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DOI:

[10.1080/13506285.2021.1918812](https://doi.org/10.1080/13506285.2021.1918812)

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Document Version

Peer reviewed version

Citation for published version (Harvard):

Hickey, C & van Zoest, W 2021, 'Foxes, hedgehogs, and attentional capture', *Visual Cognition*, vol. 29, no. 9, pp. 596-599. <https://doi.org/10.1080/13506285.2021.1918812>

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Foxes, hedgehogs, and attentional capture

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CITE AS:

Hickey, C., & van Zoest, W. (2021). Foxes, hedgehogs, and attentional capture. *Visual Cognition*, 1-4.

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ACKNOWLEDGMENTS

CH is supported by a H2020 European Research Council Starting Grant (804360-INSENSE).

ABSTRACT

Isaiah Berlin famously suggested that thinkers can be characterized into two groups, foxes and hedgehogs. Foxes multiply ideas, hedgehogs stretch them. Hedgehoggy thinking, based around core universal principles, has historically dominated capture research and is prominent in Luck, Gaspelin, Folk, Remington, and Theeuwes (2021). But results increasingly suggest that attentional control is complicated and messy. There is a need for careful identification of neural bases and the development of incremental, contextual theory. That is, there is a need for foxy thinking.

MAIN TEXT

The ancient Greek poet Archilochus wrote a parable of which little more than this snippet remains: 'The fox knows many things, but the hedgehog knows one big thing.' In a much-later essay on Leo Tolstoy, Isaiah Berlin (1953) – tongue in cheek – extrapolated from this line to draw some conclusions about human scholarship. Thinkers, according to Berlin, can be categorized into two groups: hedgehogs, who '...relate everything to a single central vision... a single, universal, organizing principle,' and foxes, who seize '...upon the essence of a vast variety of experiences... without, consciously or unconsciously, seeking to fit them into... unitary inner vision.' Hedgehogs really want the world to have discernible form, and for disparate outcomes to follow logically from limited basic principles. Foxes are comfortable with complexity, contradiction and mess, and are willing to work incrementally (rather than requiring that one answer instantaneously resolve all questions). Berlin saw the two types of scholar as necessary, complementary, and equally important. Hedgehogs skew rationalist, foxes empiricist; Plato was a hedgehog, Aristotle a fox.

Attentional capture research has had hedgehoggy beginnings. Early battle lines were drawn by two distinct unitary visions - the contingent involuntary orienting hypothesis and the stimulus-driven selection hypothesis. But foxy theory emerged quickly, not least in the idea of attentional control settings (Bacon & Egeth, 1994). This suggests that physical salience captures attention when observers have adopted a strategy to prioritize it, but does not when observers have adopted a strategy to prioritize other visual characteristics. Different principles therefore emerge as a function of context and need, and this foxy perspective reconciled a lot of conflict within the field (Leber et al., 2009; van Zoest et al., 2010).

Luck et al. (2021) is presented as a further step toward 'resolving the capture debate'. The candidate organizing principle prominently offered in the paper is the 'signal-suppression hypothesis' of Sawaki and Luck (2010) and Luck and Gaspelin (2018). This builds from studies of cells in monkey lateral intraparietal cortex (LIP; eg. Ipata et al., 2006) to suggest the existence of discrete 'priority signals' in the visual system as a basis for attentional control.

Priority signals determine how information is selected from the environment. They are defined by raw physical salience, but, importantly, are distinct from it. Proactive influences on selection – implicit learning and, perhaps, volitional strategy – impact priority signals through effects on the feature maps that define salience. But priority signals can also be directly suppressed, after stimuli appear, in a way that precludes full-blown attentional selection of the evoking stimulus. Signal suppression theory links this kind of reactive suppression, without preceding selection, to emergence of the distractor positivity component in the ERP (Pd; Hickey et al., 2009). The signal suppression hypothesis is thus clearly rooted in a long tradition of computational / representational cognitive models. To paint in broad strokes, these conceive of the mind as a turbo-charged computer. Just as data and computations are distinct in your computer, computational / representational models of cognition define representations (like priority signals) and algorithms that act on representations (like suppression).

Priority signals are a distinctly hedgehoggy idea, a conceptual abstraction explicitly removed from messy implementation. Plato would have liked them. But there are fuzzy edges to the idea. In particular, we remain confused about the precise mechanistic and physiological distinction between 'priority signal' and 'physical salience'. In early formulations of the signal suppression hypothesis this distinction appeared to rest on two assumptions. First was the idea of a discrete

'master map' that lies above lesser maps in the visual hierarchy, where priority signals are exclusively represented. Second was the idea that changes can be made directly to this master map without influencing lesser maps.

The first premise seems reasonably safe; if there isn't a 'master map', there are at least a set of high-level maps that integrate information from lesser maps (though the set of such high-level maps may be very large and involve subcortical and cortical areas; eg. Serences & Yantis, 2006). But the idea that one or more of these master maps are insulated from the rest of the system seems untenable. Attentional effects, as a rule, propagate through the visual system such that change at one level rapidly emerges everywhere. Consistent with this, neural indices of distractor suppression – for example, alpha oscillations or the P_D – are big, reflecting activity in broad swathes of parietal, temporal, and occipital cortices, and probably subcortex too. This is hard to reconcile with the idea of discrete inhibition at one isolated level.

A slight reformulation of the signal suppression hypothesis is provided in Luck et al. (2021), but this appears only to muddy the waters. The original idea built from a distinction between priority signals, which do not carry feature information, and physical salience, which does. But Gaspelin and Luck (2018) found that participants could only reactively suppress the priority of a color singleton when they knew what color it would have. Luck et al. (2021) update the signal suppression hypothesis to reflect this new data, suggesting that reactive suppression of priority signals might also act on the feature maps that contribute to physical salience, rather than the master map itself. This is in line with the observation that neural indices of suppression appear to reflect change in the broad representation of stimuli, rather than a discrete representation of priority. But it means that all effects on priority signals, both proactive and reactive, may be mediated by effects on physical salience. Priority signals are left conceptually hanging, derived from salience but not necessarily sensitive to any other influence. They do not appear logically necessary.

Without the distinction between priority signal and physical salience, the signal suppression hypothesis starts to look a lot like earlier theories about the time-course of attentional control (eg. Donk & van Zoest, 2008; Hickey & van Zoest, 2012; van Zoest et al., 2004), reverse hierarchy models of selective attention (eg. Hochstein & Ahissar, 2002; Tsotsos et al., 1995), and other formal models of attention that emphasize recursive processing (eg., Heinke & Humphreys, 2003; Wyble et al., 2020). The idea here is that physical salience propagates

rapidly through the brain, activating reweighting mechanisms that feedback through the hierarchy to establish control. Saliency therefore briefly drives visual representation, but this is short-lived, and feedback soon integrates high-level information into low-level representations to make early visual cortex 'smart' (Di Lollo, 2018; Lamme & Roelfsema, 2000).

Putting feedback at the front-and-center of attentional theory is mechanistically hedgehoggy, but foxy in its implication. Consider that different kinds of information can follow different paths through the visual brain, activating different networks of functionally specialized cells. Each network has distinct connectivity, so the local and long-range feedback triggered by activation of any given node will have different targets and emerge with different temporal dynamics. As activity in lower levels is changed, this will propagate through the network to higher levels, creating feedback loops that oscillate at speeds determined by the number and type of connections in the chain. These few lines give an insufficient picture of the actual complexity of this decentralized, nonlinear system, but serve to demonstrate that representation is not easily distinguished from computation, and that selective control is likely to be established in many ways at many speeds. The question of 'resolving *the* capture debate' becomes the question of 'resolving a capture debate': the efficacy and speed of attentional control is not a product of any single unitary principle or system, but fundamentally dependent on context and on the nature of information that a stimulus conveys.

Berlin – who revered Tolstoy – suggested that Tolstoy was '...by nature a fox, but believed in being a hedgehog.' Abstract, universal organizing principles – like priority signals – have undeniable appeal and value, not least because they motivate consideration of their limitations. At the same time, attentional capture has had its fair share of this kind of account. The field is mature, simple answers have not emerged, and evolutionary pressure is at least as likely to generate complicated and decentralized systems as it is tractable and unitary ones. If attentional control is as complex and contextual as we think to be the case, it is unlikely to be well captured by a single core representation or principle, or even a limited set of such principles. Characterization of this system is going to require the development of contextual theory, embedded in neurophysiology and computational modelling, that identifies discrete phenomenon associated with specific brain networks activated under defined circumstances. It will need foxy thinking.

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<https://doi.org/10.1037/rev0000245>