Attention and the precision of color perception

(2998w)

Abstract

Attention makes things look crisper, with sharper spatial boundaries and more vivid colors. In virtue of these effects, it is usually accepted that attention increases the determinacy and precision of visual perceptual experiences. Representationalist philosophers have further proposed that these effects are changes in the contents represented by these experiences, so that attentive experiences have more precise or determinate contents than inattentive ones. Although they have a fairly strong case for spatial properties like shapes and locations, the evidence is less conclusive for non-spatial properties like colors. In this paper, I discuss a recent empirical argument by Ned Block (2015) countenancing that attentive color perception is not more precise than inattentive color perception, and I offer a response on behalf of the representationalist. I also discuss some potential lines of empirical support for the view that attention can make the color contents of visual experience more precise and determinate.

1

The way we distribute our attention affects what we perceive and how we perceive it. If I focus my attention on the red mug on my desk while looking at it directly, I enjoy a crisp and rich experience of the mug's shape and color properties. By contrast, if I draw my attention away from the mug (for instance, by letting my thoughts wander as my eyes remain fixed on the mug, or if I move my gaze and my attention to my laptop screen instead), the crispness and richness of my perception of the mug's shape and color properties feels diminished.

Psychophysical studies suggest that attention can indeed make objects appear brighter, larger or more colorful, thus lending empirical support for the proposed contrast between attentive and inattentive experiences (see Carrasco & Barbot 2019 for a review). One way of thinking about the described effects is that attention increases the *precision* or *determinacy* of perceptual experiences: an attentive experience of an object is more precise or determinate than an inattentive experience of the same object. But how this precision should be cashed out is a matter of ongoing controversy.

One pressing point of debate is whether the felt changes in precision or determinacy are changes in the *contents* represented by experience. The content of a perceptual experience is the sum of the properties attributed to a perceptual scene in that experience (Nanay 2010). For example, the content of my visual experience of the red mug is the sum of the relevant color, shape and location properties.[1] Representationalist thinkers often defend the view that attentive visual experiences have more precise contents than inattentive ones. A well-known proposal by Bence Nanay (2010) is that inattentive perception represents mostly *determinable* properties, which are highly abstract and admit of further specification. The telephone in your office, he says, might look light-colored when you perceive it inattentively. But if you direct attention to the telephone, your visual experience will represent more determinate properties. Your attentive experience represents the more determinate property *beige*, which is not represented in your inattentive experience.

Adduced support for this view includes empirical evidence that attention increases visual spatial resolution, perceived brightness and perceived contrast. For example, James Stazicker (2011) argues that attention makes the contents of visual experience more determinate insofar as it increases spatial resolution. The latter is a fairly well-established finding, evinced by behavioral studies showing that attention can improve ability to detect gaps (Yeshurun & Carrasco 1999; Montagna et al. 2009; Gobell & Carrasco 2005) or segregate very fine-grained textures (Yeshurun & Carrasco 1998; Yeshurun et al. 2008). Further support comes from neuroscientific findings suggesting that attention "shrinks" neuronal receptive fields (Reynolds et al. 2000; Martinez-Trujillo & Treue 2002, 2004; Moran & Desimone 1985) and also "remaps" them to extract more information from attended spatial locations (Anton-Erxleben & Carrasco 2013; Anton-Erxleben et al. 2007).

While these findings do support the proposal that attention elicits representation of more precise or determinate spatial properties, like shapes or locations, it is not clear whether support can be extended to all properties represented in visual experience. Particularly, it is not

[1] Content is sometimes characterized in terms of associated propositions: the content of my experience of the red mug is associated with the proposition *there is a red mug on my desk*. Some representationalists hold the stronger position that this proposition *is* the content of my experience. The arguments in this paper do not hinge on the nature of content. See Brogaard (2014) for discussion.

obvious how increasing spatial resolution could yield more determinate *color* contents. Consider the determinable-determinate pairs *rectangular-ish–telephone-shaped* and *light-colored—beige*.[2] The difference between representing *rectangular-ish* and representing *telephone-shaped* plausibly turns on level of spatial detail, so that increasing spatial resolution seems indeed sufficient for representing the more determinate shape. But the difference between representing *light-colored* and representing *beige* does not seem to be a straightforward matter of spatial resolution. Even though increasing spatial resolution might be necessary for representing the more determinate property, it might not be sufficient.

To add to this difficulty, anti-representationalist philosopher Ned Block (2015) cites a psychophysical study (Asplund et al. 2014) revealing that the precision of color reports is comparable for attended and unattended targets. This suggests that attentive and inattentive experiences might represent colors with equal precision, despite what it might appear to us on introspection.

Nonetheless, the representationalist proposal that attentive experiences have more determinate color contents is not completely refuted by these difficulties. In what follows I offer a response to Block's argument, as well as some potential empirical support for the representationalist view.

2

Block (2015) defines precision as a matter of the range of values attributed to an object within a property dimension: the narrower the range of values attributed, the higher the precision. For example, a representation that attributes the height *between 5'8'' and 5'10'' feet* is more precise than a representation that attributes the height *between 5'6'' and 6' feet*, because the range of values it attributes is narrower. Block uses the term *range contents* to refer to this kind of intervallic property (see also Boone 2020). The idea is that for attention to increase the

[2] The relevant determinate need not be the high-level property *telephone-shaped*; it could also be a low-level property like *t-gestalt* (in the sense proposed by Alex Byrne in Siegel & Byrne 2017). The present arguments do not hinge on the question of whether perceptual experience can represent high-level contents.

precision of a representation, it must narrow down its range content. According to Block, Asplund and colleagues' (2014) study strongly suggests that attention does not do this for color contents.

Asplund and colleagues used the attentional blink paradigm to compare responses to attended versus unattended targets. Participants must locate the color of the second of two targets presented in rapid succession in a color wheel composed of 180 hue values. They must also report whether the first target was black or white. As per the attentional blink, when the second target appears within the interval known as lag 2 (within 200-400ms after first target onset), attending to the first target impairs the capacity to attend to the second one. Lag-2 targets were thus considered unattended. Responses to these targets were then compared with responses to targets presented at different intervals after 400ms, when the 'blink' effect has vanished and participants can attend to the second target. For example, targets at the much later lag 8 were already deemed attended.

Responses were highly accurate for lag-8 targets, whereas for lag-2 targets they were at chance. However, the precision of responses was comparable for both sets of targets. Importantly, precision in this study (as it seems standard in psychophysical studies) is defined as a measure of how tightly a pool of responses cluster together. Asplund and colleagues compared the error distributions in the response pools for lag-2 and lag-8 targets. The range of error went from 0 (i.e., perfect accuracy) to 180 degrees off (maximal inaccuracy). The "tightness" with which a pool of responses clusters together is defined by the portion they cover within this range. To illustrate, suppose you have two pools of four responses each. In the first pool, all responses are off by 10 degrees. In the second pool, two responses are off by 10 degrees and two more are off by 15 degrees. The four responses in the first pool are more tightly clustered, whereas the four responses in the second pool are more spread out: this means that the former have higher precision than the latter.

In the present study, responses to lag-2 and lag-8 targets had equal precision insofar as they were equally spread out. Both pools spread over the same ranges of error: in both, responses were off for as much as 180 degrees. If precision was higher for lag-8 targets, then the most inaccurate responses within this pool should have been off by *less* than the 180 degrees off observed for lag-2 targets. Furthermore, the bulk of responses in both pools concentrated around the 90 degrees of error. If precision was higher for lag-8 targets, then more of these responses would also be concentrated more tightly around 0: the bulk of these responses would have been around, say, 80 degrees rather than the 90 degrees observed for lag-2 targets.[3] But since this is not the case, the experimenters conclude that precision does not differ between attentive (lag-8) and inattentive perception (lag-2). And on these grounds, Block proposes that attention might not make visual experience represent more precise color contents. According to his definition of precision, this is to say that attention does not narrow down the ranges of values attributed within the color dimension.

Now, one worry with this argument is that the kind of perceptual precision that Asplund and colleagues' study reports on might not be the one invoked by representationalists. Moreover, the range contents that attention arguably fails to narrow down might be of a different kind than those needed to support the view that attention makes color contents more precise. Notably, Asplund-precision is a statistical property of attentive and inattentive perception in general, not a property of individual attentive or inattentive experiences. This already makes us wonder how the discussed results bear on the claim that attentive experiences of coffee mugs and telephones represent determinate properties like *vermillion* or *beige* while inattentive experiences of these things represent indeterminate properties like *reddish* or *light-colored*. Note that the former properties could also count as *more precise* by Block's lights: within the color space, *vermillion* and *beige* carve out smaller regions of the color space than *reddish* and *light-colored*, so that they plausibly involve narrower ranges of values.

I think that Asplund and colleagues' study is silent regarding whether attention can be responsible for visual experience representing *vermillion* rather than *reddish*. For one thing, this

[3] More formally, the idea is that the standard deviation (σ) was virtually indistinguishable between both response pools. Note, however, that σ is slightly smaller for lag-8 targets, which in all strictness should indicate a slightly higher precision (σ = 20.4 versus 20.6).

paradigm is admittedly not designed to measure the precision of individual percepts. A single trial measures only accuracy: responses are accurate if participants pick the correct hue value, and inaccurate otherwise. But single trials do not measure how narrow or wide is the range of hue values attributed to a target. Thus, this paradigm cannot distinguish between individual responses that are both precise and accurate, accurate but imprecise, or precise but inaccurate. In every individual trial, participants could only pick a single value within the color wheel, so that every individual response is automatically as precise as it can be. Hence, in a way it should not be surprising that precision does not differ between lag-2 and lag-8 percepts.

Finally, imagine what an increase in the statistical kind of precision measured by this study might be. Suppose that responses did cluster more tightly for attentive lag-8 percepts than for inattentive lag-2 ones. Say that the worse responses in attentive perception were only 120 degrees off. In what sense would this make attentive perception represent narrower range contents than inattentive perception? It is not that any given attentive percept represents a 120-degree-wide range of hue values, whereas any given inattentive percept represents a 180-degree-wide range. As we saw, this kind of precision is not about the range contents represented by a single percept. But then it is not clear what the relevant range contents are. What is the content that both attentive and inattentive color perception represent in virtue of having a range of error of 180 degrees? Is this something like a range of values within the "error" dimension? Is this kind of range content on the same level as range contents within dimensions like length, contrast or hue?

It seems to me that this kind of content would be of a higher order, whereas color or hue contents are first-order. Attention is sometimes treated as affecting precision in this higher-order way, especially within the predictive coding literature (see Clark 2013; see also Ramson et al. 2017 for a critical take). However, Block (2015: 4) is explicit that he does not intend to adopt this characterization of precision.

I conclude that Asplund and colleagues' findings are compatible with the view that attentive experiences have more precise or determinate color contents. I will now consider some positive empirical support for this view.

3

Berit Brogaard (2015; Kentridge & Brogaard, 2017) proposes that the residual visual experiences of type-2 blindsight patients evince that visual experience can indeed represent highly indeterminate color properties. These experiences are described as of faint flashes, ill-defined poorly-formed blobs, or black shadows on a black background (Weiskrantz 1980; Shefrin et al. 1988). Brogaard suggests that they may be likened to photographs with very low contrast and resolution. See figure 1:

Fig. 1: Residual visual experience in type-2 blindsight represents very indeterminate color and shape properties.

Brogaard further argues that this kind of perceptual indeterminacy is plausibly due to damage in the brain mechanisms for brightness perception, which results in stimuli appearing to have lower contrast. This in turn results in representation of more indeterminate properties. Some of these are *color* properties. For instance, the right-hand image on figure 1 fails to represent a full range of colors, and only represents some generic ones instead (yellowish green, but not blue).

According to this proposal, there is a link between perceived brightness/contrast and color-content determinacy, so that the former is required and might even be sufficient for the latter. Now, it is fairly well established that attention has similar effects to increasing physical contrast: attended stimuli appear to have higher contrast than they actually do (Carrasco, Ling & Read 2004), and attention enhances contrast sensitivity in early vision (Carrasco et al., 2000; Cameron et al., 2002; Reynolds et al., 2000; Treue 2001). Thus, if increasing brightness/contrast increases the determinacy of color contents, attention does so as well.

Brogaard's view enjoys some further empirical support. Color perception involves three dimensions: brightness, saturation, and hue. See figure 2:

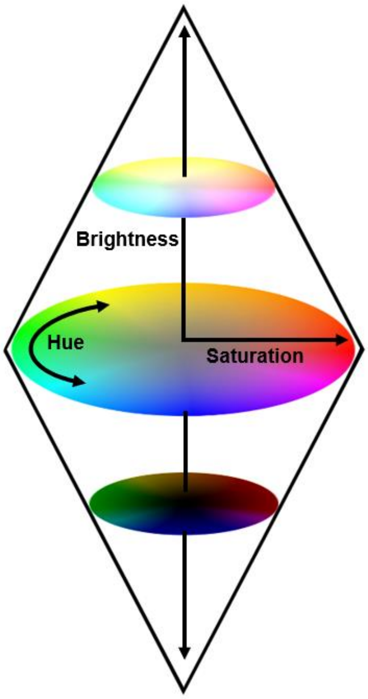

Fig. 2: Tridimensional color space[4]

Insofar as perceiving color involves perceiving brightness, effects on perceived brightness must be reflected on perceived color. Furthermore, studies from Carrasco's lab reveal that attention also increases perceived saturation (Fuller & Carrasco 2006; Kim et al. 2014). Participants instructed to report the orientation of the more colorful-looking (i.e., "redder", "greener",

[4] Thanks to X for supplying this figure.

"bluer") of two ovals consistently picked the one to which their attention was cued, which reveals that attended ovals looked more colorful. The effect was robust under a reverse-instruction control condition: when participants were instructed to report the orientation of the *less colorful* oval instead, they consistently picked the unattended ones.

Attention thus makes colors appear brighter and more saturated. This might indeed underpin an increase in determinacy. The difference between representing the office telephone as light-colored and representing it as beige might at least partially turn on how bright and saturated its color is represented. Increasing brightness and saturation may be a way of extracting more information of the kind required for isolating the particular perceived color from the rest of the color space.

However, this is not conclusive evidence for the representationalist position. For one thing, we still need to clarify what is it to represent *a color* more determinately. For shapes, there is a fairly good answer: shapes are represented more determinately when more information about spatial boundaries is represented. However, for colors the situation is less clear. What kind of information is required? Would the required information be supplied by increased brightness or increased saturation, either taken each on their own or jointly? And what about hue?

A plausible possibility is that representing more determinate colors requires more information about each of the three color dimensions.[5] However, if this is the case then color representationalists face trouble, for attention does not seem to affect hue perception (Fuller & Carrasco, 2006). In a study where participants were instructed to report the orientation of the oval that looked more blue or more purple, directing attention to one of the ovals did not affect which oval was picked.[6] This indicates that attention leaves intact the values attributed within

[5] X suggested a proposal along these lines.

[6] Interestingly, participants did pick the attended ovals more frequently when asked to report the more purple one. However, the experimenters point out that if this result indicated a reliable effect on hue, it should have been found also in the "report more blue" condition (participants would then have picked the attended oval less frequently under this instruction). But since this was not the case, the effect could have been due to something else. Note that a cue bias is not a likely explanation, since this kind of bias would have also been present in the remaining conditions of the experiment, which was not the case either.

the hue dimension of the color space. Moreover, Fuller and Carrasco interpret their results as showing that attention does not increase sensitivity to hue differences. This kind of sensitivity might be crucial for our ability to perceive more determinate colors. For instance, the difference between vermillion and maroon is plausibly a (subtle) difference in hue values rather than in brightness or saturation values. If my experience of the mug represents vermillion rather than reddish, then maybe that means that the content of this experience is somehow sensitive to the difference between vermillion and other determinates of the determinable *red*.

To be sure, it is still possible that attention may contribute to the representation of more hue information, so that attentive visual experiences contain more hue information than inattentive ones. It is also possible that a color experience is made more determinate by making it represent higher values of brightness and saturation for the same hue value. These questions might be decided by future conceptual and empirical work.

References

Anton-Erxleben, K. and Carrasco, M. (2013). Attentional enhancement of spatial resolution: Linking behavioural and neurophysiological evidence. *Nature Reviews Neuroscience 14*,18-200.

Anton-Erxleben, K., Henrich, C. and Treue, S. (2007). Attention changes perceived size of moving visual patterns. *Journal of Vision*, *7*(1),1-9.

Asplund, C. L., Fougnie, D., Zughni, S., Martin, J. W. and Marois, R. (2014). The attentional blink reveals the probabilistic nature of discrete conscious perception. Psychol Sci. 2014 Mar;25(3):824-31. doi: 10.1177/0956797613513810.

Block, N. (2015). The puzzle of perceptual precision. In T. Metzinger & J. M. Windt (Eds.), *Open mind* (Vol. 5). MIND Group.

Boone, T. (2020). Range content, attention, and the precision of representation. *Philosophical Psychology* 33 (8):1141-1161.

Brogaard, B. (2015). Type 2 blindsight and the nature of visual experience. *Conscious Cogn*. Mar;32:92-103. doi: 10.1016/j.concog.2014.09.017.

Brogaard, B. (ed.) (2014). *Does Perception Have Content?* OUP: USA.

Cameron, E.L., Tai, J. & Carrasco, M. (2002). Covert attention affects the psychometric function of contrast sensitivity. *Vision Res*.; 42:949–967. [PubMed: 11934448]

Carrasco, M., & Barbot, A. (2019). Spatial attention alters visual appearance. *Current Opinion in Psychology, 29,* 56–64. https://doi.org/10.1016/j.copsyc.2018.10.010

Carrasco, M., Ling, S. and Read, S. (2004). Attention alters appearance. *Nature Neuroscience*, *7*(3), 308-313.

Carrasco, M, Penpeci-Talgar, C. & Eckstein, M. (2000). Spatial covert attention increases contrast sensitivity along the CSF: support for signal enhancement. *Vision Res.*; 40:1203–1215. [PubMed: 10788636]

Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, 36_(3), 181-204. doi:10.1017/S0140525X12000477

Fuller, S. & Carrasco, M. (2006). Exogenous attention and color perception: performance and appearance of saturation and hue. *Vision Res*. 46(23): 4032-47.

Gobell, J. and Carrasco, M. (2005). Attention alters the appearance of spatial frequency and gap effect. *Psychological Science*, *16*(8), 64-651.

Kentridge, R. W., and Brogaard, B. (2017). The functional roles of attention. In *Current Controversies in Philosophy of Perception* (pp. 139-147).

Kim, S., Al-Haj, M., Fuller, S., Chen, S., Jain, U., Carrasco, M., & Tannock, R. (2014). Color vision in ADHD: Part 2 - Does Attention influence Color Perception? *Behav Brain Funct*; 10: 39. doi: 10.1186/1744-9081-10-39

Martinez-Trujllo J. C., and Treue, S. (2002). Attentional modulation strength in cortical area MT depends on stimulus contrast. *Neuron*;35:365–370. [PubMed: 12160753]

Montagna, B., Pestilli, F. and Carrasco, M. (2009). Attention trades off spatial acuity. *Vision Research*, *49*(7), 735-745.

Moran, J., and Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, 229(4715), 782–84.

Nanay, B. (2010). Attention and perceptual content. *Analysis* 70 (2):263-270.

Ransom, M., Fazelpour, S., & Mole, C. (2017) "Attention in the Predictive Mind", *Consciousness and Cognition*, 47, 99-112.

Reynolds, J.H., Pasternak, T. & Desimone, R. (2000). Attention increases sensitivity of V4 neurons. *Neuron*.; 26:703–714. [PubMed: 10896165]

Shefrin, S. L., Goodin, D. S., & Aminoff, M. J. (1988). Visual evoked potentials in the investigation of ''blindsight''. *Neurology*, 38(1), 104–109.

Siegel, S. and Byrne, A. (2017). Rich or thin? In Bence Nanay (ed.), *Current Controversies in Philosophy of Perception*. New York, USA: Routledge.

Stazicker, J. (2011). Attention, visual consciousness and indeterminacy. *Mind & Language*, 26(2): 156-184.

Treue, S. (2001). Neural correlates of attention in primate visual cortex. *Trends Neurosci.*; 24:295– 300. [PubMed: 11311383]

Weiskrantz, L. (1980). Varieties of residual experience. *Quarterly Journal of Experimental Psychology* 32, 365–386.

Yeshurun, Y. and Carrasco, M. (1999). Spatial attention improves performance in spatial resolution tasks. *Vision Research*, *39*(2),293- 306.

Yeshurun, Y. and Carrasco, M. (1998). Attention improves or impairs visual performance by enhancing spatial resolution. *Nature*, *396*(6706), 72-75.

Yeshurun, Y., Montagna, B., and Carrasco, M. (2008). On the flexibility of sustained attention and its effects on a texture segmentation task. *Vision Research*, 48, 80–95.