1 Discussion

1.1 Distinguishing between types of motion stimuli and types of motion mechanisms.

In the history of visual science there have been many observations that there are multiple mechanisms, or more generally aspects, involved in the perception of visual motion. Different stimuli and parameterizations have been invented to characterize these aspects, with the either advocating or rejecting some particular boundary between a simple or low-level aspect and a more complicated or higher-level aspect. There have been multiple strategies employed to draw distinctions between motion systems.

One strategy is to construct a stimulus that can be controlled along some variable, such as a continuous spatial or temporal parameter of the stimulus. For example, varying the length of displacement is used to distinguish long-range from short-range motion [cite], and varying the stimulus asynchrony serves to distinguish phi from beta motion [cite, or cite below]. Here the boundary delineating motion mechanisms is associated with a qualitative change in the appearance, or some response measure, as a function of the controlled variable.

A second strategy begins with stimuli that are *a priori* distinguished, usually in accordance with a particular hypothesis about the functioning of at least one of the motion mechanisms. We may compare stimuli designed to drive that mechanism with stimuli that are designed to isolate that mechanism (but which still contain "motion" in some sense.) For example, Chubb and Sperling (1988) designed "drift balanced" motion, with the aim of identifying mechanisms that could compute motion on . Here again, the strategy is to seek a qualitative change between some measure that can be used to characterize both systems, and use this qualitative change (or its lack) to argue for against a distinction between motion mechanisms. Since the stimuli used in this approach are distinguished by kind rather than by parameterization, extra care is required to distinguish qualitatively different responses to two kinds of stimuli from merely less or more effective responses from one mechanism. However, if this approach succeeds in effectively nulling one motion mechanism so that the other carries the perception, large quantitative differences can indeed be shown.

Our approach in this work is somewhat of a hybrid of the above approaches. Similarly to the second approach, we have constructed our stimuli with a low-level and a high-level mechanism in mind, corresponding to the carrier strength and envelope motions, and we hope that adjustments to carrier or envelope effect changes in the response of the the low-level and high-level mechanisms respectively. However, more like the first strategy, we prefer to let the differences between motion mechanisms "fall out" as we continuously vary stimulus parameters. What we have observed is that the sensitivity to envelope motion increases as the spacing between objects increases spacing, while the sensitivity to carrier strength decreases. We propose that this illustrates a difference between the operation of two mechanisms of motion perception, except, though we have not attempted to null the stimulus to either mechanism.

We do not attempt to construct stimuli with the aim of isolating or providing null input to any mechanism; rather we consider all motion mechanisms to be active for all of our stimuli. Recall Helmholtz's (1925) observation that "Black is a real sensation, even if it is produced by entire absence of light. The sensation of black is different from the lack of all sensation." We posit that the same applies to motion as applies to color. A stationary object, or an object with nulled motion, is distinctly different from the absence of an object. So, for instance, we do not consider pure second-order motion stimuli to be absent of first-order content; rather they contain first order content that is consistent with a non-moving object. In fact all second-order motion stimuli contain considerably more flicker than would a stationary object, even if the flicker lacks direction as far as first-order mechanisms are concerned.

Each scheme for exploring has effectively picked a different boundary along which to cleave the lower-level aspect of motion perception from the higher-level aspect. Interestingly they appear to differ in where the delineation is to defined: in the space of sensation, the space of stimulus configuration, to a delineation between mechanisms. There are differences and commonalities between all the approaches, and we consider how our project relates to each.

1.1.1 Phi versus beta Sekuler (1996) and Steinman et al. (2000)

Perhaps the earliest observation of multiple aspects of visual motion was due to Wertheimer (1912); Wertheimer et al. (2012) . these experiments generally involved the use of a tachistoscope to present two still images in rapid succession. Spatial properties of the images were manipulated as well as the temporal interval between stimulus onsets. What Wertheimer did that remains unique, and which was to carefully catalogue, not only a tally of responses suitable for psychophysical analysis but the observers' subjective, phenomenological impressions of the motion stimuli. Starting from near simultaneous and increasing, Wertheimer and his observers denoted a sequence of qualitatively different forms of stimuli, as well as the inter-stimulus interval increases, Wertheimer found the sequence of phenomena, in sequence: perceived simultaneity, ..., "optimal" motion, and finally, succession. Wertheimer also found that the phi-phenomenon and the optimal motion phenomena were most easily

Today we identify the phi-phenomenon with the earliest stages of the motion sensing system; this accords both with what we have learned of the psychophysics, and with its subjective appearance as a form of motion that is without attachment to object or form.

We engage in this historical discussion to raise the point that the separate motion systems are not on equal perceptual footing perceptually equal. While we have engaged in a more psychophysical analysis and task which attempts to put each component of our motion stimulus on equal footing, we are aware that these motions. Even though we engage in a form of 'nulling' by finding stimulus conditions in which, given a particular mixture of carrier and envelope, observers may, this does not mean that. In some experiments not detailed here, where observers adjusted the mixture of carrier and envelope, observers noted that the region of equivocation was not was the “most confusing”

1.1.2 Fourier and non-Fourier motion

The distinction between Fourier and non-Fourier motion is tue to Chubb and Sperling (1988)observing that existing explanations of motion mechanisms could be characterized in terms of calculating motion from Fourier components, that some motion mechanisms could mme explained by filtering in the designed “drift balanced” motion stimuli that contained no Fourier motion

1.1.3 Short range and long range motion

1.1.4 First and second order motion

1.1.5 Reification of boundaries across domains, synecdoches, and other confusions.

Apparent motion An example of the reification of a phenomenological distinction backward into is with the term “apparent motion.” In contemporary usage this tem is used to refer to a particular class of motion stimuli, that of discretely sampled motion stimuli, and more particularly stimuli that translate in discrete jumps. Chubb and Sperling (1988) designed “drift-balanced apparent motion” stimuli. Now, the contemporary sense of “apparent motion” as a stimulus that translates in discrete jumps is not consistent with Chubb and Sperling’s usage, as by design their drift-balanced stimuli has no correlation between successive frames that could be described as translation; rather

Local and global

1.1.6

1.2 An interpretation of motion sensing in terms of processing with limited input

1.3 The interactions of different motion-sensing systems in motion perception

1.4 The physiology of lower- and higher- order motion perception

1.4.1 Higher order motion is not in MT, probably not in MST, but MT does seem ripe for out “summation” process

Cast “availability of information as parameterized” as the constraining factor

(interaction of cortical constraints on the organization of information; crowding constrains object localization and MT constrains motion localization.) We have seen that, and have determined that the

We should discuss the ways in which this stimulus differs from crowding (and yet, how the phenomena are similar.) Draw the connection between "feature spread" and crowding. I.e. Several studies have

First there is the question of what kind of motion system the long-range component is engaging. We have tried to avoid the tempting terms "local" and "global" to describe the two

Another form of large-scale integration of short range motion occurs in the computation of optic flow, which term describes a pattern of motion over the entire visual field that is consistent with being generated by the motion of an observer through the environment, opposed to the motion of objects relative to a stationary observer. The simplest examples of optic flow stimuli are patterns such as global expantion or contraction, or rotation around a central point. The patterns of motion that in our motion illusion are consistent with a rotation around the axis parallel to the viewer's gaze, so an optic flow mechanism is likely being driven my our stimulus. This raises the question of whether optic flow mechanisms are involved in the illusion of reversal. [some sense of] However, [no second order global motion] [our experiment on number versus shape] [however we found that...]

In the monkey, it appears that [the dorsal subdivision of] area MST is specialized for optic flow patterns.

1.5 Classification of this stimulus among the various types of motion stimuli

Some models for detection of non-luminance-defined motion posit a mechanism that operates much like first-order, short-range motion, but applies some (space-time separable) nonlinearity to the image before applying the motion energy analysis. This would be called "second order" motion system in the scheme of Lu and Sperling (1995). We noted in**??**that for a lone element, it is more difficult to discern the direciton of its short-range motion than the clear long-range movement. By adjusting the parameters to further favor the long-range component, we can produce stimuli where the direction of the short-range motion is nearly undetectable, yet these stimuli still elicit a motion after-effect according only to the direction of hort range motion. Nonetheless, these stimuli still elicit a direction-elective response in area MT only to the short-range component(Shadlen et al., 1993). motion and independent the direction of long-range motion. Thus, while the have added have quantitatively demonstrated the presence of this phenomenon, which they term 'motion capture.' That is, the long-range motion is capable of masking and obscuring short range motion. Additionally, a mechanism driven by a single input nonlinearity (and in some formulations, any purely local mechanism (Zanker, 1993) would be driven by first-order motion stimuli as well as second-order; this is consistent with results showing that adding second-order noise, or even coherent second-order motion, does not interfere with the decection of first-order motion, but first-order noise does interfere with detection of second-order motion (Edwards and Badcock, 1995; Cassanello et al., 2011). However, this behavior is not consistent with our separate long-range and short-range motion; local motion opposes it. So while a second-order mechanism seems to exist and is able to detect some forms of non-Fourier motion, we do not think a second-order mechanism plays a significant explanatory role in our illusion and is not responsible for the illusory reversal.

Bex et al. (2003)investigated crowding for discrimination of moving objects in a variation of the typical crowding task where targets and flankers moved around an annulus. They found that the size of the region of interference between the target and a lateral flanker was invariant with target speed (if anything, there was a maximum at 2-4 "angular degrees per frame" (at 75 Hz; at 8 degrees ecentricity, 2 degrees per frame ˜21 degrees-of-visual-angle per second. That's a lot faster than out stimuli.) They did find that the zone of interference around a moving target was asymmetric contingent on motion; a flanker moving ahead of the target crowded at a greater distance than a flanker that trailed the target. If this were simply due to temporal summation (i.e. motion blurring,) "we would expect crowding to increase with speed because motion blur increases with speed of sharp objects"

Bex and Dakin (2005)show that crowding applies to the identificaiton of direciton of motion of a textured patch within a window. Since the stimulus in that study does not include a global direction component, it is not (all of our local motion features are identical.) Actually the format of this study shares many similarities to our own, but what they establish is the spatial interference of flanking (short-range) motion on identification of neighboring patches of (short–range) motion, wherewas what be identify in this study is the interference of flanking (short-range) motion in the identification of (long-range) motion – this is an interesting distinction, as it shows that spatial interference happens in a way that prevents

References

Bex, P. J. and Dakin, S. C. (2005). Spatial interference among moving targets. *Vision Res*, 45(11):1385–1398.

Bex, P. J., Dakin, S. C., and Simmers, A. J. (2003). The shape and size of crowding for moving targets. *Vision Res*, 43(27):2895–2904.

Cassanello, C. R., Edwards, M., Badcock, D. R., and Nishida, S. (2011). No interaction of first- and second-order signals in the extraction of global-motion and optic-flow. *Vision Res*, 51(3):352–61.

Chubb, C. and Sperling, G. (1988). Drift-balanced random stimuli: a general basis for studying non-fourier motion perception. *J Opt Soc Am A*, 5(11):1986–2007.

Edwards, M. and Badcock, D. R. (1995). Global motion perception: no interaction between the first- and second-order motion pathways. *Vision Res*, 35(18):2589–602.

Lu, Z. L. and Sperling, G. (1995). The functional architecture of human visual motion perception. *Vision Res*, 35(19):2697–2722.

Sekuler, R. (1996). Motion perception: a modern view of wertheimer's 1912 monograph. *Perception*, 25(10):1243–1258.

Shadlen, M. N., Zohary, E., Britten, K. H., and Newsome, W. T. (1993). Directional properties of MT neurons examined with motion energy filtered apparent motion stimuli. *Investigataive Ophthalmology and Visual Science Supplement*, 34(4):908.

Steinman, R. M., Pizlo, Z., and Pizlo, F. J. (2000). Phi is not beta, and why Wertheimer's discovery launched the gestalt revolution. *Vision Research*, 40(17):2257–2264.

von Helmholtz, H. (1925). *Treatise on Physiological Optics*. Electronic edition (2001): University of pennsylvania edition. J. P. C. Southell, Trans. From the 3rd German ed., 1910.

Wertheimer, M. (1912). Experimentelle studien über das sehen von bewegung. *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, 61:161 – 265.

Wertheimer, M., Spillmann, L., Sarris, V., and Sekuler, R. (2012). *On perceived motion and figural organization*. MIT Press, Cambridge, Mass.

Zanker, J. M. (1993). Theta motion: a paradoxical stimulus to explore higher order motion extraction. *Vision Res*, 33(4):553–69.