Perceptual Integration of Local Motion Signals

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Motivation and Background

Motion is crucial for everyday tasks, such as navigation and figure/ground segregation. Motion analysis is generally considered to begin with the extraction of local motion signals. Three kinds of local motion signals are recognized: Fourier (F) signals (Reichardt, 1961), which correspond to 2-point spatiotemporal correlations; non-Fourier (NF) signals, which consist of spatiotemporal correlations of a feature (e.g. edge or flicker (Chubb & Sperling, 1988) and correspond to 4-point spatiotemporal correlations; and glider (G) signals, which include expansion and contraction and correspond to 3-point spatiotemporal correlations (Hu & Victor, 2010). Studies using synthetic stimuli that isolate each these motion signals and their subtypes have shown that each elicits behavioral and neurophysiological responses in a wide range of species, from insects to mammals. However, in naturalistic stimuli, these motion signals occur together rather than in isolation (Nitzany & Victor 2014). Here, using a novel class of synthetic stimuli, we ask:

How distinct kinds of local motion signals interact?

Methods

Visual stimuli

- Movies: 1-sec clips containing one or two kinds of local motion signals
- Each movie:
  - 10 frames, 100 ms each
  - Frames: 20 x 30 array of black and white checks
  - Check size: 0.45 x 0.45 degrees
  - Fixation aid: movies preceded and followed by central red X on gray background
  - Motion direction: randomly right or left

Task: Determine the direction of motion (two-alternative forced choice)

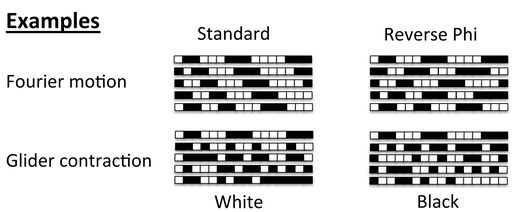
Stimulus construction

Two motion signals and their combinations were investigated: Fourier and Glider contraction. Each signal corresponds to a correlation rule inside a space-time template of checks (see table and app). For Fourier (F) motion, the array is a pair of checks on a diagonal in space-time. For Glider (G) motion, the template consists of three checks in a spatiotemporal triangle. Short XT-slices of standard Fourier motion and Glider contraction, at maximum strength, are shown below. Stimuli with intermediate strengths are shown on the right.

Motion signal types

Kind	Subtype	Template	Subtype	# black	# white
2-point (Fourier)			Standard	0 or 2	0 or 2
			Reverse phi	1	1
3-point (Glider)	Expansion		Black exp.	1 or 3	0 or 2
			White exp.	0 or 2	1 or 3
	Contraction		Black cont.	1 or 3	0 or 2
			White cont.	0 or 2	1 or 3
4-point (non-Fourier)			Positive	0,2 or 4	0,2 or 4
			Negative	1 or 3	1 or 3

Examples



Experimental Results

Setup

- 7 ratios of motion signal strengths :
  - Pure Fourier
  - Pure Glider contraction black
  - Pure Glider contraction white
  - 4 mixtures of Fourier and Glider contraction
- 5 strength points along each of the above rays

Rays
(Maximum percentage levels)

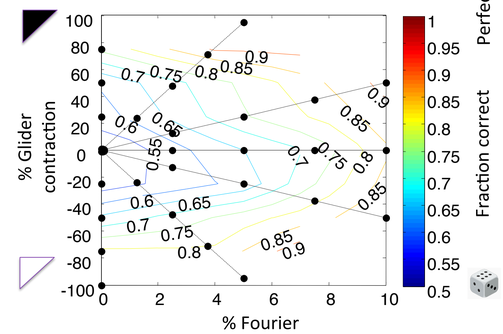
% Fourier	% Glider contraction
0	100
5	95
10	50
10	0
10	50
5	95
0	100

Glider Black
Pure Fourier
Glider White

0.48	0.58	0.61	0.76	0.91
0.55	0.64	0.78	0.90	0.92
0.51	0.73	0.74	0.82	0.92
0.49	0.58	0.65	0.71	0.84
0.41	0.60	0.62	0.77	0.89
0.52	0.61	0.70	0.77	0.99
0.54	0.52	0.66	0.91	0.97

1 25 50 75 100
Strength (% along ray)

Fraction correct

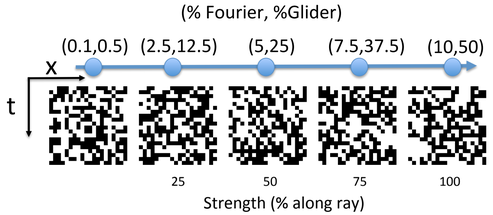


Findings

- Sensitivity for pure motion signals are consistent with previous studies
- Accurate performance at maximal strength for mixtures
- Fraction correct increases when motion signals are combined
- Asymmetric interaction of Fourier motion with Glider contraction black vs. white

Combining Two Local Motion Signals

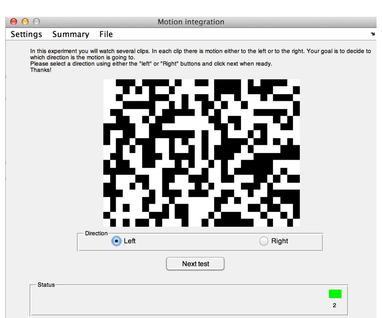
(% Fourier, %Glider)



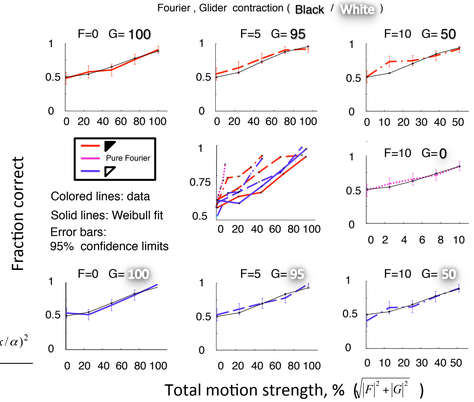
To combine two kinds of local motion signals, we used a maximum-entropy approach: we created clips that had the required Fourier and Glider local motion signals, but were otherwise as random as possible. This was done by adapting the texture generation algorithms of Victor and Conte (2012) to spatiotemporal stimuli.

Program

- Simple and intuitive 2-alternative forced choice
- ~100 repeats for each combination
- Clip length: 1 second
- 10 frames of 100 ms each
- Randomly selected motion direction



Determination of Thresholds

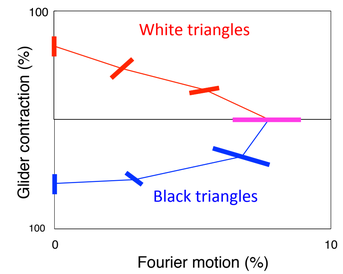


Psychometric function

$$\textit{Fraction correct} = \frac{1}{2} + \frac{1 - 2^{-(x/\alpha)^2}}{2}$$

- A Weibull function with exponent 2 yields a good fit
- Fourier sensitivities are approximately 10-fold greater than Glider

Isodiscrimination contour
(fraction correct = 0.75)



- Asymmetric interaction of Fourier motion with Glider black vs. white

Summary

- Considered separately, Fourier motion signals, as expected, are stronger than Glider motion signals
- Subthreshold Fourier and Glider motion signals interact substantially
  - Combined Fourier and Glider contraction is perceived at a lower threshold than either one separately
  - The interaction is stronger for Glider contraction black than for Glider contraction white

Future

This approach extends to study:

- Integration of other motion signals (e.g. classical non-Fourier motion)
- Integration of motion signals in opposing directions

References

- Chubb, C., and Sperling, G. (1988) Drift-balanced random stimuli: a general basis for studying non-Fourier motion perception. J. Optical Soc. Am. A5, 1986-2006.
- Hu, Q., and Victor, J.D. (2010) A set of high-order spatiotemporal stimuli that elicit motion and reverse-phi percepts. J. Vis. 10, 1-16.
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Acknowledgments

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