention accounts for. Lambert's commentary makes a similar point. Bundesen suggests that categorizations that involve complex, compositional representations may require what we called "attentional routines", but simpler categorizations may be done in a single step. Bundesen may well be correct here. Many interesting questions can be asked in the attempt to distinguish empirically between categorizations that require attentional routines and those that can be done in a single step. Perhaps this baby should not have been thrown out with the bathwater.

Lamberts

Lamberts amplifies our call for examination of the role of attention in cognition, going deep where we went broad, focusing sharply on the role of attention in categorization. He points out two important roles for attention in similarity-based categorization (which may be the single-step categorization that Bundesen had in mind): People must chose the dimensions that figure into the computation of similarity and, having chosen the dimensions, they can vary the weight they give to different ones. These ideas were present, seminally at least, in Medin and Schaffer's (1978) original context model of classification. They were sharpened considerably by Nosofsky's (1984, 1986, 1987) formalization and generalization of the theory, now known as the generalized context model. Lamberts (1995) himself has taken the theory even further, in his extended generalized context model.

Even though attention has played an important role in theories of categorization for 20 years, that work has had little impact on what most of us recognize as the field of attention. Indeed, in the last few years, four books have been published by prominent attention researchers, and not one of them cites Nosofsky's work on attention in categorization (Cowan, 1995; LaBerge, 1995; Pashler, 1998; Van der Heijden, 1992). We hope that our article and Lambert's commentary will prompt attention researchers to redress this omission in the future.

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