Abstract:
Recently there has been much interest in the epistemic roles of attention. Philosophers have debated whether visual attention is necessary for warranting (basic) visual belief. Arguably it is not. But attention nevertheless has an important role to play in our warrant from vision. Visual attention is crucial to transsaccadic vision: vision that integrates information across several movements of the eyes. Transsaccadic vision, in turn, is central to explaining how vision can be rich: detailed and as of spatio-temporally extended visual scenes. Many of our visual beliefs are based on transsaccadic percepts. I argue that we must appeal to a competence for shifting visual attention in explaining transsaccadic vision and our epistemic warrant from it. So even if not necessary for visual warrant or vision, visual attention plays a central role in both.

Words: 8382

Warrant from Transsaccadic Vision[1]

1 Epistemic Roles of Attention

Recently there has been much interest in the epistemic roles of attention for warranting basic visual beliefs. Several philosophers – including John Campbell, Declan Smithies, and Imogen Dickie – have argued that visual attention to a particular is necessary for visual beliefs about the particular to be warranted. Visual beliefs are formed *directly* from visual perceptual states. The formation of the beliefs (or percepts) does not involve higher cognitive processes, such as reasoning. Visual beliefs are candidates for being epistemically *basic* insofar as the (positive) epistemic standing of their underlying visual state alone may warrant these beliefs. The aforementioned philosophers claim that we could not have a warranted visual demonstrative belief about a red circle in front of us unless we attended to that circle: because attention is required for grasping visual demonstrative concepts (Campbell 2002, 2011); because attention makes visual information useable for warranting visual belief (Smithies 2011a, b); or because attention enables non-lucky tracking of visual objects for warranting belief about them. (Dickie 2011) I am not convinced that visual attention is necessary for warranting visual belief. There are armchair considerations against this claim. (Siegel & Silins 2013a) There are empirical reasons to doubt it. (e.g. Block 2013)

Does this result entail that there are *no* interesting epistemic roles for visual attention to play in warranting visual belief? I think that the answer is 'no.' Not only does attention

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plausibly play an important role as an interface between perception and thought.[2] Visual attention also plays a more primitive role in the generation of a range of visual percepts. Both roles bear on our warrant for visual belief. But it is the latter role that I want to focus on in the present paper.

Consider the following case. A cube, rotating around its own axis, rapidly moves from your far left to your far right. You see the cube as performing one coherent motion. Your visual system generates this motion-percept by fixating the eyes on different locations – by performing saccades – throughout the duration of the motion-event. The system maintains information about the cube's orientation at different positions and times in a transsaccadic memory. The system integrates this information so as to generate the resulting transsaccadic percept: a single, coherent percept as of the entire motion event's unfolding. Much vision is transsaccadic in this way. I will argue that shifts of visual attention are central to transsaccadic vision.[3]

Transsaccadic vision, in turn, is crucial to understanding how vision can be rich: how it can represent large parts of the visual scene in detail; how it can yield coherently integrated representations of spatio-temporally extended objects and events; and all despite the fact that intake of visual information is confined to when and where the eyes fixate. We see one and the same cube's detailed motion while it unfolds, against a backdrop of detailed, spatially distributed, temporally persisting objects such as a window frame, a desk, and a floor. But the visual system resolves detail only at the highly circumscribed locations where the eyes fixate. And the system takes in novel information only during fixation – often lasting merely 200 ms. Why do we not see a concatenation of unrelated snapshots? Why is our visual

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[2] Wu 2014 and Siegel & Silins (forthcoming) have gestured in this direction.

[3] This role of visual attention bears some similarity to what Susanna Siegel calls 'selection effects.' Suppose that an individual forms a false belief that all squares in a display are red. The individual engages in a visual search that results in a 'compound experience' containing a series of percepts of red squares. (Siegel 2013b, 253 & 2017, 167) She forms a belief based on this experience. By assumption, the individual's over-confidence in her ability to detect red squares causes her to ignore non-red square items. (Siegel 2013b, 253; 2017, 164/5) Siegel argues that over-confidence tampers with selection so as to undermine the experience's epistemic standing. (Siegel 2013b, 257 & 2017, 168) Siegel considers such selection an effect of *attention* on experience. (Siegel 2017, 161)

But, first, Siegel does not explain why such selection effects are *attentional* effects on vision. Not all psychological selection involves attention. Any kind of selective combination of percepts, including of inattentive conscious percepts, could be epistemically flawed. Second, Siegel also does not explain whether the resulting 'compound experiences' are *visual*. She writes that "it seems straightforwardly part of the phenomenal character [that there is a] … phenomenal feature that goes with universally quantified contents." (Siegel 2013b, 253) But arguably, universal quantification is not something a visual system is capable of. (Burge 2010)) Finally, Siegel deliberately sidesteps questions as to whether such effects *actually* occur. (Siegel 2013b, 244) I am, however, precisely interested in the warrant that actual (human) believers have for their visual beliefs.

experience nevertheless rich, spatio-temporally integrated, and coherent? Our answer to these questions will centrally appeal to transsaccadic vision.

Visual attention, I will argue, is not merely central to transsaccadic, and hence rich, vision. Visual attention is also central to explaining our warrant for beliefs directly based on transsaccadic vision – transsaccadic belief. Since transsaccadic vision is central to explaining our rich visual experience, and since our warrant from rich visual experience is a core explanandum in the epistemology of vision, visual attention therefore is central role in explanations of warrant from vision, more generally. So even if not necessary for vision or for visual warrant, attention is central to both.

To understand the epistemic role of attention in transsaccadic belief, we must understand how attention contributes to generating the visual percepts that these beliefs are based on. In this paper I describe this role. I will present and defend the following argument:

(1) Many visual beliefs are formed directly on the basis of transsaccadic visual percepts.
(2) Many transsaccadic visual percepts involve deploying visual attention in certain ways.
(3) So, the formation of many visual beliefs involves deploying visual attention in certain ways.
(4) The ability for deploying visual attention in certain ways is a component of a visual competence that functions to generate veridical transsaccadic percepts, and that reliably does so in the visual system's normal environment.
(5) If the ability to deploy visual attention in certain ways is a component of a visual competence that functions to generate veridical transsaccadic percepts, and that reliably does so in the visual system's normal environment, then that ability plays a role in warranting transsaccadic belief.
(6) So the ability to deploy visual attention in certain ways plays a role in warranting transsaccadic belief.

I explain and defend each of premises (1) and (2) in the following two sections. Next I defend the truth of (4). Premise (5) derives support from several influential conceptions of epistemic warrant. Arguing for a conception of warrant is beyond the scope of this paper. I will merely explain how the conceptions support (5). The appeal of my argument is hence limited to those who find the relevant conceptions of warrant independently attractive.[4] I will refer to the argument (1) – (6) as *the main argument*. In the last section I elaborate on the role of transsaccadic vision – and hence attention – in rich vision.

[4] I return to this point in Section 4 below. See especially fn. 15.

2 Transsaccadic Vision

Many visual beliefs are formed directly on the basis of visual percepts that result from shifting attention and integrating visual information across saccades. I call such visual percepts 'transsaccadic percepts' and the beliefs based on them 'transsaccadic beliefs.' In arguing for premise (1) of *the main argument* I focus on establishing that there is such a thing as transsaccadic vision that does not involve higher cognitive processes in its generation.

Consider, again, the case of the cube:

> <u>*Complex Motion Event*</u>
> A cube moves from the far left of your field of vision to the far right, while rotating in the three dimensions of space. You have a transsaccadic percept as of one single, smoothly integrated event of movement and rotation.[5]

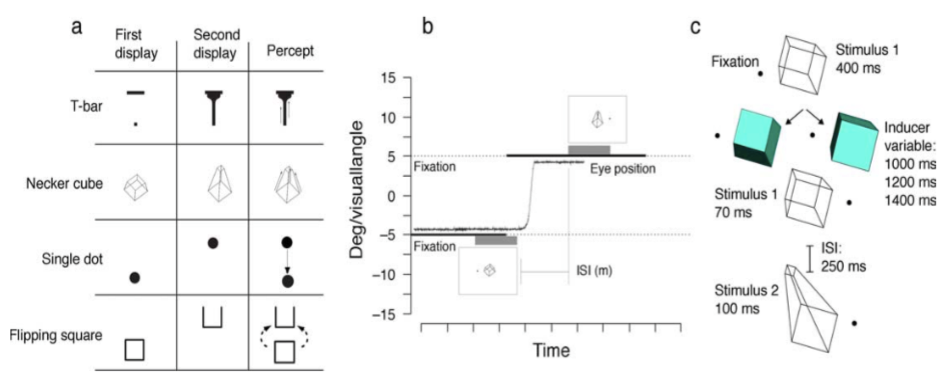
In this case, your visual system integrates visual information from different fixations into one single transsaccadic percept. A cube appears to your far left. The cube exhibits some specific orientation in three-dimensional space. During the first fixation, your visual system takes in and processes information about the object's shape. The system processes the cube's location, its three-dimensional orientation, and the direction and speed of its motion. The cube moves to your far right. It rotates in the third dimension by a certain angle. You shift your eyes to the cube's new location. During the second fixation, your visual system updates information about the object's shape, location, orientation, direction, and speed. A transsaccadic memory maintains information from the first fixation for integration with information from the second fixation. Information from the two fixations integrates so as to generate a single, coherent percept as of the cube's motion and rotation.

Appreciate how initially plausible it seems that the visual system should integrate perceptual information across saccades into unified, coherent percepts. We perform saccades three to five times per second. The visual system takes in visual information only during fixation. Fixations last fractions of a second. Nevertheless our visual experience is

[5] Here are two more examples: <u>*Detailed Objects*</u> You are looking at a large octahedron that has a small crack on its lower left side and another on its upper right side. Performing an object-recognition routine, you first foveate the crack on its front, then the crack on its left side. You have a transsaccadic percept as of one object with two cracks on its different sides. <u>*Intricate Spatial Relations*</u> You are looking at the center of a large, intricate contour embedded in a crowded visual scene. Performing a very fast visual routine, you next foveate an object to the far right of the contour. Finally you trace the contour so as to determine whether the object is inside or outside the contour. You have a transsaccadic percept as of the object inside the contour.

uninterrupted, coherent, and smoothly integrated. We do not perceive a concatenation of snapshots. Indeed, we are usually not even aware that we perform saccades. Our coherent visual experience suggests that visual information is integrated across saccades. But also, if the visual system did not maintain and integrate visual information across saccades, then we would have to re-perceive the entire visual scene during each fixation. Constantly re-perceiving our environment would be an ineffective way of using time and processing resources. So again, it seems plausible that information from a fixation should be maintained and integrated across saccades.

Empirical psychology supports the claim that the visual system maintains and integrates information across saccades in the way just sketched. A study by Fracasso *et al.* 2010 illustrates this research. Fracasso *et al.* provide direct evidence for the phenomenon illustrated in *Complex Motion Event*. They asked subjects to fixate attention on a cross. When the subjects were ready, a first stimulus appeared on a screen for 400 ms. The stimulus could be a T-bar, a Necker cube, a single dot, or a square. Next appeared a variable blank that was presented for between 105 ms and 400 ms. Finally a second stimulus appeared on the screen. For the T-bar and the Necker cube, the second stimulus consisted in a translation/rotation of the first shape. The dot changed vertical location. The square shifted vertical location and lost one of its sides.



[Fig. 1. *1a* shows the stimuli used in the experiments, *1b* shows the trial procedure, *1c* the trial procedure used to bias the type of shape transformation. (Fracasso *et al.* 2010, 3)]

The experiment featured two crucial conditions. In a no-saccade condition, subjects maintained fixation on a cross throughout the trials. In the saccade condition, the fixation cross was displaced by 10 degrees during a trial. The subjects had to perform a saccade approximately 300 ms into the first stimulus, while that stimulus was still visible. Subjects then indicated whether they had two distinct percepts corresponding to the first and the second stimulus, or whether they had a coherent percept as of a motion event. For both the no-saccade and the saccade condition, subjects consistently reported "a compelling percept of object transformation." (Fracasso *et al.* 2010, 6) They saw a single, coherent motion event. They saw the T-bar as moving up or down and the Necker cube as translating or rotating in space. They saw the dot as moving vertically and the square as flipping from the bottom to the top of the display. The fact that Fracasso *et al.* did not find a significant difference between reports in the no-saccade and the saccade condition provides *prima facie* evidence that the perception of these different motion events occurred across saccadic eye movements. Fracasso *et al.*'s results suggest that the visual system integrates information about objects' motion, their shape, and their three-dimensional orientation across saccades into a single percept.

One may worry that individuals in the Fracasso *et al.* studies do not really report their visual states. The reports might rather be the result of rapid cognitive processing, possibly reasoning. Transsaccadic vision would then not be vision *proper*. Fracasso *et al.* provide evidence against this possibility by showing that transsaccadic vision exhibits perceptual adaptation. In perceptual adaptation, the visual system's sensitivity to a specific kind of stimulus first rises, then falls. For example, if a subject first looks at a pattern tilted leftward for sufficiently long enough, and next at a horizontal pattern, then the horizontal pattern will seem tilted rightward. By raising the threshold for detection of the leftward tilt, the visual system biases the subsequent perception toward rightward tilt. Adaptation effects are ubiquitous in visual perception. We do not find them in most thought. (Block 2014; Block 2015; for a cautionary note see Burge 2014) A widely accepted indicator of motion perception is the motion aftereffect. The aftereffect consists in the visual system's adapting to a motion stimulus. Fracasso *et al.* showed (*Experiment 4*, Fracasso *et al.* 2010, 11ff.) that the motion percept that their subjects report exhibits perceptual adaptation. Their subjects viewed a pattern of dots, moving either upward or downward. The dot patterns were presented for 105 ms, during which the subject had to saccade from one fixation point to another. That is, their perception of the dot pattern's motion was transsaccadic. Next, a directionally neutral test pattern appeared for 2 sec. The test began with the exact same dot pattern that had been presented in the final frame of the adapter. When subjects reported the motion-direction of the test stimulus, they showed strong adaptation. They perceived upward-moving neutral patterns as moving downward, and vice versa. (cf. also Melcher 2008)[6]

One may still worry that transsaccadic memory is a type of working memory. Working memory, however, is not a perceptual, but a cognitive memory, possibly involving reasoning, one might think. So, again, transsaccadic vision would not be vision *proper*.[7] Two features characterize working memory stores. The contents of such memory stores are occurrently activated for carrying out some cognitive task. And working memory stores have a characteristically small capacity of about four items. *Visual* working memory obtains its contents mostly through the visual modality. And representations stored in this memory have visual representational format. (Luck & Vogel 2013; Brady, Konkle & Alvarez 2011)

Visual working memory is indeed often involved in transsaccadic vision. But we have evidence that the memory underlying transsaccadic vision *differs* from visual working memory. A study by Germeys *et al.* 2010 illustrates this evidence. Subjects performed a change detection test. In the critical *Experiment 2*, subjects first fixated a cross on a screen. Next, a letter array appeared for 250 ms. In addition to the letters, the array contained a prompt that indicated which letter the subject should saccade to next. The last display contained one letter, either the same as the letter in the corresponding location of the initial display, or different from that letter. Subjects had to indicate whether the letter was the same or different from that in the first display. The location of the letter in the test display did not have to coincide with the target of the saccade. *Experiment 2* contained several conditions in

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[6] These data on adaptation converge with two further sets of data that speak against transsaccadic vision's being due to cognitive processing. First, there is direct empirical evidence that the relevant processing that underlies transsaccadic vision is *visual* processing. The neural mechanisms presumably underlying transsaccadic vision form parts of the visual brain. Melcher & Morrone (2007, esp. 227) argue that transsaccadic memory could be explained by a mechanism that remaps receptive fields across saccades. Visual stimuli receive initial processing by neurons in visual areas V1 – V5. These neurons' receptive fields respond to stimuli projected upon a specific retinal location. The neural networks devoted to processing the form, contrast, motion, or color of a stimulus continue their processing while the fovea is shifting. Due to remapping, those neuronal networks now respond to a stimulus at a different retinal location – the retinal location upon which the original stimulus should project after the saccade. In this way, processing of information from the same stimulus could be integrated across saccades. Visual areas V1 – V5 are widely assumed to constitute the neural underpinnings of the visual system. (cf. also Melcher 2005 & Melcher & Morrone 2003) Second, some of the stimuli stored in transsaccadic memory are of what is assumed to be basic visual nature. Melcher 2005 provides evidence for integration of visual information across saccades for stimuli involved in both lower and higher visual-form processing, such as tilted gratings, sinusoidal luminance patterns, dynamic form patterns, and faces. It seems unlikely that such integration should occur in thought. These results further support the claim that the processing is visual, not cognitive in nature. (cf. also Melcher 2003; Melcher & Morrone 2007, 217)

[7] It is not obvious that a visual working memory influence on processing would render it cognitive. Visual working memory's perceptual format suggests that a top-down visual working memory influence might constitute a form of *visual* processing. We would need a principled reason for thinking otherwise.

which the display was blanked for 950 ms before the test display appeared. The second and third blanking condition contained a cue indicating the location at which the test letter would appear in the test display. The cue in these conditions appeared early (50 ms) or late (450 ms) during the blanking period.

Germeys *et al.*'s main interest was in the effect of blanking. Blanking postpones overwriting of information by post-saccadic input. Attending to a specific region in space *after* blanking should insulate information from that location against decay. Germeys *et al.* found, not surprisingly, that change detection performance for *non*-saccade target (or bystander) items was overall worse than for the attended saccade target. But they also observed a positive blanking effect for bystander items in the early cue condition. Germeys *et al.* reasoned that selective attention to any cued location transfers items at the location from transsaccadic memory into working memory for subsequent change detection. But any of the items in the display could be cued. So the transsaccadic memory that visual attention accesses through the cue must be much larger than the four items characteristic for working memory. Also, change detection was worse if the cue appeared 450 msec after the disappearance of the initial display. This result suggests that the memory that visual attention taps into decays after 300 msec, much earlier than contents in visual working memory. Finally, the fact that bystander items could be remembered fairly reliably only in the blanking conditions strongly suggests that transsaccadic memory, unlike visual working memory, is fragile and easily overwritten. Each of these features distinguishes transsaccadic memory from visual working memory.[8]

One might finally worry that carrying out the saccades themselves requires cognitive processing, even reasoning. I refer to relevant patterns of eye movements as 'attentional routines.' They are highly stereotyped, quasi-automatic patterns of saccades (and attention shifts) for reliably perceiving certain distal features or events. In order to perceive, e.g., the *Complex Motion Event*, the visual system must track the cube's trajectory. If the system's processing resources shift in the direction opposite the cube's movement, the system will not have available detailed information about the cube's orientation in its new location. The visual system overcomes this difficulty by performing attentional routines. Features of the stimulus often determine which kind of routine is triggered. There is evidence for such

[8] See also Melcher 2006, 13ff. This transsaccadic memory bears similarities to *fragile visual working memory*, identified in the context of partial report studies. (Sligte *et al.* 2008; Block 2011)

routines in support of perceiving affordances, visual scene types, and three-dimensional object-shapes. (Leek et al. 2012; Tatler *et al.* 2011; Tatler *et al.* 2008; Rothkopf *et al.* 2007; cf. also Wu 2014, 35ff.)

Do *all* attentional routines involve cognitive processing, even reasoning? There is no reason to think so. First, many of the relevant routines are quite minimal. They involve no more than saccading from the left to the right end of the field of vision, as in the case of the motion event. The patterns of eye movements, even during more complex routines, are highly stereotyped and their execution is quasi-automatic. Psychology distinguishes between these routines and more sophisticated, voluntary eye movements in a systematic way. If higher cognitive processes such as reasoning were involved in carrying out routines, one would expect greater complexity and flexibility in their execution, too. Certainly, no appeal to reasoning is *needed*. (Wright & Ward 2008; Hayhoe 2000; Ullman 1998) Second, we find similar routines in animals such as goldfish, sea snails, and insects. It seems highly unlikely that any of these animals engage in cognitive processes, even reasoning, as we find it in primates. If visual systems in these animals can carry out attentional routines, our most parsimonious theory will allow that at least the simpler routines in primates can be achieved by their visual system alone. Indeed, many of these routines are plausibly innate in humans. We may have inherited them from ancestors incapable of reasoning. (Land 1995; Land & Nilsson 2012, Chapter 9) I am not aware of any independent grounds for thinking that attentional routines in primates require cognitive processing, much less reasoning.

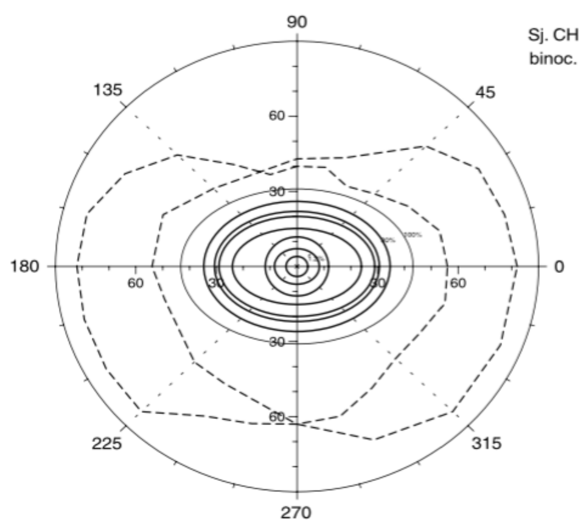
I conclude that the evidence favors the claim that transsaccadic vision, as per step (1) of *the main argument*, is visual perception *proper*. In what follows I will assume that my description of the *Complex Motion Event* is accurate.[9] Since there is such a thing as transsaccadic vision, we may assume that beliefs can be directly based on transsaccadic visual perceptions.

3 Attention in Transsaccadic Vision

[9] Similar results have been obtained for the orientation of line drawings (De Graef & Verfaille 2002), the orientation of gratings, sinusoidal luminance patterns, dynamic form patterns, and faces, shapes (Melcher & Morrone 2003; Melcher 2005; Prime, Niemeier & Crawford 2006), and detailed information about several objects in complex visual scenes. (Melcher & Morrone 2007; Melcher & Colby 2008; Prime, Tsotsos, Keith & Crawford 2007)

When generating transsaccadic percepts, individuals shift their eyes so as to gather information from different parts of the scene. The visual system integrates this information, though transsaccadic memory, for the generation of a transsaccadic percept. Why and how is *attention* involved in the generation of such percepts, as I claim in step (2) of the *main argument*?

Let me first explain *why* the visual system generates many percepts across saccades. The visual system integrates information across saccades due to its inherent limitations. A perceiver's high-resolution fovea subtends only a very small segment of the field of vision, about 2 deg of visual angle. Foveal and attended vision encompasses about twice your thumb's width when your arm is stretched out. Most vision is peripheral and non-attended. To appreciate the visual system's limitations, have a look at fig 2.



[Fig 2. Central and peripheral vision. (Strasburger *et al.* 2011, 25)]

The figure shows recognition fields for simple shapes and objects at different contrasts. The stimulus that you can perceive at the fovea may not be perceptible outside the heavy lines, depending on the stimulus' level of contrast. This feature of vision is due to the fact that neurons receiving information from the fovea have the smallest receptive fields. They respond to stimuli from smaller portions of stimulus space. So, more processing resources are devoted to smaller portions of the scene. (Anton-Erxleben & Carrasco 2013, 189) Detection decays with eccentricity. In particular, spatial resolution worsens rapidly beyond 10-25 deg of eccentricity (the innermost oval in the figure). We can clearly discriminate two nearby points at the fovea that we will no longer be able to discriminate outside the fovea. Perceptual performance at more spatially fine-grained tasks declines even more rapidly. Whether and how well perceivers perceive things around them depends, e.g., on these things' contrast and angular size. Attention increases spatial resolution and contrast sensitivity for attended locations. (Carrasco 2011) So how well or whether some object can be perceived *also* depends on whether attention fixates it. The visual system performs saccades in order to overcome its inherent limitations and acquire information about the entire visual scene, not merely the relatively small area where the eyes are focused.

To illustrate, reconsider the *Complex Motion Event*. When the cube appears at the far left of your visual field, suppose that it is at a distance great enough for you not to be able to recognize its precise shape and orientation without foveating the cube. Next, suppose that the location of the second fixation of your eyes is located at 40 deg eccentricity relative to your first fixation. When the cube performs its rapid motion from the left to the right, your visual system will not be capable of computing the cube's precise shape and orientation at the new location. Both pieces of information are needed for the visual system to reliably compute the precise way in which the cube rotated in 3D space while moving from the left to the right. Without recognizing the cube's precise shape and orientation in both locations, the visual system lacks the information for reliably computing the precise way in which the cube moves. A reliable perception as of the cube's motion would, in this case, not be possible without moving the eyes.[10] (Virsu *et al.* 1987; Strasburger *et al.* 2011)

But how does overcoming the limitations of the visual system involve *visual attention*? Visual attention makes three distinctive contributions to transsaccadic vision.[11] First, shifts of visual attention provide information about the visual scene beyond a given fixation's location. Empirical psychology distinguishes between overt and covert attention. Overt attention consists in the fixation of the eyes – more specifically the fovea – upon some item

[10] I do not mean to suggest that low-acuity, peripheral vision *cannot* be reliably accurate. In many cases, it is. To reliably perceive something as bounded and large, spatial resolution at some peripheral location may often be sufficient. My point is rather that for many cases of *detailed* transsaccadic vision, low-acuity, peripheral vision would not be reliably accurate.

[11] In recent years, a series of constitutive accounts of attention have been proposed. Attention has been said to consist in our mental capacities's cognitive unison (Mole 2011), the selection of a stimulus for a response by the individual (Wu 2014), the regulation of priority structures (Watzl 2017), the making-available of information to thought (Smithies 2011) and to working memory (Prinz 2012). Each of the rivaling metaphysical accounts can accommodate my claims about attention as increasing spatial resolution and as shifting in attentional routines. Both claims are basic to the scientific study of visual attention. Thanks to an anonymous referee for prompting clarification.

or location. Covert attention involves the allocation of additional processing resources to items or locations other than those currently foveated. Insofar as transsaccadic percepts involve shifting the fovea, they involve shifting overt attention. Shifting overt attention is the primary way to overcome the visual system's limitations and gather detailed information from across the visual scene. Does covert attention play a role in transsaccadic vision, too? Yes. Covert attention can shift without corresponding shifts of the eyes – or overt attention. Covert attention, too, improves visual acuity, giving an additional boost to spatial resolution at some retinal position.[12] Covert attention, too, provides detailed information that would not have been available, for integration into a rich, complex transsaccadic percept. (Anton-Erxleben & Carrasco 2013, 191ff. & 195) So shifting covert attention is another way to overcome the limitations of vision. By shifting covert and overt attention, the visual system avails itself with detailed information from across the scene.

Second, covert attention initiates and guides saccadic eye movements. It is the "motor" of all attention shifts. Shifts of covert attention to the saccade-target initiate movement of the eyes. While covert attention can shift without movement of the eyes, saccades normally require shifts of covert attention. Thus it has been shown repeatedly that individuals shift covert attention to the target of their saccade, prior to performing the saccade, even if instructed to shift covert attention elsewhere. (Hoffman & Subramaniam 1995; Kowler *et al.* 1995; Godjin & Theeuwes 2003; Peterson *et al.* 2004) But furthermore, attention apparently guides saccades to their precise location. Kowler *et al.* investigated individuals' performance on a perceptual task that concurred with a saccade to either a fixed or a randomly changing saccade-goal. They found strong interference with saccade accuracy in both conditions. This result shows that visual attention is not only needed to program a saccade-goal. Since Kowler *et al.* found interference even when the saccade-goal was fixed across trials, and selecting it hence could not take up attentional resources, they concluded that attention also successfully guides the saccade to its goal. (Kowler *et al.* 1995, 1912ff.; Kowler 2006; Kowler 2011, 1463 & 1469; Zhao *et al.* 2012; Rolfs 2015; but see also Wright & Ward 2008, 137ff.) These behavioral results converge with neuroscientific data that identify covert attentional neural modulation for saccade-targets prior to performance of the

[12] Does therefore all reliable vision trivially require visual attention to boost resolution? No. As per fn. 11, many visual percepts will be sufficiently reliable even if unattended. The role of visual attention that is of crucial importance for my argument (and for understanding vision, cf. section 5) consists in shifting processing resources beyond any one fixation of attention. Thanks to an anonymous reviewer for prompting clarification.

actual saccade. (Rolfs *et al.* 2011; Krautzlis 2014) So plausibly, in perceivers like us, successful shifts of overt attention typically require shifts of covert attention.

Third, and finally, target locations for covert and overt attention shifts alike appear to be determined by the same computational mechanisms. These are the mechanisms that generate attentional routines. The mechanisms determine assignments of priority on a priority map of a visual scene. This priority map assigns locations in the scene relative priority for shifting attention there next. Attentional routines depend on assignments of priority that are generated on the basis of innate or implicitly learned patterns of locations that tend, in the normal environment, to extract the information needed for reliably performing some perceptual task – such as perceiving an object's precise movements, shape, and so forth. Studies of patterns of attention shifts support the claim that the same mechanisms are responsible for shifting eyes and attentional resources. (Geisler & Cormack 2011) Studies of neural mechanisms underlying both kinds of shifts further support the claim. (Miller & Buschman 2013; Rolfs 2015)

So transsaccadic vision relies on shifts of visual attention for gathering detailed visual information from across the scene, for initiating and guiding saccades, and for programming patterns of shifts that will extract visual information from the right locations. There hence is strong empirical reason for thinking, as per step (2) of *the main argument*, that visual attention, in perceivers like us, systematically drives shifts of processing resources for transsaccadic visual perception.

4 A Role of Attention in Warranting Visual Belief

Suppose that you have a visual percept with a content that can be roughly expressed as <u>that moving cube</u>. The resulting belief <u>that cube is moving</u> would be formed *directly* from the percept if neither the percept's, nor the resulting belief's, formation involved higher cognitive processes such as reasoning in their formation. Here I take for granted that it is possible to form transsaccadic beliefs directly from transsaccadic percepts.[13] In sections 2 and 3 I have argued that the formation of transsaccadic percepts does not involve higher

[13] A step of *conceptualization* transforms elements of the percept's representational content into essentially the same conceptual representational content. The transformation is one from visual to conceptual format, while the representation's content – being as of a moving cube – stays fixed. (Burge 2003, 542)

cognitive processing either. So transsaccadic beliefs can be directly based on visual percepts. Whatever warrant for a visual belief stems from its underlying visual state alone – not relying on background beliefs or further reasoning – constitutes a basic warrant. Why does visual attention play a role in thus warranting transsaccadic visual beliefs, as I claim in steps (4) and (5) of *the main argument*?

Let me first briefly comment on step (5): if the ability for deploying visual attention in certain ways is a component of a visual competence that functions to generate veridical transsaccadic percepts, and that reliably does so in the visual system's normal environment, then that ability plays a role in warranting transsaccadic belief. Step (5) follows from standard externalist conceptions of visual warrant. Here I adopt Tyler Burge's account of such warrant – what he calls an 'entitlement.'[14] For a perceptual state to yield an epistemic warrant, it must be generated through well-functioning exercise of a perceptual competence

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[14] Naturally, I do not presume that Burge's account of perceptual warrant is uncontroversial. But an argument for this conception would lead too far afield. (cf. Burge 2003, 2010) Burge's conception goes beyond classical reliabilism. (Goldman 2008, 1979) On Burge's conception reliability of competence is merely a necessary condition on warrant. Another component is that of functioning to represent veridically. Both components help establish a non-accidental connection between exercises of the competence and the primary epistemic good, truth. An argument for externalism about warrant would also lead too far afield.

My claims in the main text *are* compatible at least with some internalist accounts, such as Susanna Siegel's. She writes: "An etiology X of experience E with content C is rationally assessable iff etiology X* of belief B with content C is rationally assessable, where X* has similar psychological elements as X, except it leads to belief without intervening experience." (Siegel, S. 2013a, 714; Siegel 2017, Chapter 6) In the main text I sketch what kind of transition between perceptual states generates transsaccadic vision. That transition is analogous to the following inference:

> (*Fixation 1**) That cube at time *t1* and position *p1*, oriented at angle *a1*, moves with speed *s*, in direction *d1*; and
> (*Fixation 2**) That cube at time *t2* and position *p2*, oriented at angle *a2*, moves with speed *s*, in direction *d2*; therefore
> (*Transsaccadic Percept**) That cube moves with speed *s* at time *t1 – t2* from position *p1* to *p2*, rotating from angle *a1* to *a2*.

This type of inference is rational because of the kinds of perceptions that form the input to the visual system at each fixation. Why is visual attention needed as part of a 'rational' etiology? Here is one consideration: to warrant a transition to the conclusion-belief (*Transsaccadic Percept**), we need both premises (*Fixation 1**) and (*Fixation 2**). Reasoning from either premise alone to the conclusion would ignore too many close-by possible scenarios compatible with either premise, but incompatible with the conclusion. Reasoning from either of these premises alone to the conclusion would resemble a 'jumping-to-conclusions.' In order to have both percepts, analogous to both (*Fixation 1**) and (*Fixation 2**), and in order to acquire them in the appropriate way, visual attention must shift. The etiology of (*Transsaccadic Percept**) must involve attention in the right way to resemble rational inference.

Other traditional forms of internalism such as dogmatism (Pryor 2000) or evidentialism (Feldman & Conee 2001) may deny that attention plays the role in warranting transsaccadic percepts that I describe in the main text. I am inclined to think that the fact that these accounts cannot explain this intuitive normative import of attention adds to the case against these conceptions. But establishing this last claim is beyond the scope of this paper. My aim in this paper is more modest: it consists in arguing that, on several influential conceptions of epistemic warrant, visual attention plays a role in warranting transsaccadic beliefs.

that functions to generate veridical visual states, and that reliably generates such states in the visual system's normal environment. (Burge 2003, 535; cf. also Sosa 2011) If a perceptual competence is thus reliable in its normal environment, and functions to represent veridically, then there is a non-accidental explanatory route from competence to truth. For the competence is individuated partly in terms of its successes in representing veridically in its normal environment. Believers are then entitled to rely on the competence's fulfilling its function. Assume, then, that it is true that an ability for deploying visual attention in certain ways is a component of such a visual competence that functions to generate reliably veridical transsaccadic percepts, and that reliably does so. Assume, further, that we accept that basic perceptual warrant stems from the well-functioning exercise of such a perceptual competence. Then exercises of the ability to deploy visual attention contribute to generating the warrant for relevant transsaccadic beliefs.

I will now focus on establishing step (4) of *the main argument:* that the ability for deploying visual attention in certain ways is a component of a visual competence that functions to generate veridical transsaccadic percepts, and that reliably does so in the visual system's normal environment. Consider again the *Complex Motion Event*. A reliably veridical percept as of the moving cube plausibly depends on visual information from both fixations. In generating the perception of the cube, the competence plausibly transitions from

> (*Fixation 1*) Cube at time *t1* and position *p1*, oriented at angle *a1*, moving with speed *s*, in direction *d1*; and
> (*Fixation 2*) Cube at time *t2* and position *p2*, oriented at angle *a2*, moving with speed *s*, in direction *d2*; to
> (*Transsaccadic Percept*) Cube at time *t1* – *t2*, moving with speed *s* from position *p1* to *p2*, rotating from angle *a1* to *a2*.

The perceptual competence underlying this transition takes visual information from (*Fixation 1*) and (*Fixation 2*) as inputs. For the competence to process information from both fixations, a reliable transsaccadic memory must store that information until (*Transsaccadic Percept*) has been generated. A *formation law* governs the transition from the two fixations to the resulting (*Transsaccadic Percept*). (Burge 2010, 346ff.; Pylyshyn 2003; Hatfield 2009) Formation laws are law-like regularities in the transitions between visual perceptual states that mirror law-like regularities in the environment. In the present case, the visual system's transformations may be governed by a formation law to the effect that the system takes visual percepts such as (*Fixation 1*) and (*Fixation 2*), to generate a percept as of a moving, rotating cube. This law mirrors regularities about how cubes move and rotate in the individuals' normal environment. The mirroring of environmental regularities in the formation law helps explain why the resulting transsaccadic perception *reliably* indicates the relevant kind of motion event, in the individual's normal environment. The visual system's general function to represent veridically supports attributing the function of generating veridical representations as of motion events to the competence at issue.

How is the ability for deploying visual attention a component of the visual competence? First, the visual system in perceivers like us would in many cases not have available *any* visual information from (*Fixation 2*) without shifting attention. Information from (*Fixation 1*) alone does not suffice to reliably generate a perception as of the motion event. Even in the normal environment, this input is compatible with too many scenarios that do not contain the complex motion event. The cube might stop rotating, be diverted, or hit an obstacle. So in order to explain the warrant for our transsaccadic perceptual beliefs, the perceptual competence must use information from *both* fixations to generate (*Transsaccadic Perception*). But information from both fixations would not normally be available unless visual attention had shifted from one location to the next. In normal perceivers, under normal circumstances, attention-shifts ensure that information from both fixations feeds into the generation of the transsaccadic percept.

Second, in many circumstances, acuity of visual perception without shifting covert and overt visual attention would not be sufficient to *both* generate the reliably veridical percept (*Fixation 1*) and the percept (*Fixation 2*). This would often be the case even if peripheral vision provided *some* of the information available at (*Fixation 2*). In many circumstances, shifting covert and overt visual attention from (*Fixation 1*) to (*Fixation 2*) is required to resolve visual detail needed for generating the resulting reliable (*Transsaccadic Percept*). Without shifting visual attention, the visual system might have generated a highly resolved percept during (*Fixation 1*) while generating only a very unreliable, approximate peripheral representation of the cube's subsequent position and orientation. A (*Transsaccadic percept*) as of the motion event generated from this information may then not be reliably veridical. If the inputs for the competence are not sufficiently reliable for the actual, fairly precise (*Transsaccadic Percept*), then the output-percept will not generate warrant for transsaccadic belief.

Third, for the competence to reliably generate (*Transsaccadic Percept*), it must reliably extract the *right kind* of visual information (*Fixation 1*) and (*Fixation 2*) for generating (*Transsaccadic Percept*). Extracting this information requires reliably shifting attention to the right locations. The 'right locations' here are locations that systematically tend to provide information to support generating a transsaccadic percept of a certain kind – such as a motion percept – from information gathered across fixations. In our case an attentional routine for perceiving motion-events takes information from (*Fixation 1*) as input to determine where attention should fixate next, in order to extract sufficient detail for generating a detailed motion-percept. Suppose that attention lands *by mere accident* in a location that provides the visual system with sufficient information to move from (*Fixation 1*) and (*Fixation 2*) to (*Transsaccadic Percept*). So suppose that the competence that generates the motion-percept does not do so reliably. In this case, the resulting visual state lacks the required truth-connection, since the competence generating the visual state lacks it. The resulting state will not generate warrant for transsaccadic belief.

So visual attention contributes to individuals' warrant for their transsaccadic beliefs, as per steps (4) and (5) of *the main argument*: visual attention makes this contribution due to its role in systematically shifting covert and overt attentional resources according to attentional routines. Visual attention forms part of the visual competence that functions to generate veridical transsaccadic vision, and that reliably does so in the visual system's normal environment.

5 Rich Vision

Why is this role of visual attention of interest? Is it not a marginal phenomenon, contributing only very little to our understanding of perceptual warrant and vision? I believe not. To appreciate the central role of attention in vision, we should remind ourselves of several central features of visual experience.[15]

Our visual experience of our surroundings is rich. It is rich in being detailed and spatio-temporally extended. Again, think of the complex motion event. Suppose that the event occurs on the desk in your study, against the backdrop of an environment cluttered with papers, books, a rug, and in front of a window frame. You do not visually experience

[15] Visual experience, in this context, is phenomenally conscious vision. (Block 1995)

the cube in detail and the backdrop merely as a sketch. Rather, you experience much of the backdrop's detail, too – the rug as intricately patterned, the papers as featuring print, the window frame as having a certain color. You do not merely visually experience the cube when foveating it for a moment. Rather, you visually experience elements throughout the scene as spatio-temporally extended – papers, books, and rug as distributed in space, and persisting throughout the motion event. [16]

At the same time, our visual experience appears to be coherently integrated. You do not visually experience snapshots, disparate percepts of cubes at spatio-temporal positions. Rather, you have a coherent visual experience as of the cube's complex movement from here to there, extending in time and space. You visually experience, not a first cube, oriented at one angle against part of a window frame behind it; then another cube, oriented at another angle, against another part of a window frame. Rather, your visual experience integrates information from different percepts into a percept as of one movement, by one and the same cube, performing a rotation against the backdrop of one and the same window frame with some overall shape.

How can we explain these aspects of visual experience, while knowing about the visual system's limitations: low resolution outside the foveal area and information-intake only during fixation?

Vision scientists appeal to transsaccadic vision in addressing these questions.[17] The visual system generates a percept as of one motion event, involving one cube, against the backdrop of several objects, all persisting in space and time. The visual system updates this percept with more detailed information as the eyes shift across the scene, adding information not previously available and correcting errors. We need not assume that vision integrates all visual information into a temporally continuous master-percept, spanning the entire visual scene. We can see how already a tapestry of overlapping transsaccadic percepts might provide cohesion to our experience across time and space, while at the same time allowing it to be rich. Transsaccadic processing may generate a *retroactive* percept as of the motion event's stretching back in time, covering the duration from attention's first fixation to the

[16] It is an open question exactly how much detail you see and how far vision extends in space and time. For a while, researchers maintained that only minimal, coarse information survives a saccade. (Irwin 1996) This research is now outdated. There is no doubt that you see more than you could take in through your fovea during the split-second when you fixate. (Cf. e.g. Demeyer et al. 2009; Herwig et al. 2015)
[17] I here do not claim that they *only* appeal to transsaccadic vision. I merely maintain that appeals to transsaccadic vision are central to answering the above questions.

present. Or transsaccadic processing may generate a *prospective* percept as of the motion event, predicting the entire event, as it will unfold in the immediate future, on the basis of information from the first fixation. (Herwig 2015a, 4) In both ways, the visual system generates percepts that bridge supposed gaps between fixations. To explain vision's coherence we appeal to competencies for maintaining and integrating visual information into a transsaccadic percept across saccades. To explain vision's richness, we appeal to its dynamic nature:[18] to competencies for systematically shifting processing resources in order to gather relevant detailed information about the scene. (Ganmor et al. 2015; Herwig 2015a, b; Cavanagh et al. 2009; Rolfs 2015; Weiss et al. 2015; Wolf & Schütz 2015)

I have explained how visual attention is central to transsaccadic vision. Deployments of visual attention provide detailed, high-resolution information from several fixations, initiate and guide shifts of processing resources during saccades, and determine where to shift resources. Such deployments function to gather the right kind of information for reliably perceiving the scene. But transsaccadic vision is in turn central to generating rich visual experience. Our understanding of vision more generally will be importantly incomplete if we do not acknowledge attention's role in generating rich vision.[19]

I have also explained why we must appeal to a competence for deploying visual attention in the right way to explain our warrant from transsaccadic vision. We must appeal to attention to explain the reliability of transsaccadic percepts and the connection between the visual competence (and its products) and truth. But, again, transsaccadic vision is central to generating rich visual experience. In many cases, we form visual beliefs directly from such rich vision. Our warrant for such visual beliefs will often (partly) stem from competencies involved in transsaccadic vision. Our understanding this warrant will require understanding attention's role in it.

We can now put these points in proper perspective. Appeals to visual attention are not merely required for explaining the warrant for some marginal class of visual beliefs. Such

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[18] Vision scientists have long acknowledged the dynamic nature of vision. (Findlay & Gilchrist 2003) Philosophers have tended to conceive of vision in a more restrictive fashion. (But cf. Burge 2010, 445ff.) They have tended to focus on spatio-temporally local, narrowly confined percepts. Where they have appreciated dynamic aspects of vision they have assimilated them to individual-level, even cognitive processes. Seeking out information by moving the eyes was said to "draw on [our] understanding of the ways in which one's movements affect one's sensory states." (Noë 2008, 663) Experiences spanning several fixations are said to "result from inferences about how certain properties are distributed." (Siegel 2017, 168) There is no reason to do so. I propose that we update our understanding of vision and visual warrant in light of findings in vision science.

[19] I elaborate on these points in a companion paper.

appeals are required for explaining central instances of visual warrant – instances that *any* epistemology of vision must explain.

How does this outcome relate to the debate about visual warrant that I mentioned at the very beginning of this paper? The outcome allows that inattentive vision can warrant visual beliefs. An instantaneous percept as of a certain shape or color in some specific location may warrant a visual belief directly formed from the percept. If so, then attention is not necessary for visual warrant. I said at the outset that I disagree with philosophers who maintain that attention is necessary for visual warrant. (Campbell 2002, 2011; Smithies 2011a, b; Dickie 2011) But I do think that these philosophers are right to emphasize attention's importance for visual warrant. I have argued that, while not necessary for visual warrant, attention is part of a visual competence for transsaccadic vision in humans. This competence is central to rich vision, and to our warrant from such vision. Explanations of vision and visual warrant alike would be importantly incomplete without acknowledging this role of visual attention.

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