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Contrast effects on speed perception for linear and radial motion

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ABSTRACT

Speed perception is vital for safe activity in the environment. However, considerable evidence suggests that perceived speed changes as a function of stimulus contrast, with some investigators suggesting that this might have meaningful real-world consequences (e.g. driving in fog). In the present study we investigate whether the neural effects of contrast on speed perception occur at the level of local or global motion processing. To do this we examine both speed discrimination thresholds and contrast-dependent speed perception for two global motion configurations that have matched local spatio-temporal structure. Specifically we compare linear and radial configurations, the latter of which arises very commonly due to self-movement. In experiment 1 the stimuli comprised circular grating patches. In experiment 2, to match stimuli even more closely, motion was presented in multiple local Gabor patches equidistant from central fixation. Each patch contained identical linear motion but the global configuration was either consistent with linear or radial motion. In both experiments 1 and 2, discrimination thresholds and contrast-induced speed biases were similar in linear and radial conditions. These results suggest that contrast-based speed effects occur only at the level of local motion processing, irrespective of global structure. This result is interpreted in the context of previous models of speed perception and evidence suggesting differences in perceived speed of locally matched linear and radial stimuli.

1. Introduction

Speed perception is fundamental for safe interaction with our environment. However, it is known that speed perception is biased by changes in the contrast of the stimulus (Thompson, 1982). Furthermore, some investigators have suggested that this might have meaningful real-world consequences (Snowden, Stimpson, & Ruddle, 1998). In order to fully understand the mechanisms underlying this effect it is important to understand how it is influenced by changes to both the local spatio-temporal properties of the stimulus and the global properties of the scene. Changes to local properties have been systematically investigated by a number of researchers (Blakemore & Snowden, 1999; Stone & Thompson, 1992; Thompson, 1982; Thompson, Brooks, & Hammett, 2006). Here, we investigate whether, and how, changing the global properties of the stimulus, whilst keeping local properties matched, might influence the effect of contrast on speed perception. In doing so we aim to shed light on the stage in the motion processing hierarchy at which the effects of contrast are applied.

The effect of contrast on speed perception was first noted by Thompson (1982) who demonstrated that, at slow speeds, low-contrast stimuli appear to move slower than high-contrast stimuli. However, as speed increases this effect reduces and at high speeds can even reverse, such that low-contrast stimuli appear faster than high-contrast stimuli. This effect of contrast is highly robust and persists in the face of a variety of changes to the stimulus, e.g. see Blakemore and Snowden (1999) who obtained similar effects of contrast with gratings, random-dot patterns, moving dots and expanding dot stimuli.

The explanation for the effect of contrast on speed perception remains a subject of debate. Weiss, Simoncelli, and Adelson (2002) proposed that this effect can be explained using the Bayesian framework whereby the reduction in perceived speed at low contrasts arises due to the influence of a prior assumption that objects are stationary or moving slowly. It is suggested that the prior has more influence on perceived speed at low contrasts because lowering contrast increases the uncertainty of the sensory signal. Stocker and Simoncelli (2006) demonstrated that the relative speed discrimination thresholds obtained for high- and low-contrast stimuli (i.e. a proxy measure for sensory uncertainty) can be used to predict the size of the bias in perceived speed at a range of speeds. However, Thompson et al. (2006) criticised this model as failing to account for the observed increases in perceived speed with lowered contrast at higher stimulus speeds. In contrast to the Bayesian account, Thompson et al. proposed that the effect

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of contrast arises due to the inseparability of speed and contrast at early stages of visual processing. They went on to demonstrate that a simple ratio model (based on that proposed by Hammett, Champion, Morland, & Thompson, 2005), in which speed is estimated as the ratio of outputs from two physiologically plausible temporal filters, can account for both increases and decreases in perceived speed with lowered contrast. Further support for this ratio model was provided by Hammett, Champion, Thompson, and Morland (2007) who demonstrated that changes in perceived speed as a function of grating luminance were predicted by the ratio model but could not be accounted for by the Bayesian model. In addition, Hassan and Hammett (2015) found that the speed at which the cross-over from under- to over-estimation of low-contrast speeds varies as a function of luminance, an effect that is also consistent with the ratio model but not the Bayesian account.

Interest in this bias has stimulated a variety of further studies, a number of which aimed to document how changes in local spatio-temporal stimulus properties influence the size of the effect. In Thompson's original study the effect of contrast on perceived speed depended on the temporal frequency of the grating (Thompson, 1982). At all spatial frequencies considered the reduction in perceived speed with lower contrast was greatest at the lowest temporal frequency tested (1 Hz). The size of the effect was progressively reduced as temporal frequency increased up to 8 Hz, beyond which point the effect of lowering contrast was to increase the perceived speed of the stimulus. However, Stone and Thompson (1992) did not find a reversal above 8 Hz and suggested it might be that speed perception breaks down beyond this point (or at least beyond 10 Hz). In addition, Stone and Thompson found little effect of changing spatial or temporal frequency. In a later study Thompson et al. (2006) found a strong effect of temporal frequency and replicated the previous finding of Thompson (1982) that the effect reduces and reverses with increases in temporal frequency. However they also found that the temporal frequency at which the contrast-dependent reversal occurred was a function of grating spatial frequency. Specifically, the reversal occurred at roughly 6 Hz for a spatial frequency of 2 c/deg but 12 Hz for a spatial frequency of 8 c/deg. In contrast, using broadband stimuli Stocker and Simoncelli (2006) showed that for speeds up to 12 deg/s the lower-contrast stimulus was perceived to be slower than the higher contrast stimulus (i.e. no evidence for a reversal), although the size of the bias decreased with increasing speed. In summary, the local spatio-temporal properties of a stimulus have been shown to influence the size of the effect of contrast on speed perception, however there is some debate across studies on whether a reversal of the effect of contrast on perceived speed occurs.

With respect to global stimulus properties, it has been shown that, similar to a linear motion field, the effect of contrast persists when the stimulus consists of a global broadband pattern of radial expansion. Lowering contrast reduces the perceived speed of optic flow patterns in quasi-natural scenes presented in a driving simulator (Snowden et al., 1998; Pretto, Bresciani, Rainer, & Bülthoff, 2012). However, one issue with this work is that it is difficult to compare the magnitude of effects observed with those found in earlier studies focussing on local spatio-temporal properties in linear motion fields. The extent to which contrast-dependent effects might differ for stimuli that are matched for local properties but differ in global configuration should shed light on the mechanisms involved, and the stage at which the effects of contrast occur.

This question is also particularly relevant in light of results suggesting that perceived speed is affected by global stimulus properties. Bex and Makous (1997) and Bex, Metha, and Makous (1998) found that radial gratings are perceived as up to 60% faster than translating linear gratings with matched local spatio-temporal parameters. Bex and Makous (1997) showed that this result was unlikely to be caused by differences in the perception of temporal or spatial frequency of the stimuli. Furthermore, Bex, Metha and Makous demonstrated that the effect persists when stimuli consist of four smaller linear Gabor patches positioned around a fixation point, with the directions arranged such that the global pattern of motion was consistent with either translating linear or radial motion (see Fig. 4). They concluded that differences in speed perception between linear and radial stimuli were potentially explained by the radial motion stimuli being interpreted as motion in depth. If this is the case then for a given retinal speed the radial stimulus would need to travel at a faster speed than a stimulus moving purely in the fronto-parallel plane. They also suggest that since radial motion is a very commonly encountered stimulus (i.e. when moving forwards), it is possible that the brain has developed a separate mechanism for handling such motion.

Taken together these studies suggest the need to investigate how the effect of contrast on perceived stimulus speed is affected by the global pattern of motion when local spatio-temporal stimulus parameters are controlled. We use a standard 2IFC paradigm to measure contrast-dependent speed effects in which participants judge the faster of a high- and low-contrast stimulus on each trial. If contrast-dependent biases vary as a function of global stimulus configuration then this suggests some influence of contrast after integration of local motion signals. If, on the other hand, the global configuration does not affect biases it suggests that contrast effects occur only at a lower level in the processing hierarchy, before integration of local motion signals.

In addition, to shed further light on the most appropriate model of speed perception (and specifically to test the Bayesian account introduced above) we also measure speed discrimination thresholds for stimuli with matched contrast. It is generally accepted that discrimination thresholds reflect the reliability of sensory speed signals (e.g. see Weiss et al., 2002). Accordingly, under the Bayesian account, the discrimination thresholds for high- and low-contrast stimuli should then predict the extent of the contrast-dependent speed effects observed, since the proposed prior for zero motion should have more effect when the sensory information is less reliable (i.e. when discrimination thresholds are higher).

In experiment 1 stimuli were single patches of linear or radial motion, similar to those used in Bex and Makous (1997). In experiment 2 the stimuli were similar to those used in Bex et al. (1998) and comprised four smaller linear Gabor patches whose global configuration suggested either linear or radial motion. To summarise our results we find that in both experiments 1 and 2 the effects of contrast on speed perception are indistinguishable for linear and radial stimuli suggesting that contrast affects speed perception at the level of local motion processing.[1]

2. Experiment 1

2.1. Methods

2.1.1. Participants

Five participants took part in experiment 1; two authors and three participants who were naïve to the purposes of the experiment. All had normal or corrected to normal vision. Naïve participants gave informed consent and were compensated for their time

[1] Note that in a previous conference presentation (Warren & Champion, 2015) we suggested that there *were* differences in the gain of contrast dependent speed effects for linear vs. radial gratings. However, the data collected in that previous experiment were problematic because no fixation target was presented (which likely led to differential patterns of eye movements in the two global motion conditions). In addition, in the previous study we did not collect discrimination threshold data. These issues have been rectified in both experiments of the present study.