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Second-order system; Its role and mechanism

Shin'ya Nishida

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Final talk by Shin'ya Nishida (19, March,'92)

Title : Second-order system; Its role and mechanism

Abstract :

Human vision presumably involves two types of motion system. One (first-order system) extracts motion information from local spatio-temporal energy in the retinal luminance distribution, while the other (second-order system) extracts motion information in the absence of appropriate energy in the luminance distribution. My work carried out in ATR has been concerning with the role and the mechanism of second-order system.

In the first half of my talk, I will address the role of second-order system in the perception of bandpass filtered randam-dot kinematogram (RDK). It has been believed that motion perception for RDKs is mediated by first-order system. However, for RDKs spatially filtered by a bandpass filter, coherent motion is perceived towards the direction of displacement even when the displacement is so large that all the frequency components move more than a half cycle. The first-order motion detector cannot mediate this kind of perception since its theoretical displacement limit for correct response is half a cycle of its preferred frequency. Dr. Sato and I found that a 1 octave bandpass RDK induces MAE in the same direction as motion perception when the displacement corresponds to half a cycle of the lowest frequency component. The positive MAE may be brought about by adaptation of the first-order motion detector which signals motion direction opposite to the perceived motion. Our finding strongly suggests that the motion perception for bandpass RDKs is mediated by the second-order motion system at least for large displacements.

In the latter half, I will talk about the study which examined motion detection mechanism involved in second-order system. The stimulus employed was RWK (random window kinematogram), a shifting random checkerboard pattern in which each check was either a patch of random dots (uncorrelated between frames) or a patch of uniform gray having the mean luminance of the random dots. Theoretically, RWK motion is visible only to second-order system. I examined various spatiotemporal properties of motion perception for RWK, and compared the results with those for RDK, which is visible to first-order system. I found that (1) The effect of ED (exposure duration) on the RWK discrimination could be described as SOA

(stimulus onset asynchrony) dependency when the EDs of the first and second frames were the same, but SOA could not predict the performance when the first ED was short while the second was long; (2) RWK could be seen at longer ISI (inter-stimulus interval) than RDK; (3) Incoherent motion (e.g., reversed phi) could be seen for RWK; (4) The Dmax (maximum displacement limit) for RWK was comparable to that of RDK. But the Dmax for RWK increased proportional to the check size, while that for RDK did not. Suggestions from these results are as follows; Like the first-order mechanism, the second-order mechanism extract motion locally, and its motion extraction stage can be modeled as a correlation-type detector; The spatial range where it operates is comparable to that of the first-order mechanism, but the temporal range is larger; Preprocessing of the contrast motion mechanism is different from that assumed in the model previously proposed.

Second-order motion system;

Its role and mechanism

Shin'ya Nishida

ATR Auditory and Visual
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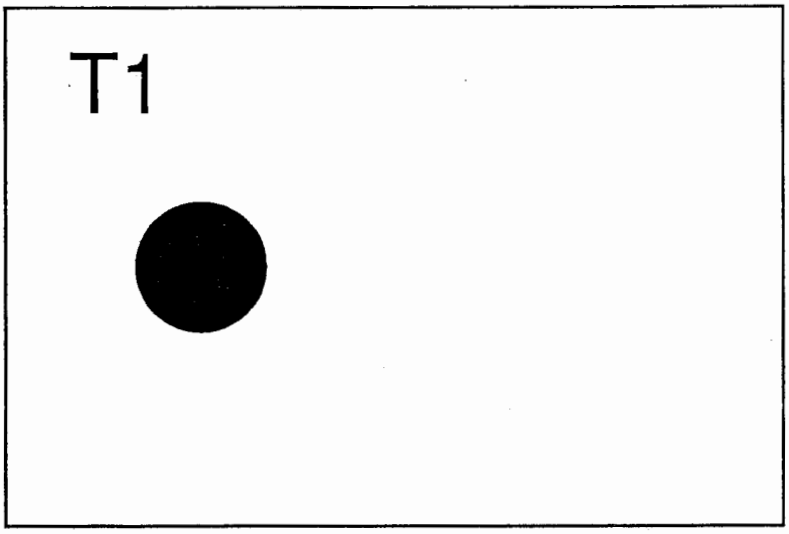
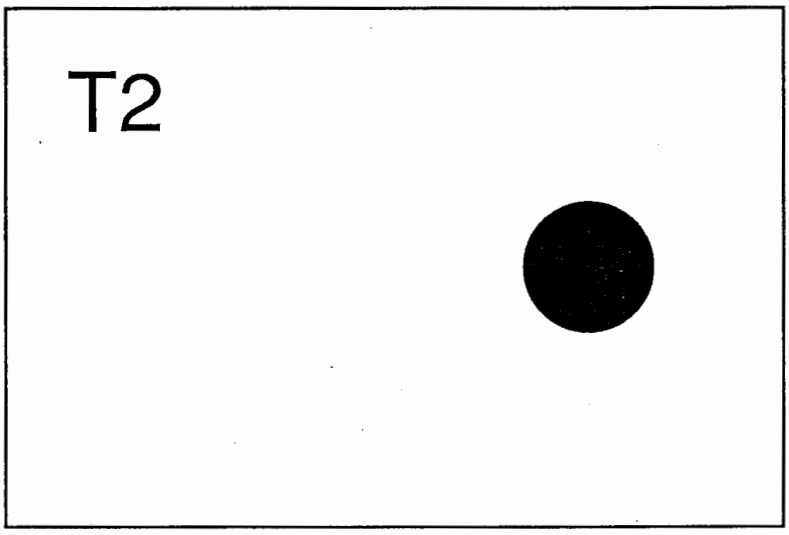
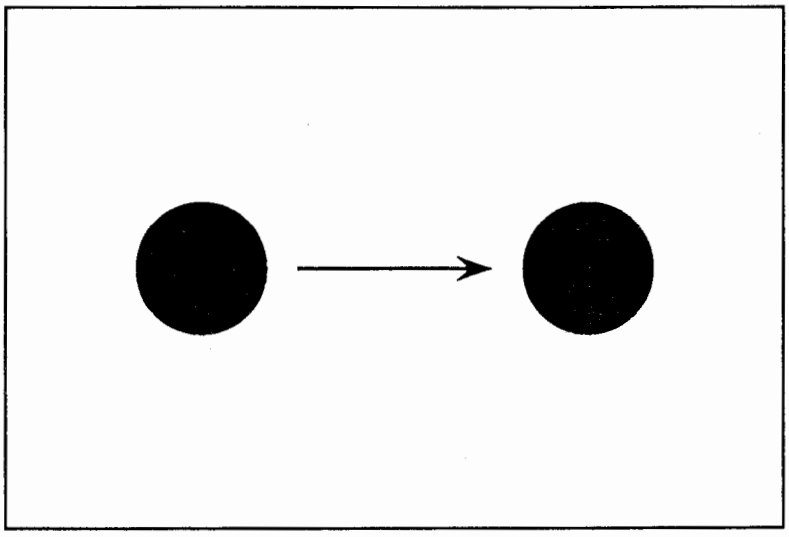
Classical Apparent Motion







「Braddick, O. J. (1974). A short-range process in apparent motion. *Vision Research, 14*, 519-527.より引用」

A SHORT-RANGE PROCESS IN APPARENT MOTION

OLIVER BRADDICK
The Psychological Laboratory, University of Cambridge, Cambridge, England

(*Received* 21 *September* 1973)

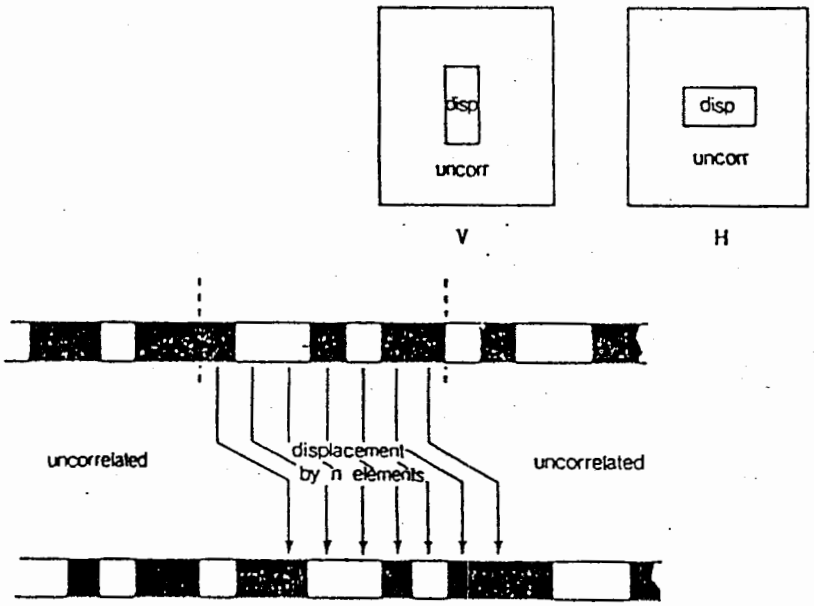


Fig. 1. Below: principles of generation of a single row of each pattern. The dotted lines mark the boundaries of the central rectangle. Above: illustrating the size and position of the displaced horizontal (H) or vertical (V) rectangle within the uncorrelated surround. Overall size of the patterns: 9 × 9°.

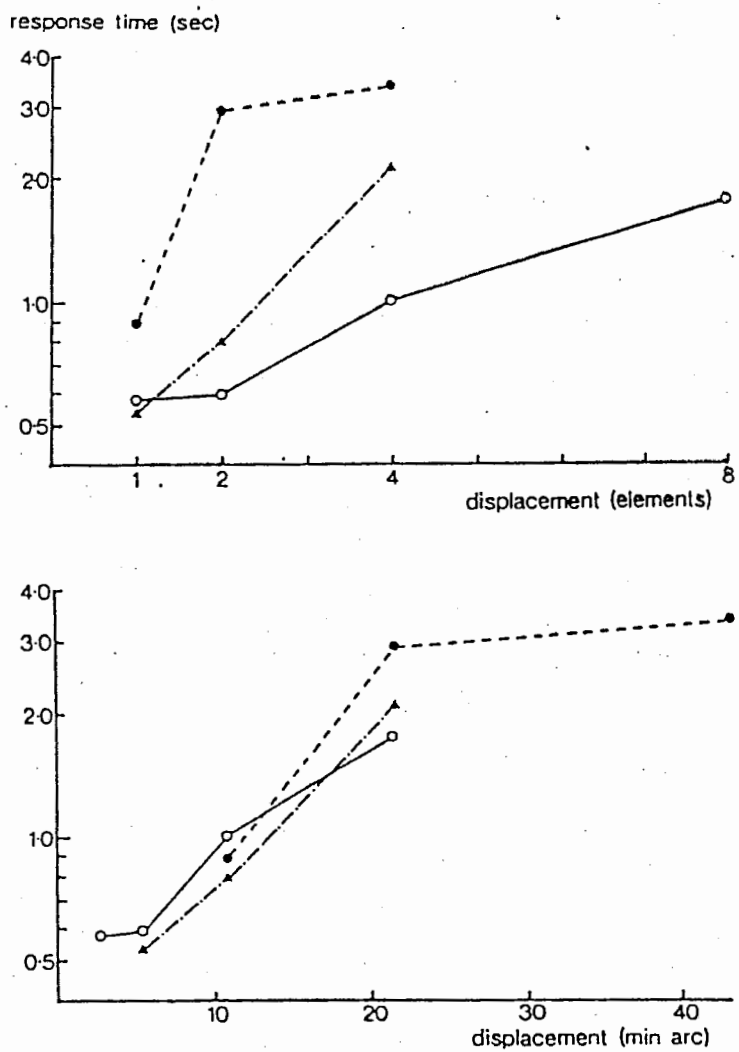


Fig. 2. Response time for report of orientation of the displaced rectangle, as a function of displacement. Data are mean of a log transform for five subjects. The ordinate is logarithmic. Above: displacement in units of one pattern-element's width. Below: displacement in units of visual angle.

—○—: 2·7′ elements. –·–▲–·–: 5·4′ elements.- - -●- -: 10·8′ elements.

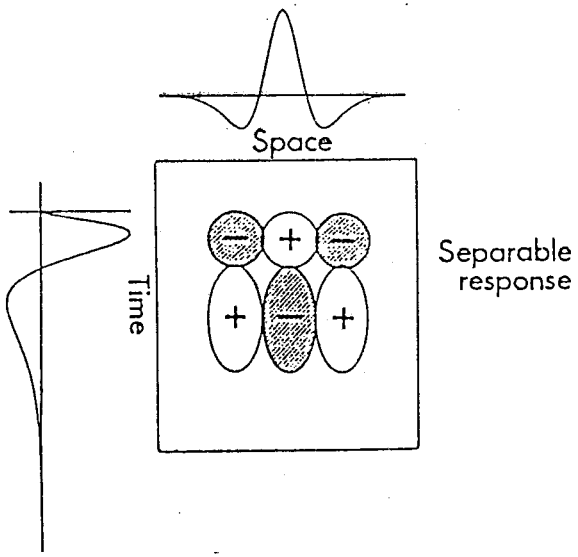
「Petersik, J. T. (1989). The two-process distinction in apparent motion.
Psychological Bulletin, 106, 107-127.より引用」

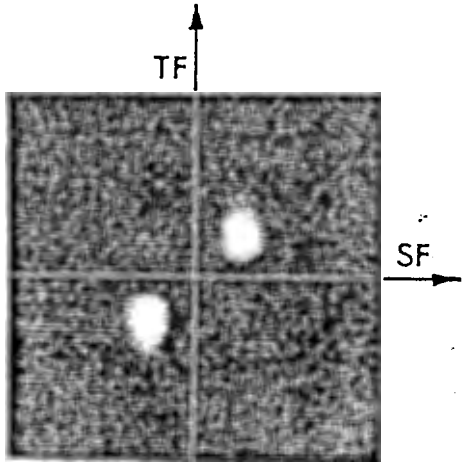
Table 1.
Properties of short-range and long-range motion processes (principally after Anstis (1980) and Braddick (1980), with some additions).

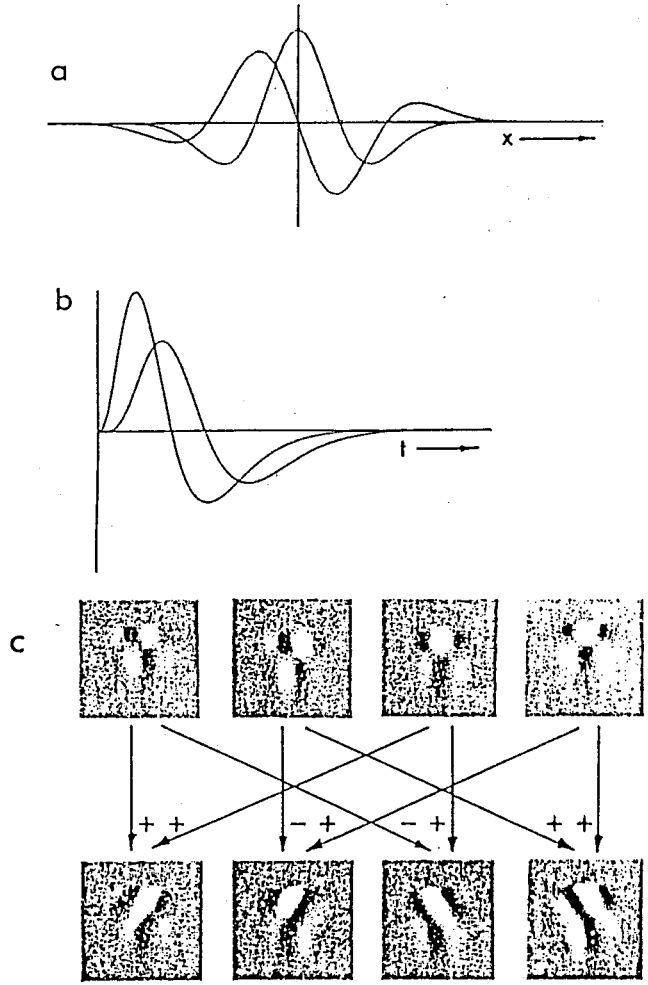
Short-range	Long-range
Short spatial range (< 15 arc min) Braddick (1974)	Operates over many degrees Kolers (1972)
Brief temporal range (80–100 ms ISI) Braddick (1974)	ISI up to 500 ms Mather (1989)
Motion aftereffect Banks and Kane (1972)	No motion aftereffect Papert (1964), Anstis (1980)
Not dichoptic Braddick (1974)	Dichoptic Shipley *et al.* (1945)
No response to colour Ramachandran and Gregory (1978)	Response to colour Ramachandran and Gregory (1978)
Low-level neural comparator	Responsive to higher-level correspondences that do not activate motion detectors
Passive motion response, velocity space computations (Adelson and Movshon, 1982)	Cooperative processes, inference

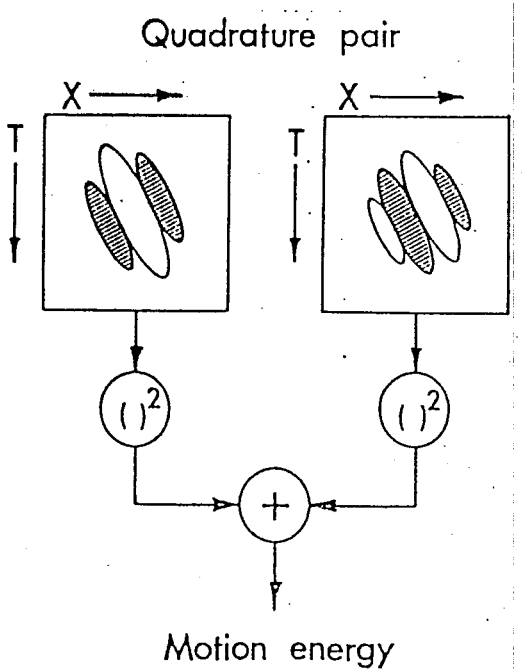
Spatiotemporal energy model of motion detection (Adelson & Bergen, 1985)

「Adelson, E. H. & Bergen, J. R. (1985). Spatiotemporal energy models for the perception of motion. *Journal of the Optical Society of America, A2*, 284-299.より引用」



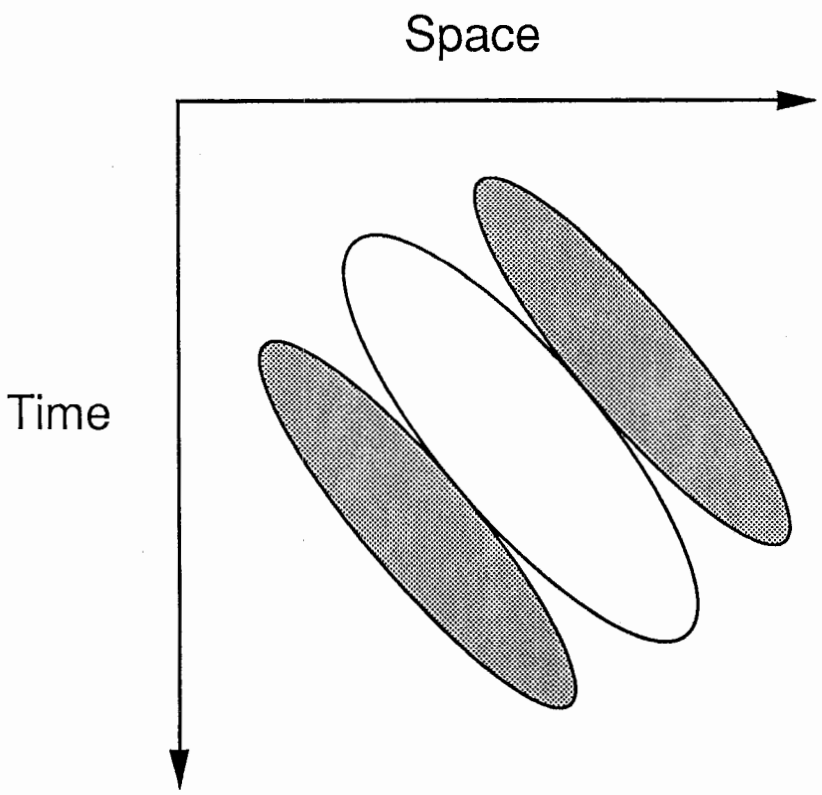




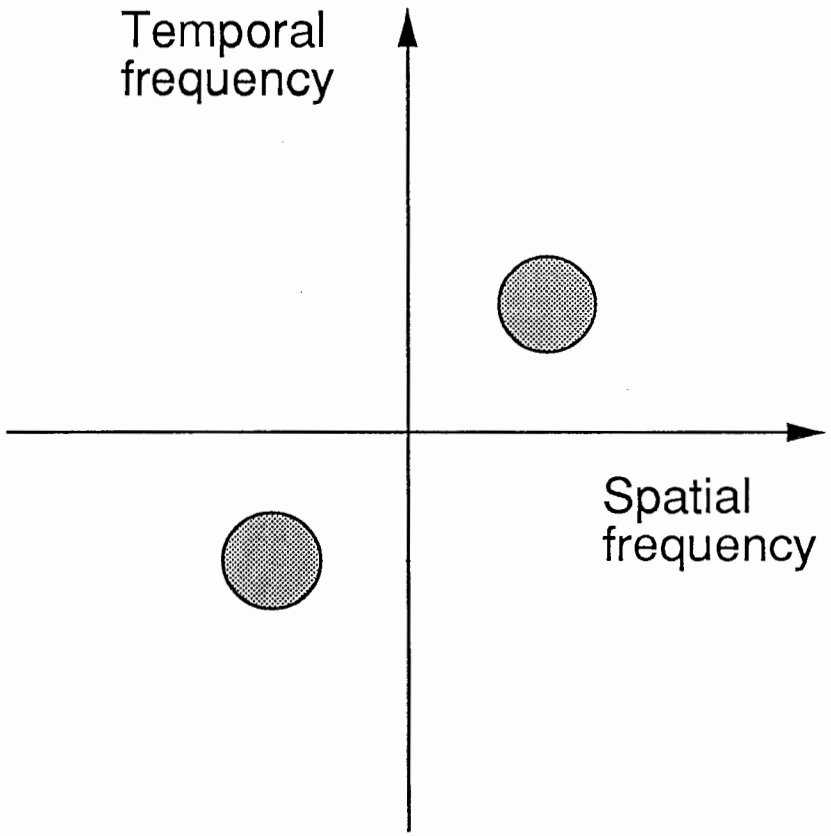


Receptive field of an ideal first-order motion detector

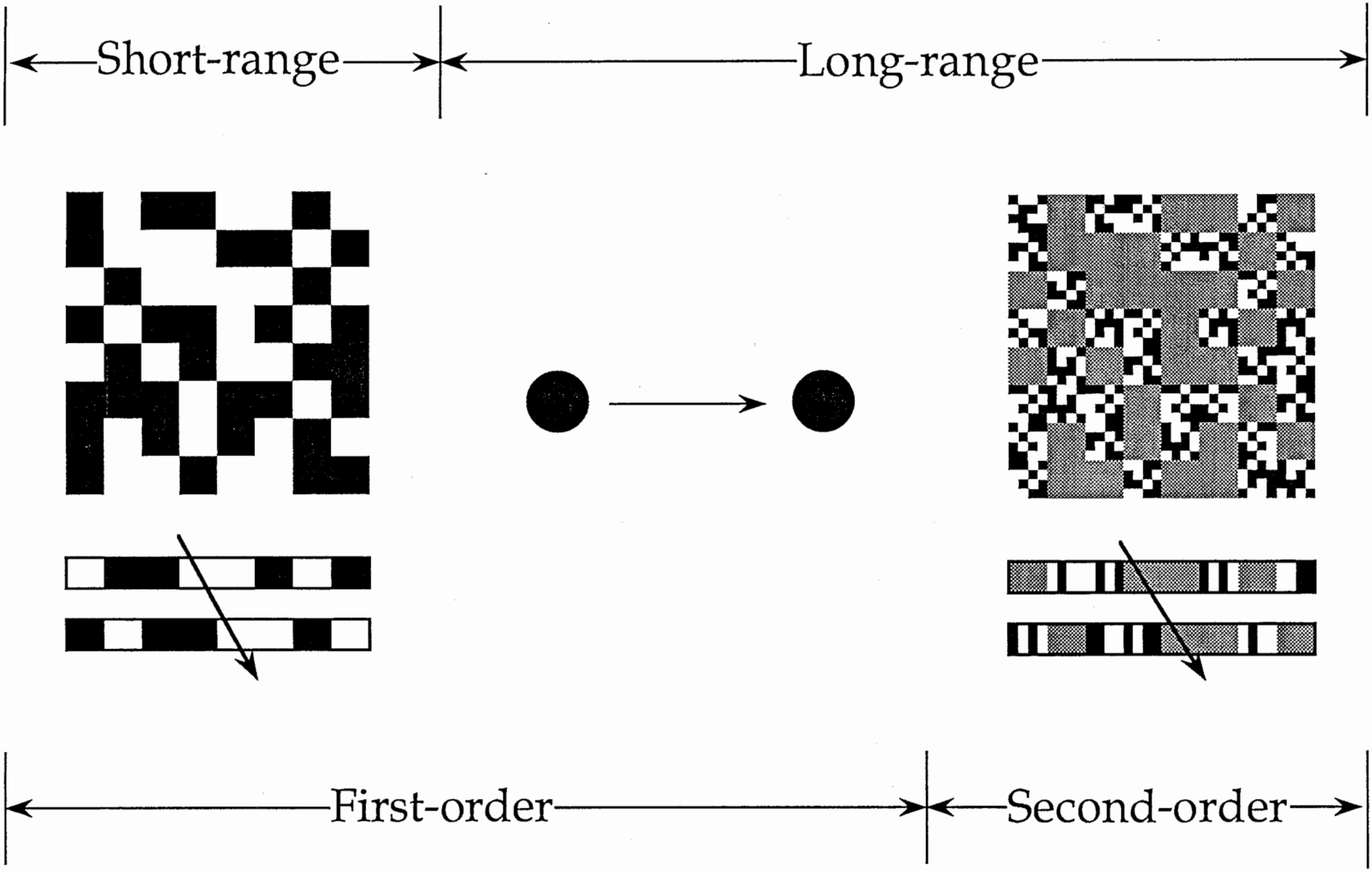
(Adelson & Bergen,1985; Van Santen & Sperling, 1985; Watson & Ahumada, 1985)



Space-time domain



Frequency domain


Short-range
Long-range
First-order
Second-order

Dichotomy of motion detection mechanism

(Anstis,1980; Chubb & Sperling,1988; Cavanagh & Mather,1989)

First-order motion detectors:	*Second-order motion detectors:*
extract motion from spatio-temporal flow in luminance distribution	extract motion after highly non-linear transformation to luminance distribution
follow the motion-from-Fourier-components (MFFC) principle	do not follow the MFFC principle
mediate motion perception for: sinusoidal grating missing fundamental grating reversed-phi motion random-dot kinematogram (?)	mediate motion perception for: contrast modulation texture-defined region (motion-defined region) (stereo-depth-defined region)
their adaptation *strongly* induces motion after-effect (MAE)	**their adaptation *only slightly* induces MAE**

Positive motion after-effect induced by bandpass random-dot kinematograms

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Takao Sato

NTT Basic Research Laboratories

Spatial-bandpass-filtered random-dot kinematogram (RDK)

The maximun displacement limit (Dmax) is inversely proportional to the frequencies. → consistent with the first-order detector model prediction

(When the bandwidth is around 1 octave)
The Dmax attains more than 0.5 cycles of the lowest frequency component. → **inconsistent with the first-order detector model prediction**

→ Effects of off-axis components ? (Bischof & Di Lollo, 1990,1991) → plausible, but only for 2D bandpass images

→ Modification of the first-order detector model. (Cleary & Braddick, 1990)

→ ***Second-order detectors*** **may contribute to the direction peception.**

↓

Examination of the motion after-effect (MAE) induced by bandpass RDK

「Bischof, W. F. & Di Lollo, V. (1990). Perception of directional sampled motion in relation to displacement and spatial frequency: evidence for a unitary motion system. *Vision Research, 30,* 1341-1362. より引用」

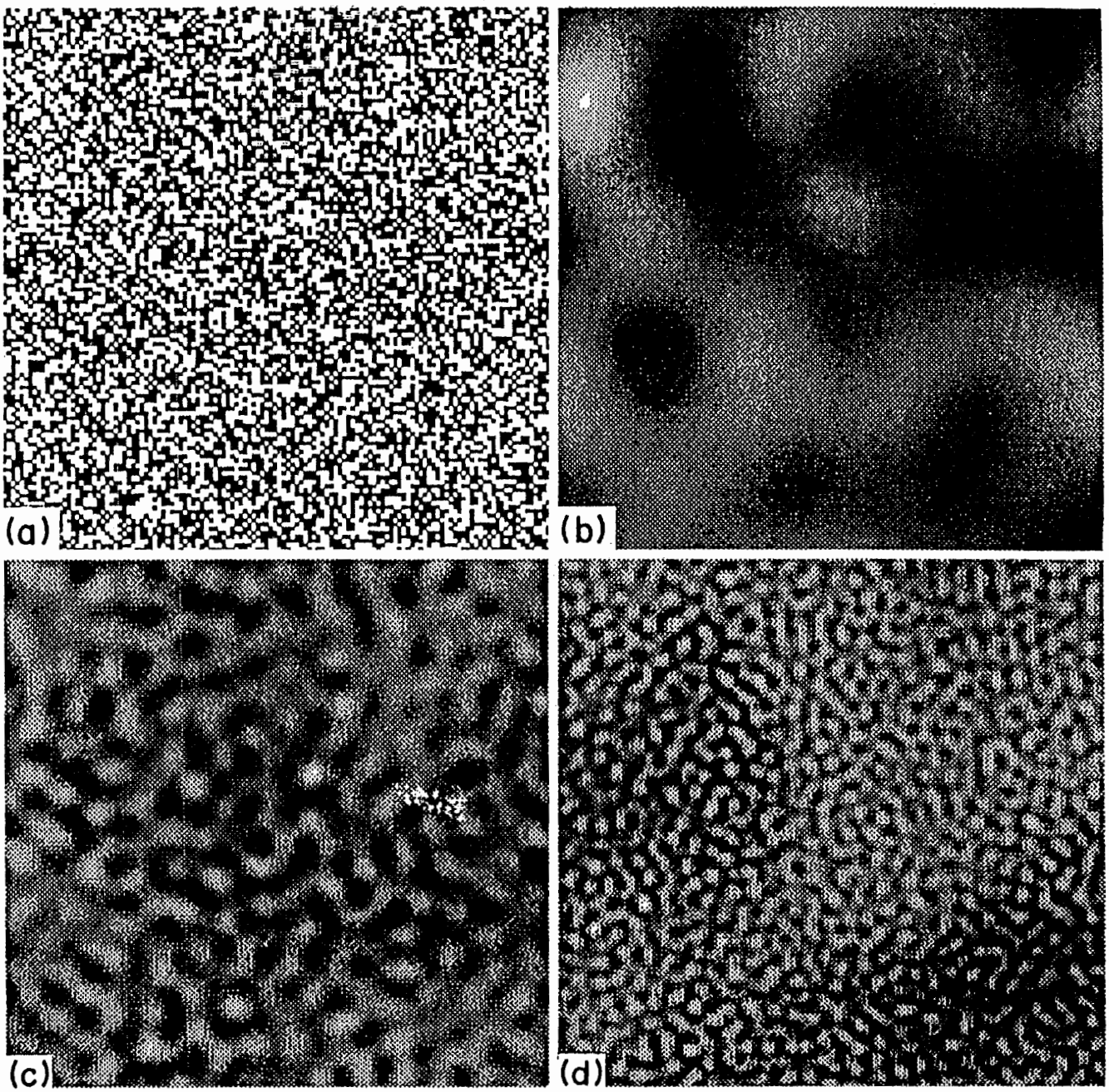
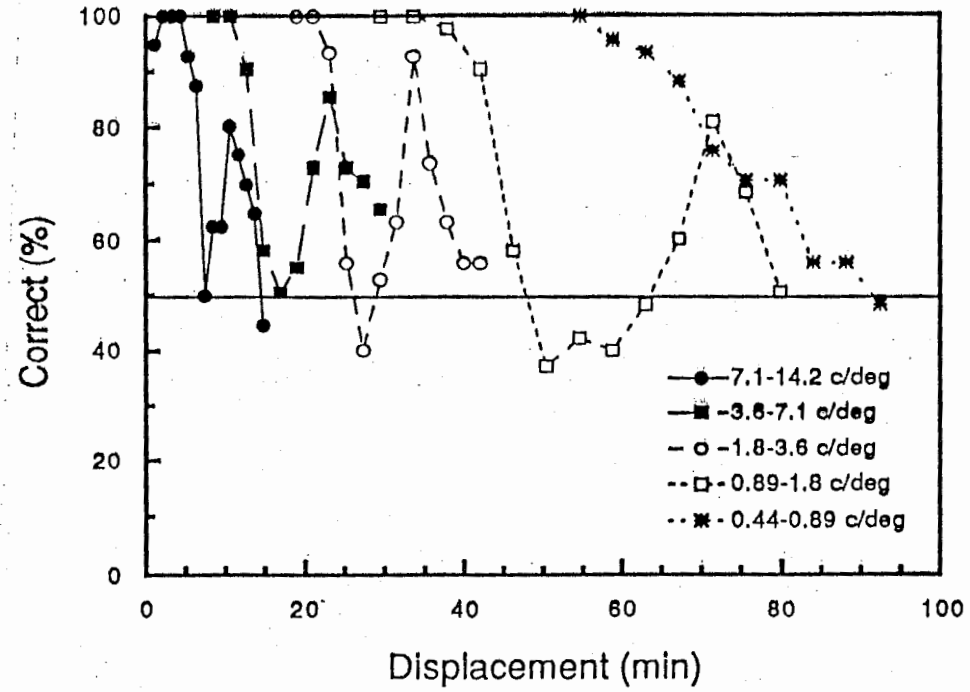
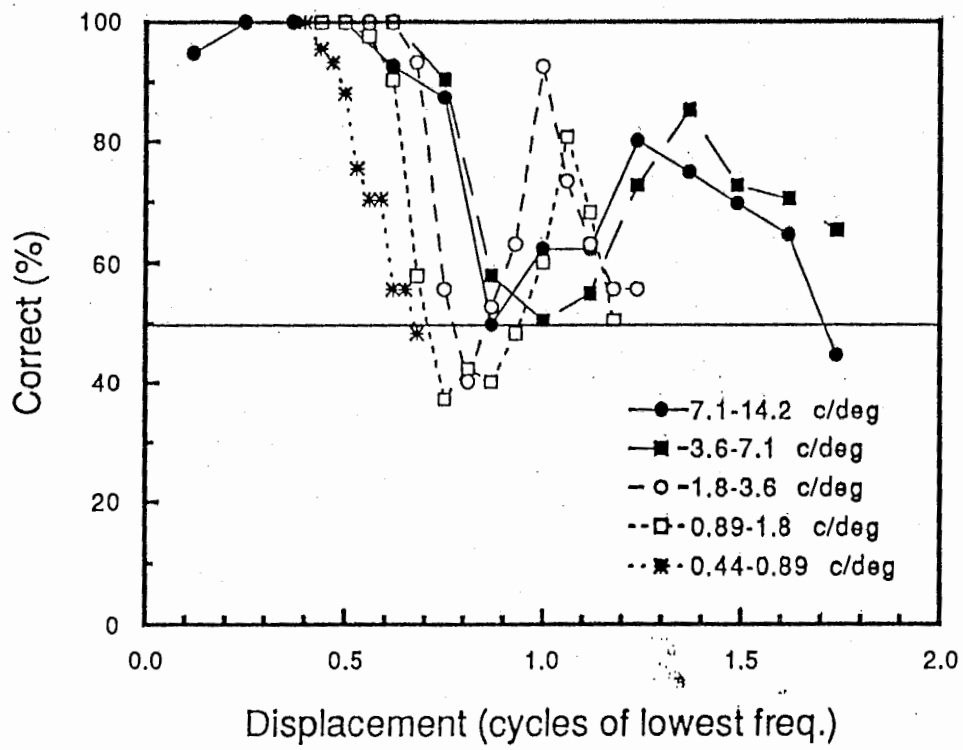


Fig. 6. Panel (a) shows an unfiltered 128 × 128 random-dot image. The remaining panels show band pass-pass filtered images as follows: (b) bandwidth: 0.5–1 c/deg, centre frequency: 0.75 c/deg. (c) bandwidth: 2–4 c/deg, centre frequency: 3 c/deg. (d) bandwidth: 4–8 c/deg, centre frequency: 6 c/deg.

Direction discrimination for bandpass filtered RDK
Data from Cleary & Braddick (1990)

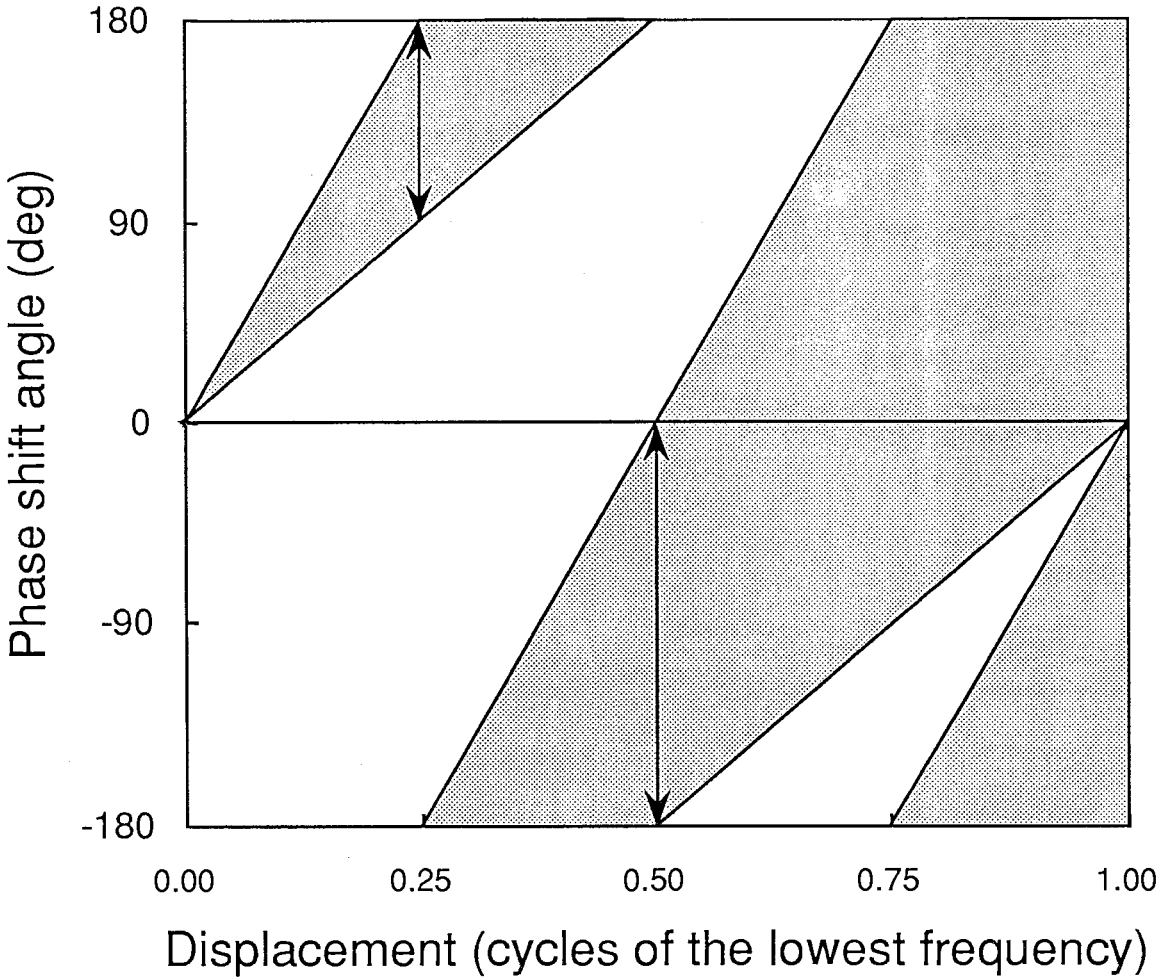




「Cleary, R. & Braddick, O. J. (1990). Direction discrimination for band-pass filtered random dot kinematograms. *Vision Research, 30,* 303-316.のデータを使用」

Phase shift angle of frequency components* of 1 octave bandpass filtered RDK as a function of displacement size

(* sinusoidal gratings whose orientations are orthogonal to the displacement direction)



Stimulus and Apparatus

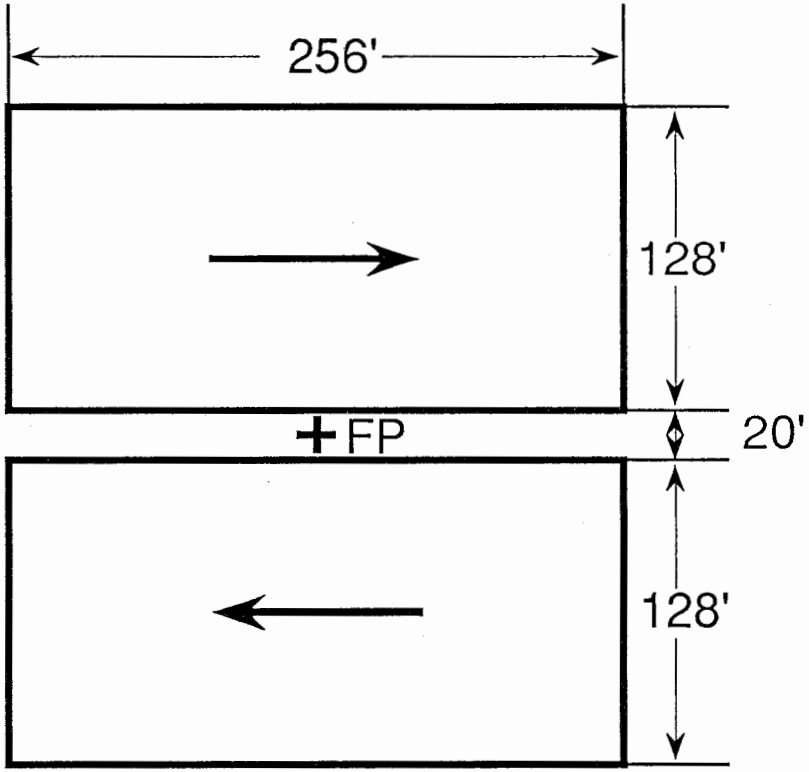
Stimulus :

see right panel
mean luminance : 30 cd/m²

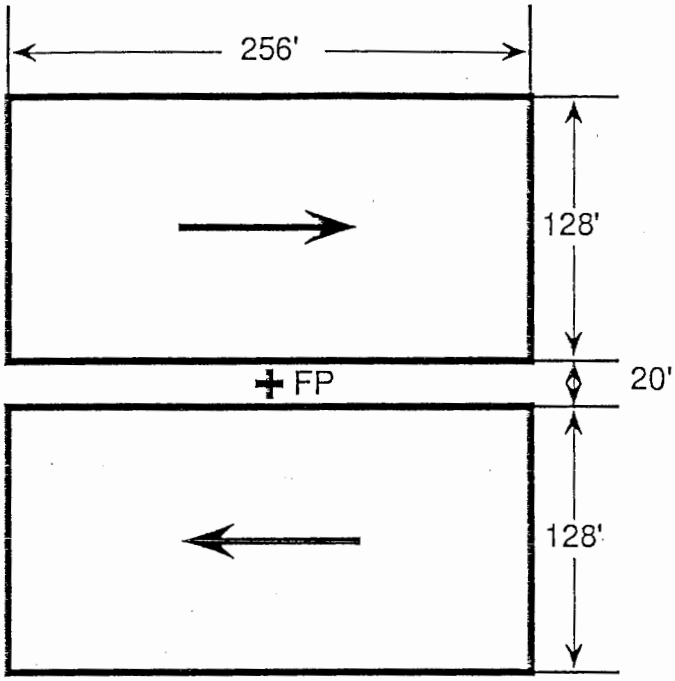
Apparatus :

Non-interlace CRT
(Sony GDM 1952; refresh rate 66.7Hz)
controlled by workstation
(Masscomp 6600)

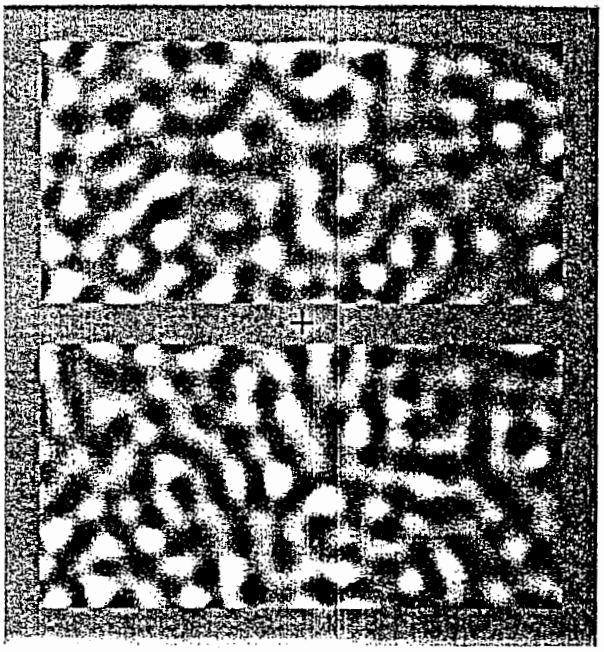
viewing distance : 104 cm



(A)



(B)



(C)

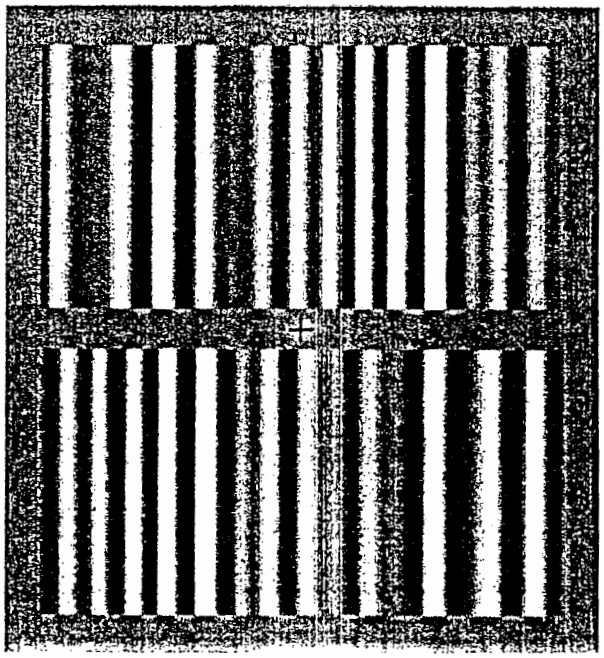
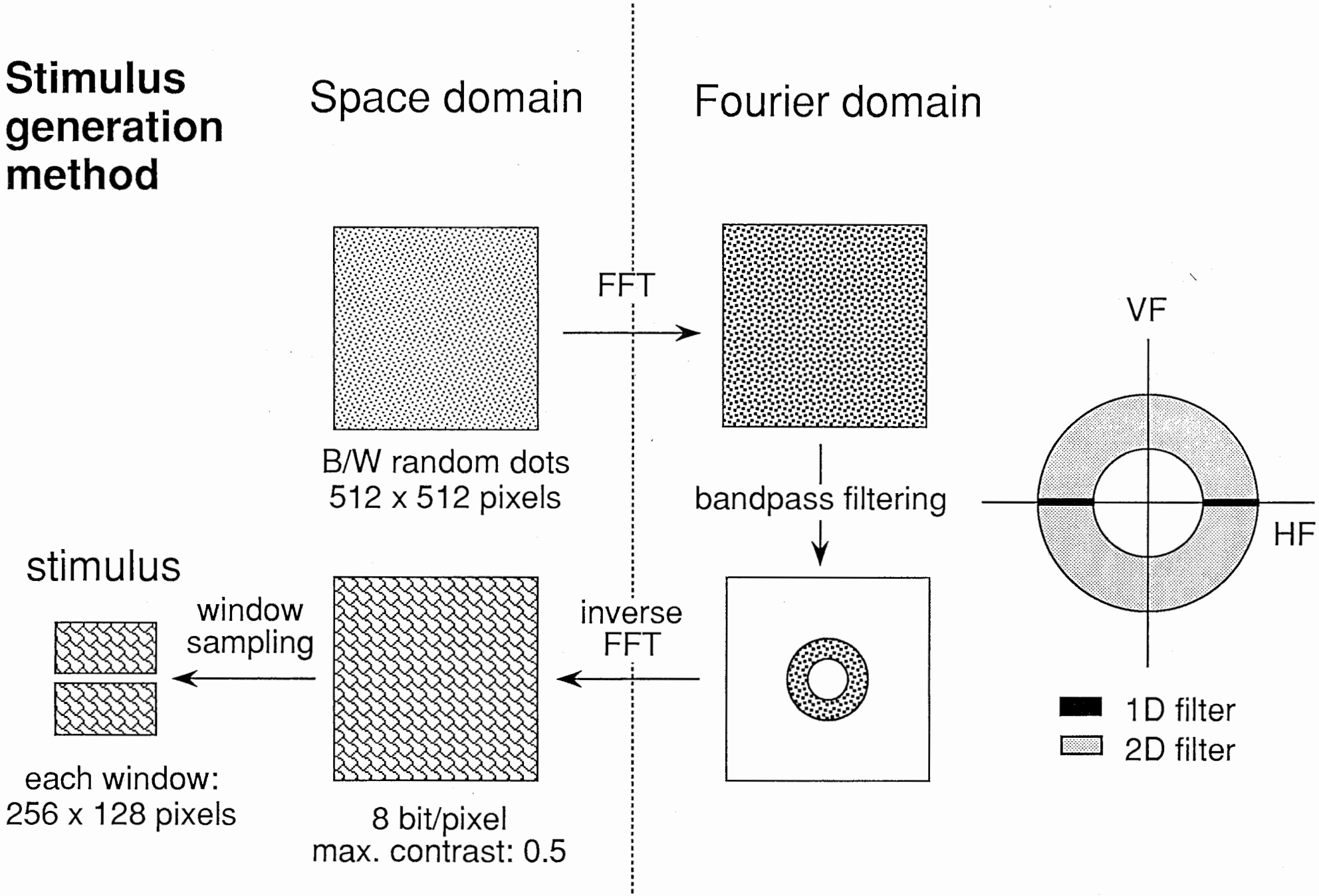


Fig. 1


Stimulus generation method
Space domain
Fourier domain
FFT
B/W random dots
512 x 512 pixels
bandpass filtering
VF
HF
1D filter
2D filter
inverse FFT
8 bit/pixel
max. contrast: 0.5
window sampling
stimulus
each window:
256 x 128 pixels

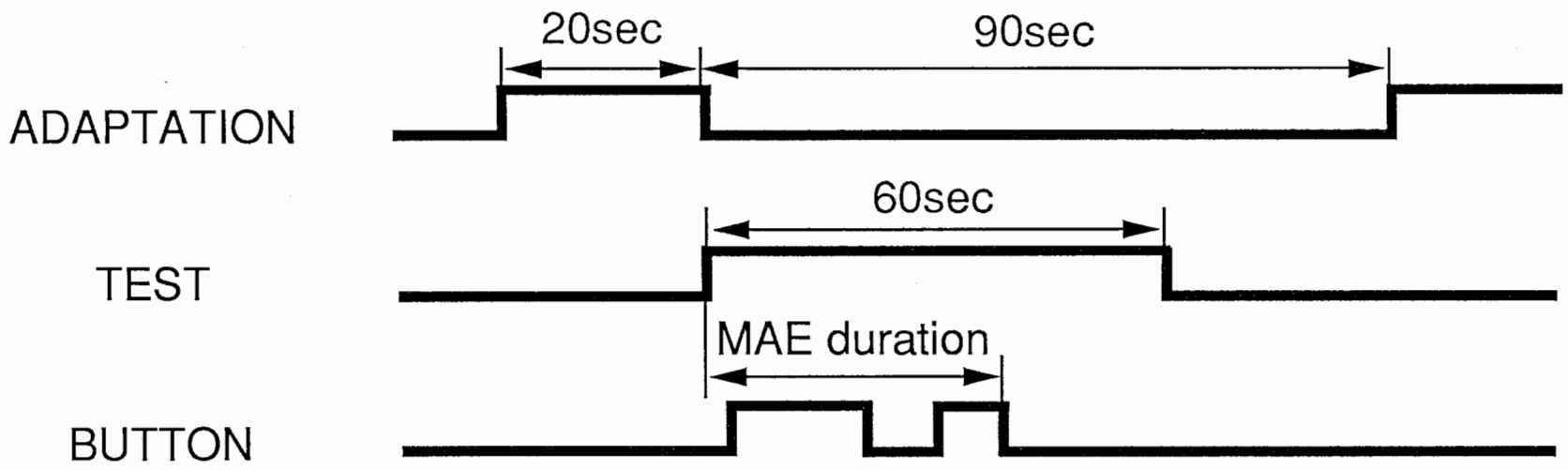
Procedure

Motion after-effect :

Measurement of direction and duration of MAE
Adaptation stimulus :
shifting bandpass RD (1 frame : 120 msec)
Test stimulus : bandpass RD without shifts
Observers pushed right or left button
depending on the direction of MAE
Time schedule : see below diagram
6 trials / displacement

Direction discrimination :

2 AFC / Constant method
No feedback
1 frame : 120 msec
Presentation frame number :
2 frames (240 msec) or
8 frames (960 msec)
48 trials/displacement



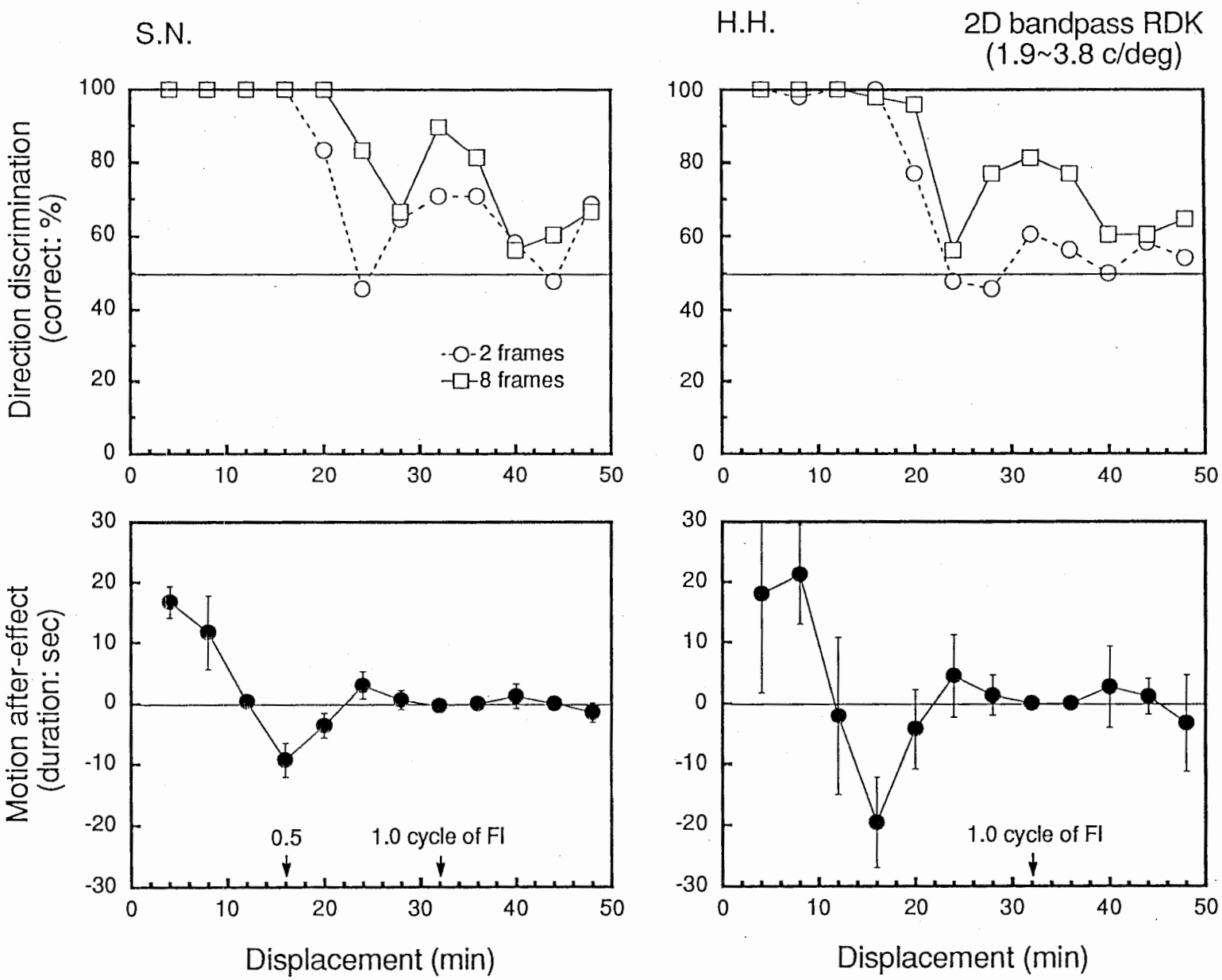
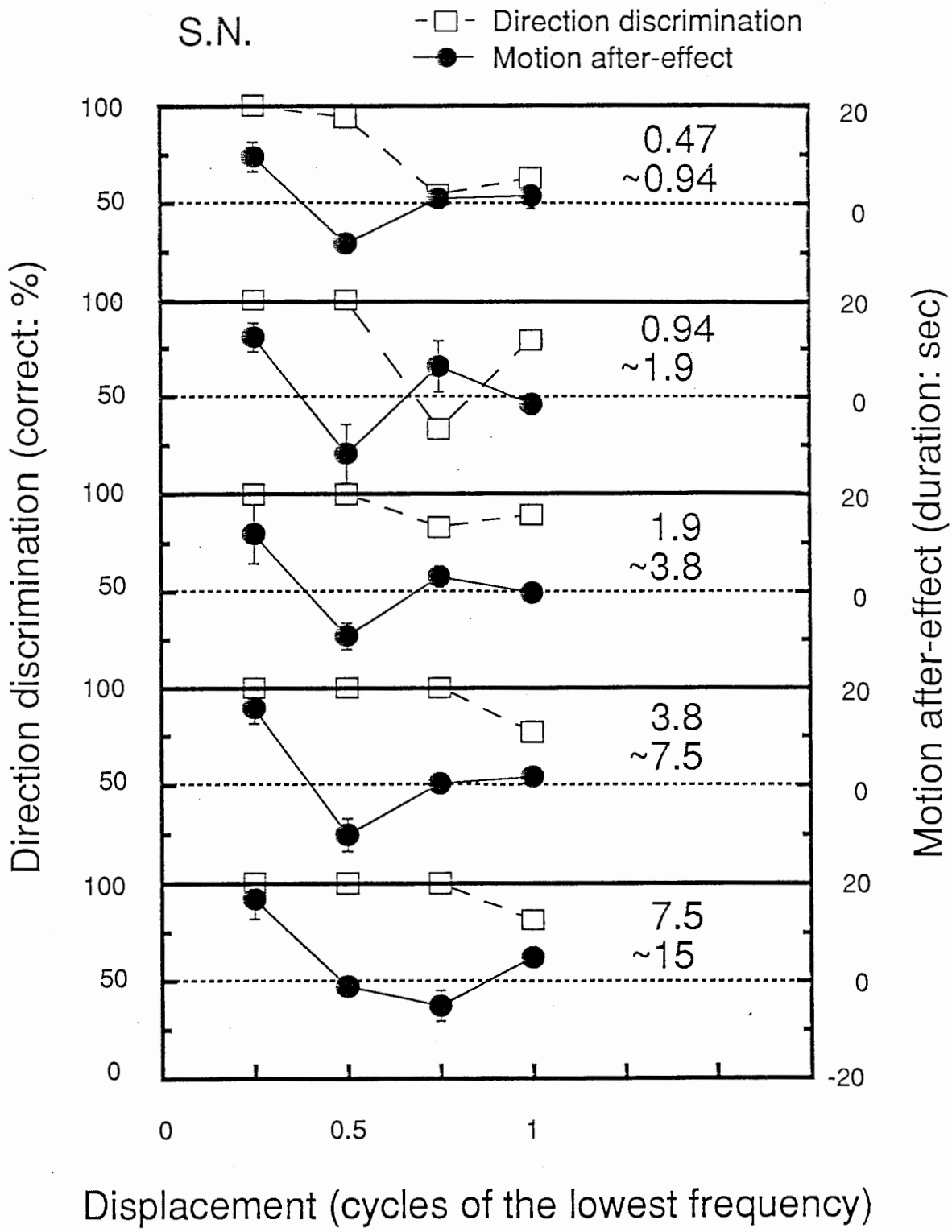

S.N.
H.H.
2D bandpass RDK
(1.9~3.8 c/deg)
Direction discrimination
(correct: %)
2 frames
8 frames
Motion after-effect
(duration: sec)
0.5
1.0 cycle of FI
1.0 cycle of FI
Displacement (min)
Displacement (min)

Fig. 2


S.N.
Direction discrimination
Motion after-effect
0.47
~0.94
0.94
~1.9
1.9
~3.8
3.8
~7.5
7.5
~15
Direction discrimination (correct: %)
Motion after-effect (duration: sec)
Displacement (cycles of the lowest frequency)
100
50
0
20
0
-20
0
0.5
1

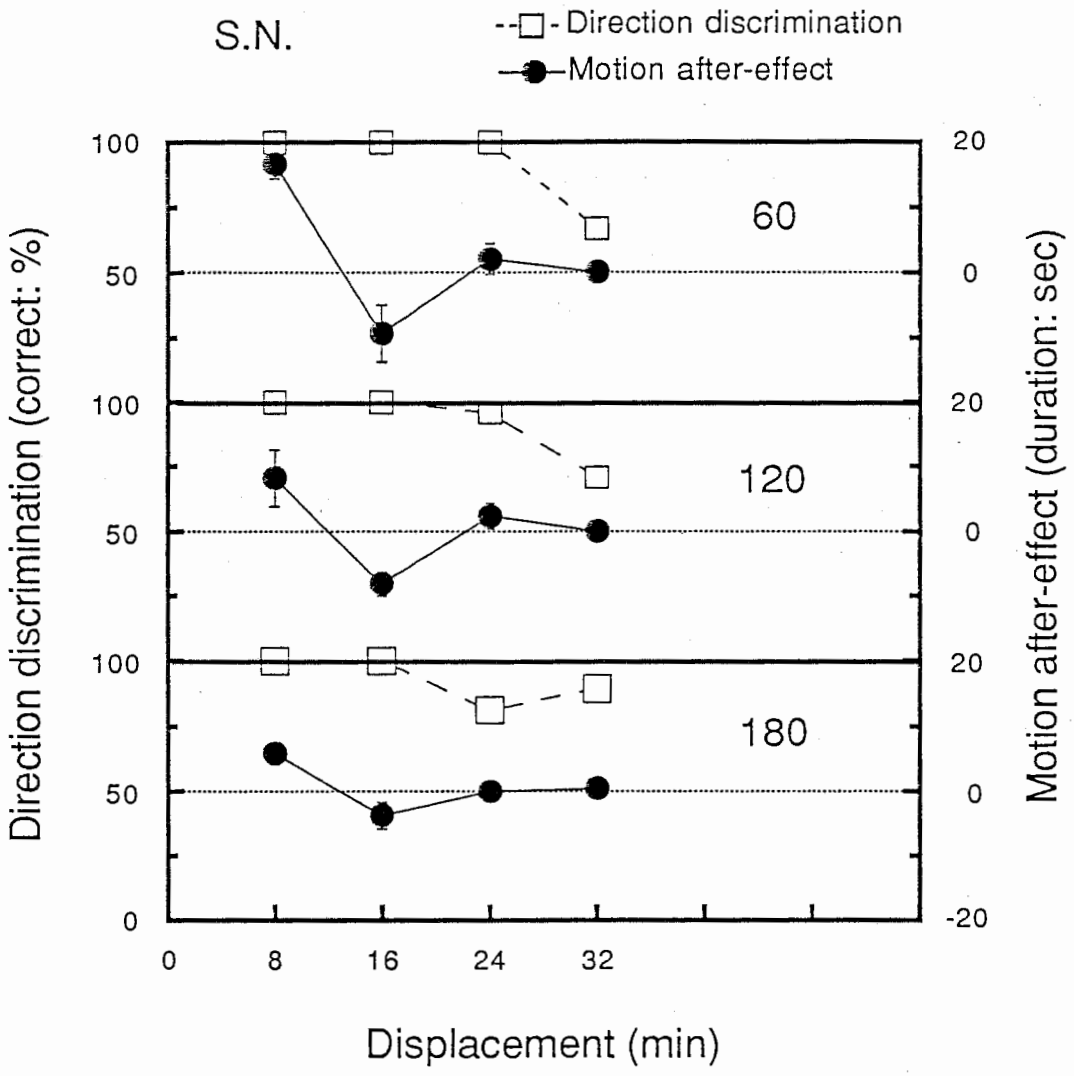

S.N.
Direction discrimination
Motion after-effect
60
120
180
100
50
0
20
0
-20
0
8
16
24
32
Direction discrimination (correct: %)
Motion after-effect (duration: sec)
Displacement (min)

Fig. 4

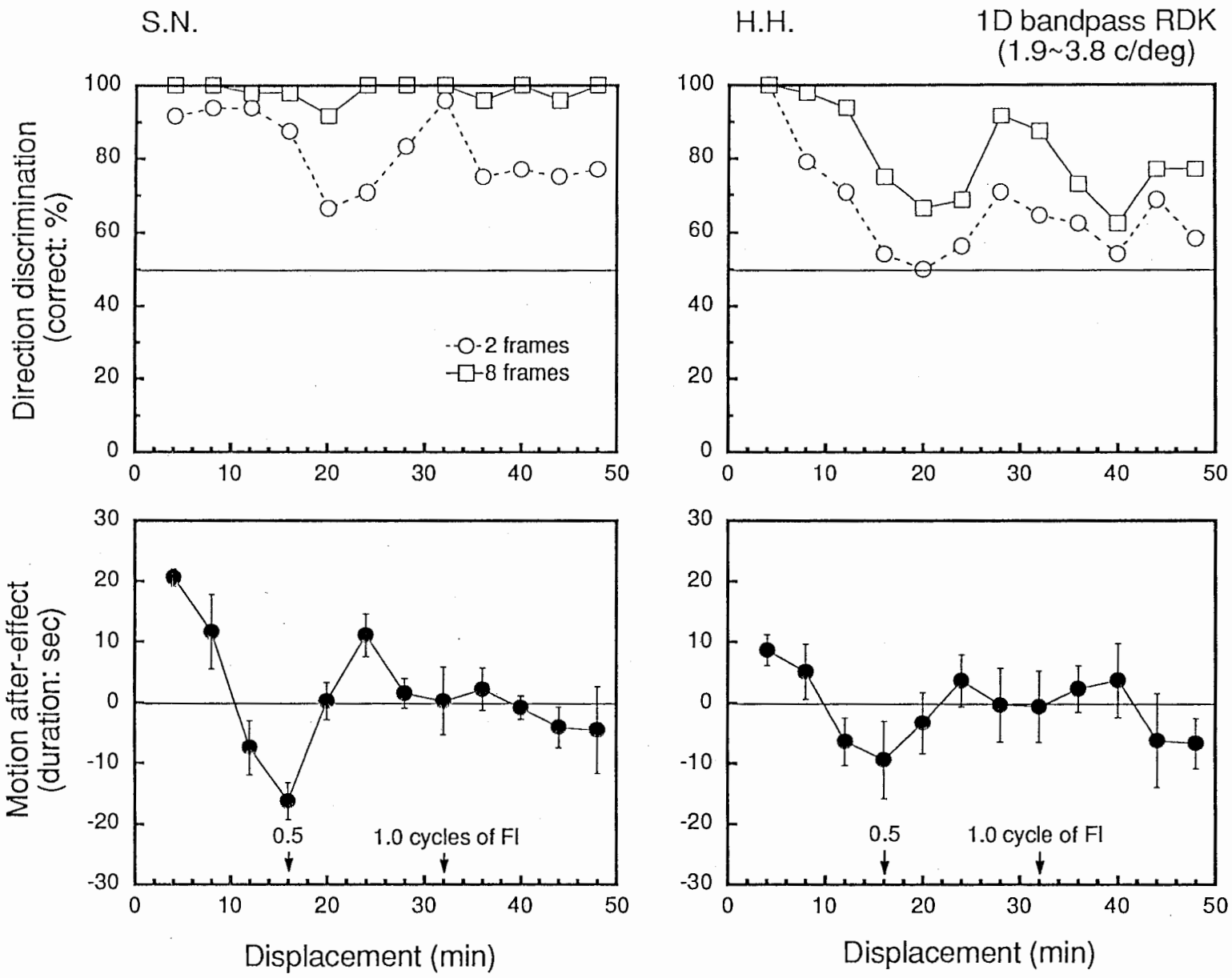

S.N.
H.H.
1D bandpass RDK
(1.9~3.8 c/deg)
Direction discrimination
(correct: %)
2 frames
8 frames
Motion after-effect
(duration: sec)
0.5
1.0 cycles of Fl
1.0 cycle of Fl
Displacement (min)
Displacement (min)

Fig. 5

Summary of the results

For 2D and 1D bandpass RDKs, the displacement dependency of the MAE was quite different from that of the motion perception.

As a result of the discrepancy between MAE and perceived direction, positive MAEs were obtained at a displacement of about 0.5 lowest frequency cycles of the image.

The motion after-effect induced by bandpass RDK

Is the displacement dependency of the MAE predictable from the change in first-order detector activity?

↓

Calculation of the net Directional Power (DP) * from 1D bandpass images.

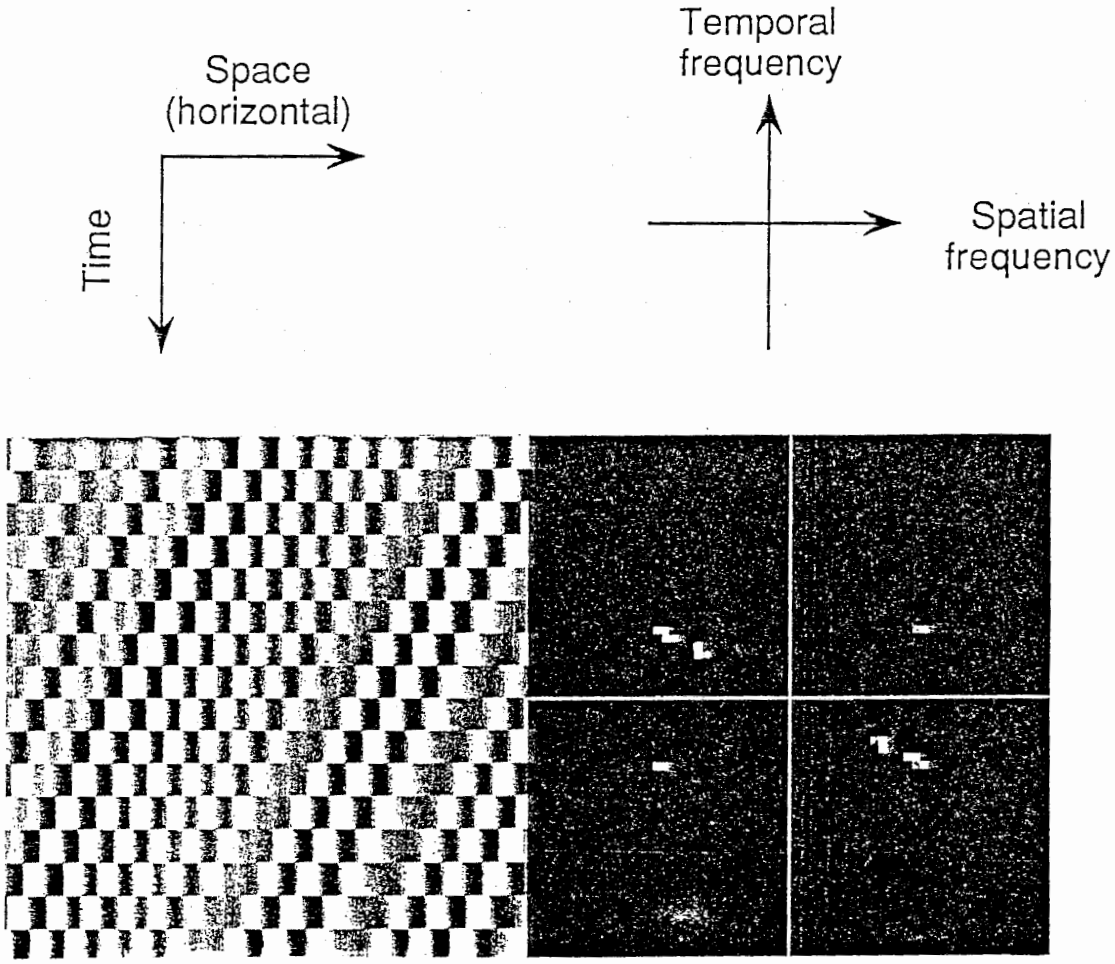
$$DP = P_{leftward} - P_{rightward} = \sum_{\substack{\omega_x \bullet \omega_y < 0 \\ |\omega_x|,|\omega_y| \leq 30}} p(\omega_x, \omega_t) - \sum_{\substack{\omega_x \bullet \omega_y > 0 \\ |\omega_x|,|\omega_y| \leq 30}} p(\omega_x, \omega_t)$$

*The DP roughly corresponds to the outputs of first-order detectors.
(Dosher, Landy & Sperling, 1989)

↓

Nearly perfect fitting between the MAE data and the DP.

(A) Displacement : 8' (0.25 cycles of the lowest frequency)



(B) Displacement : 16' (0.5 cycles of the lowest frequency)

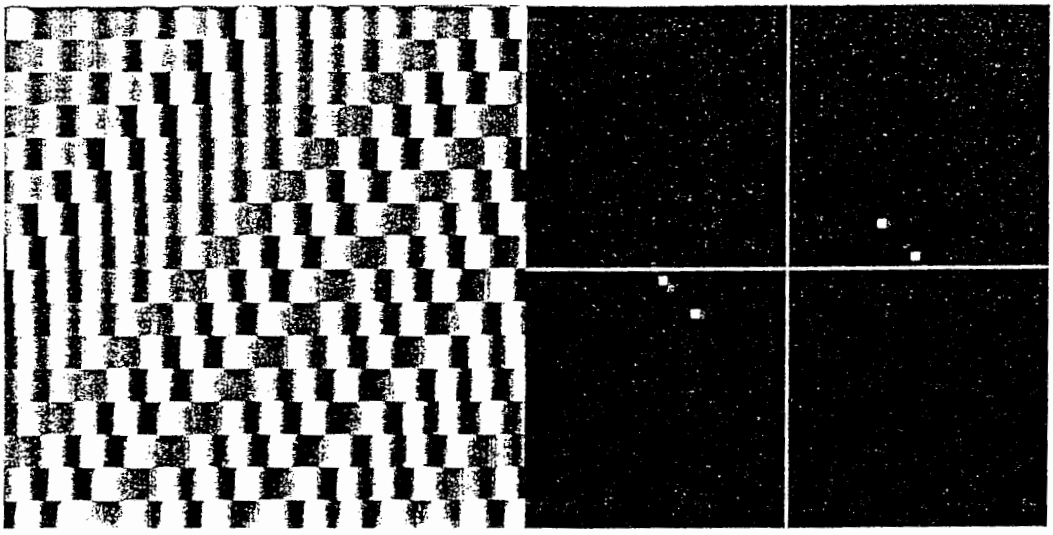


Fig. 6

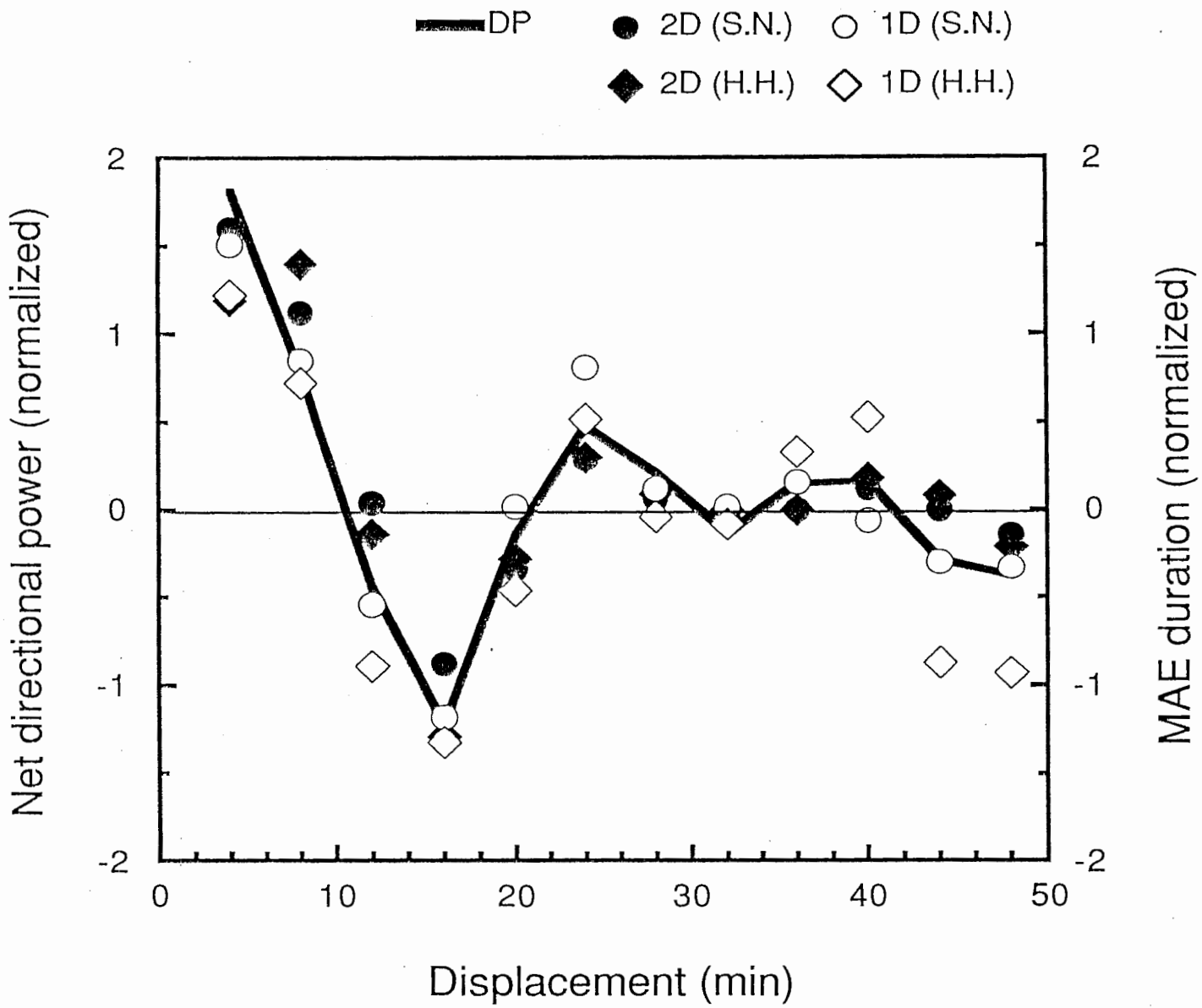

DP
2D (S.N.)
1D (S.N.)
2D (H.H.)
1D (H.H.)
Net directional power (normalized)
MAE duration (normalized)
Displacement (min)
2
1
0
-1
-2
0
10
20
30
40
50

Fig. 7

The motion perception for 1D & 2D bandpass RDK

A bandpass RDK contains sinusoidal gratings of close spatial frequencies.

Addition of close frequencies gives rise to a contrast modulation.

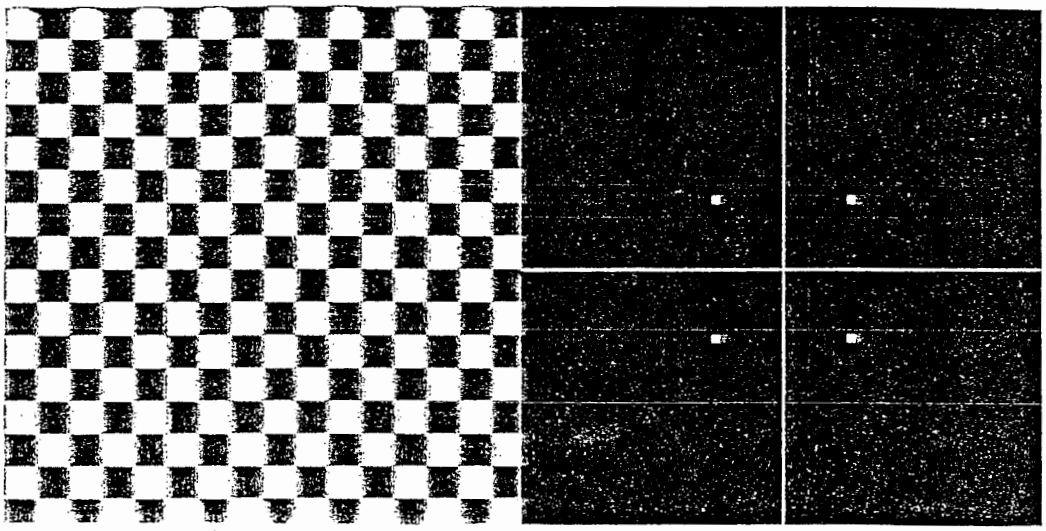
The movement of contrast modulation may be detected by second-order mechanisms.
(Badcock & Derrington, 1985; Derrington & Badcock, 1985)

↑

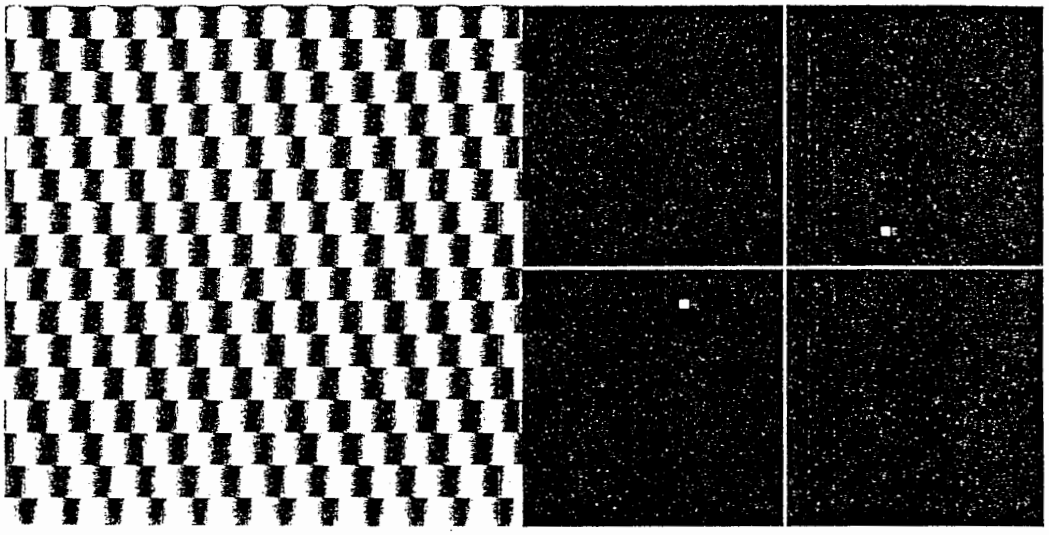
Observation: Positive MAE induced by a compound grating.

Frequency (c/deg)	1cycle (min)	Displacement Direction	Displacement Size (min)	Displacement Angle (deg)	Peceived direction	Motion after-effect Direction	Motion after-effect Duration (sec) S.N.	Motion after-effect Duration (sec) H.H.
1.88	32.0	←	16.0	180	↔		0.0	0.0
2.81	21.3	←	16.0	270	→	←	22.7	10.1
compound grating		←	16.0		←	←	17.1	15.8

(A) 1.9 c/deg



(B) 2.8 c/deg



(C) 1.9 + 2.8 c/deg

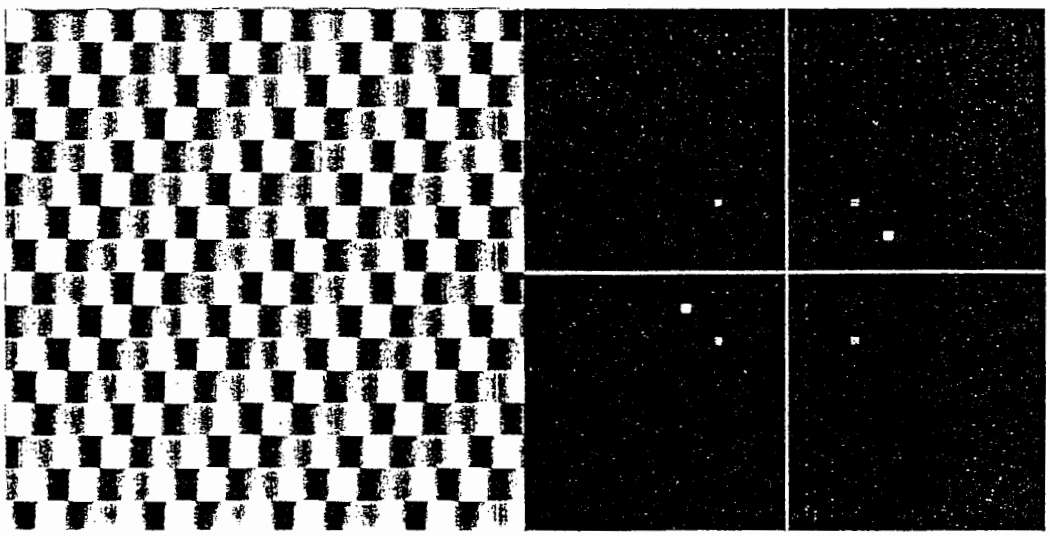


Fig. 8

For bandpass RDKs :

Discrepancy in the displacement dependencies of the MAE and the motion perception.

→ They are not mediated by an identical process.

The displacement dependency of the MAE is predicted by the DP.

→ The MAE results from adaptation of first-order detectors.

The motion perception (especially for 1D image) may be mediated by second-order system which detects movement of contrast modulation.

「Chubb, C. & Sperling, G. (1988). Drift-balanced random stimuli: a general basis for studying non-Fourier motion perception. *Journal of the Optical Society of America, A5*, 1986-2007.より引用」

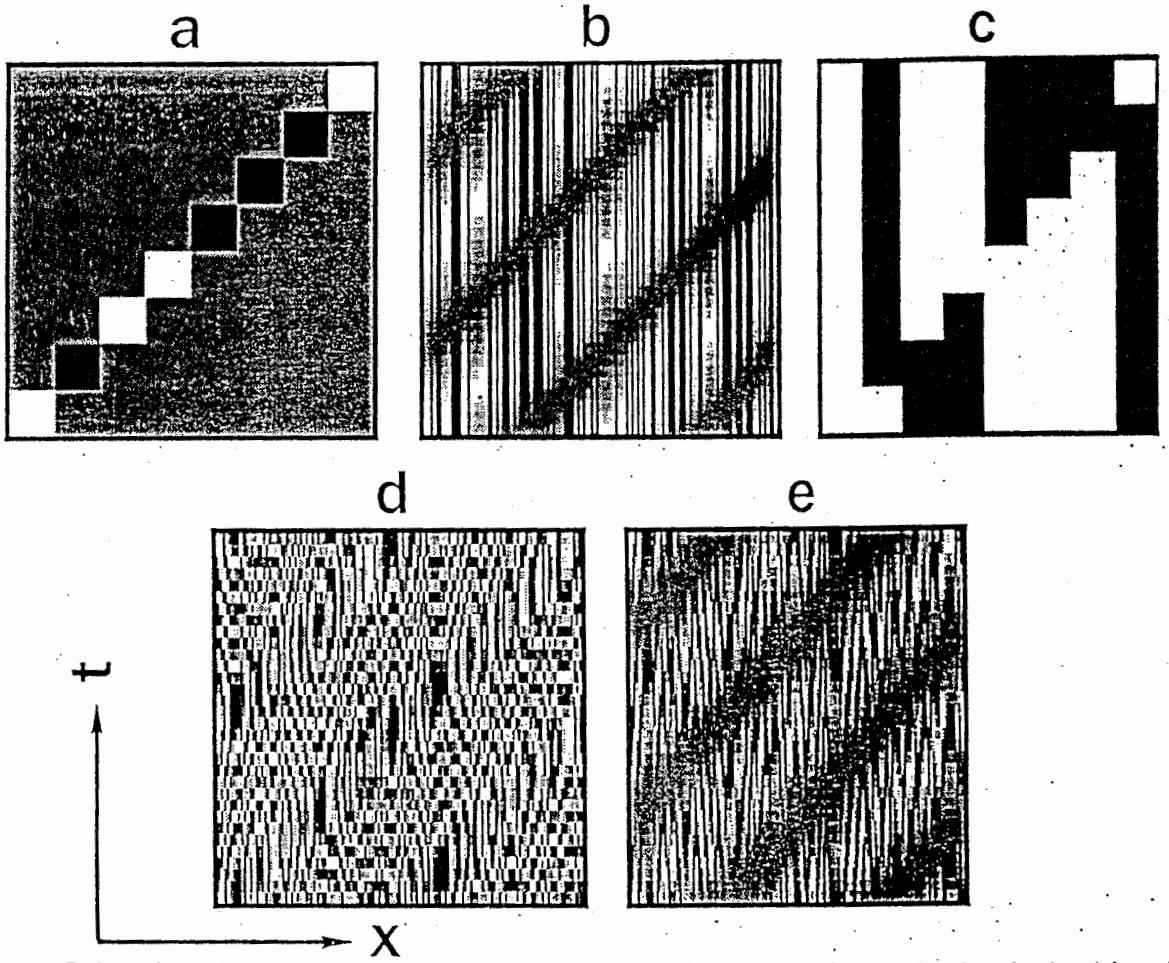


Fig. 4. a, Rightward-stepping, randomly contrast-reversing vertical bar: a horizontal–temporal cross section of a realization of the random stimulus I (see demonstration 1). I is the sum of pairwise independent space–time-separable random stimuli, each of which has an expectation of 0; consequently I is drift balanced (by corollary 1). b, Modulation of the contrast of a static noise field by a drifting sinusoidal grating: a horizontal–temporal cross section of a realization of the random stimulus K (demonstration 2). That K is drift balanced follows from corollary 1. c, Traveling contrast reversal of a noise field: a horizontal–temporal cross section of a realization of the random stimulus J (demonstration 3). J is the sum of pairwise independent space–time-separable random stimuli, each of which has an expectation of 0 and is thus drift balanced (by corollary 1). Note that, in contrast to $|I|$ (for I of Fig. 4a), $|J|$ is devoid of motion information. d, Modulation of the flicker frequency of a flickering noise field by a drifting grating: a horizontal–temporal cross section of a realization of the random stimulus H (demonstration 4). That H is drift balanced is a consequence of corollary C1 (in Appendix C). The motion of H is derived from spatiotemporal modulation of the frequency of sinusoidal flicker, where the phase of the flicker is random over space. e, Modulation of the contrast of a flickering noise field by a drifting sinusoidal grating: a horizontal–temporal cross section of a realization of the random stimulus G (demonstration 5). G is drift balanced (by corollary C1). The motion of G is derived from spatiotemporal modulation of the amplitude of sinusoidal flicker, where the flicker phase is random over space.

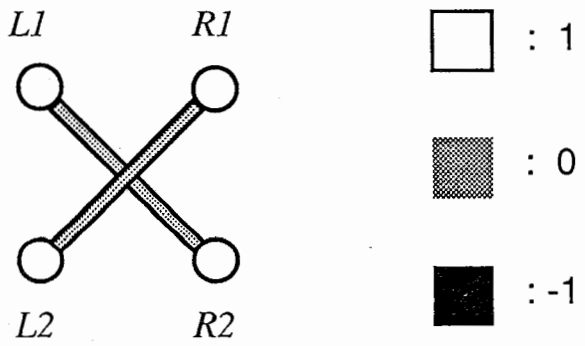
Microbalanced random stimuli

(Chubb & Sperling, 1988)

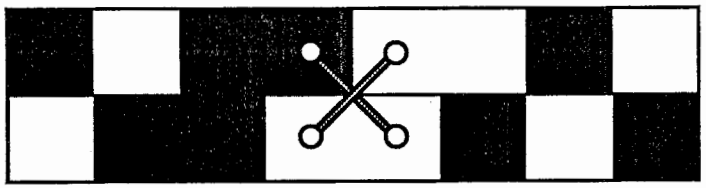
$$E[I(x,y,t)I(x',y',t')] = E[I(x,y,t')I(x',y',t)]$$

$I()$: contrast function

$E[\,]$: expectation



RDK

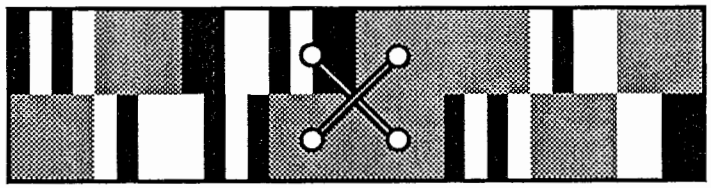


$$E[R1 \cdot L2] = 1$$

$$E[L1 \cdot R2] = 0$$

$$\Rightarrow E[R1 \cdot L2] > E[L1 \cdot R2]$$

RWK

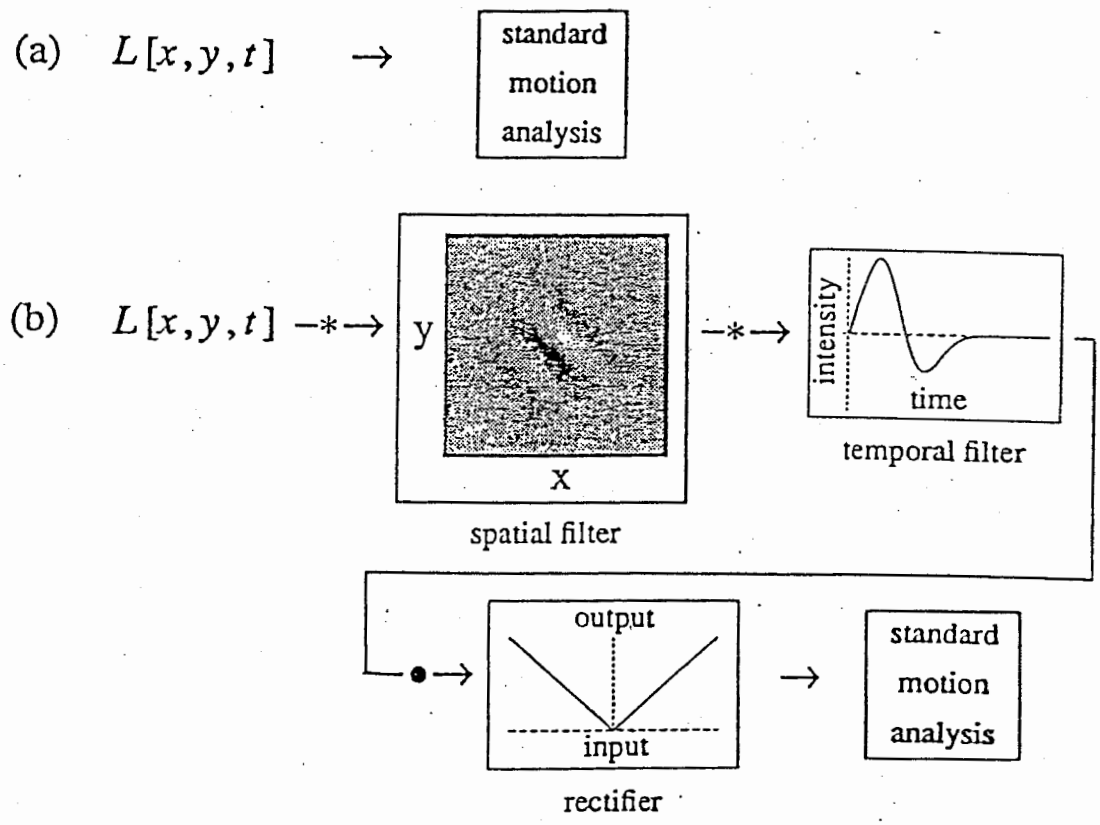


$$E[R1 \cdot L2] = 0$$

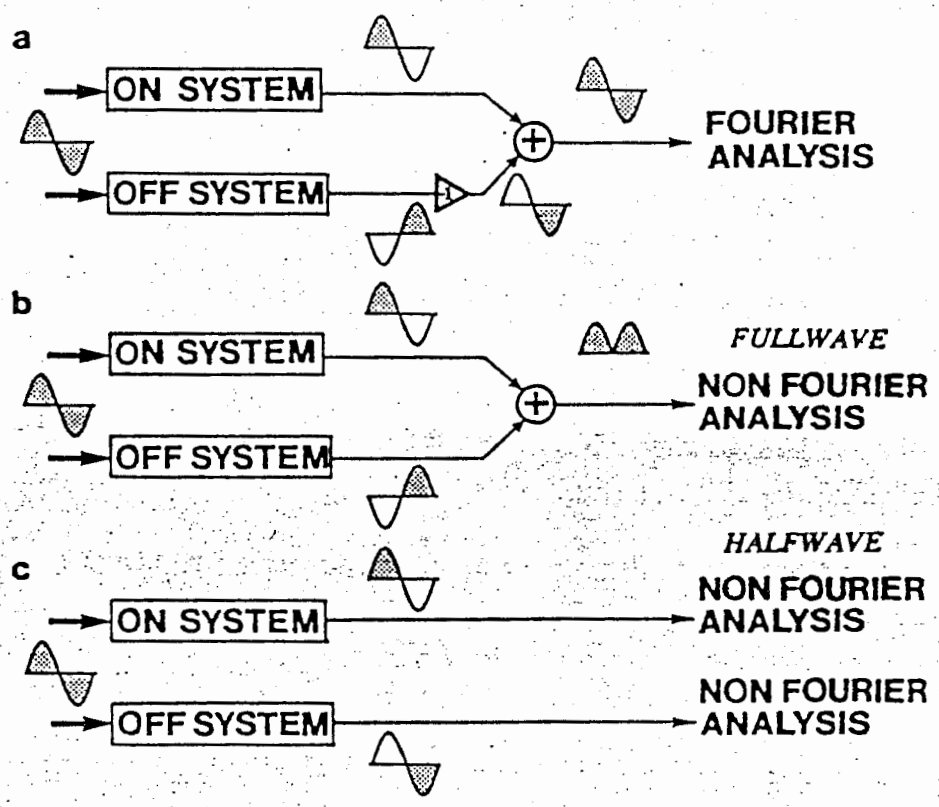
$$E[L1 \cdot R2] = 0$$

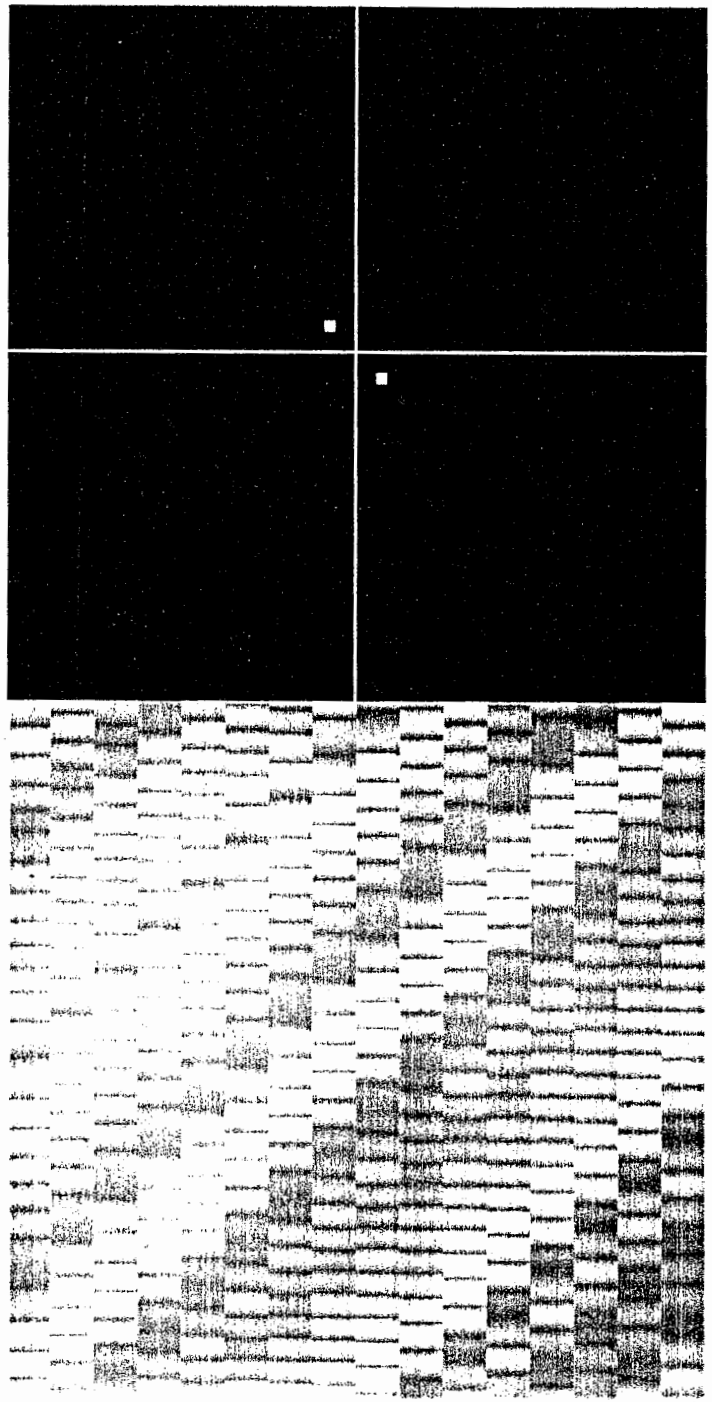
$$\Rightarrow E[R1 \cdot L2] = E[L1 \cdot R2]$$

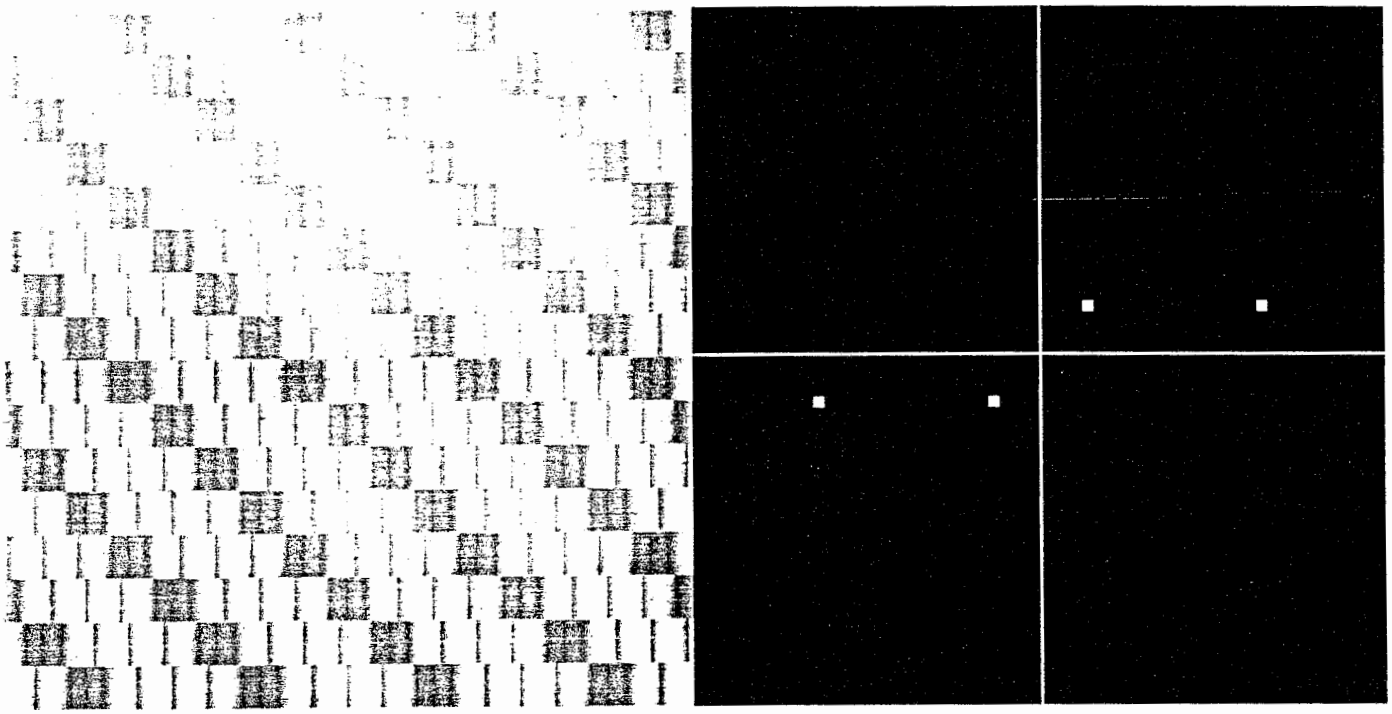
「Chubb, C. & Sperling, G. (1989). Second-order motion perception: Space/time separable mechanisms. *Proceedings of IEEE workshop on visual motion*, 126-138.より引用」



「Sperling, G. (1989). Three stages and two systems of visual processing. *Spatial Vision, 4*, 183-207.より引用」







Spatiotemporal properties of motion perception for random-check contrast modulations

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Perception Research
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Examination of the mechanism which detects the motion of contrast modulations (a kind of second-order mechanism).

(1) Investigate the effects of the stimulus parameters which supposedly tap the detection stage of the motion mechanism.

→ ED, SOA, ISI, displacement

(2) Use microbalanced random stimuli (Chubb & Sperling, 1988), since their motion is invisible to the luminance (first-order) motion mechanism.

(3) Clarify the difference between luminance and contrast motion. In the comparison, the stimulus configurations of the stimuli for both types of motion should be the same.

→ RDK & RWK

Previous studies on contrast motion

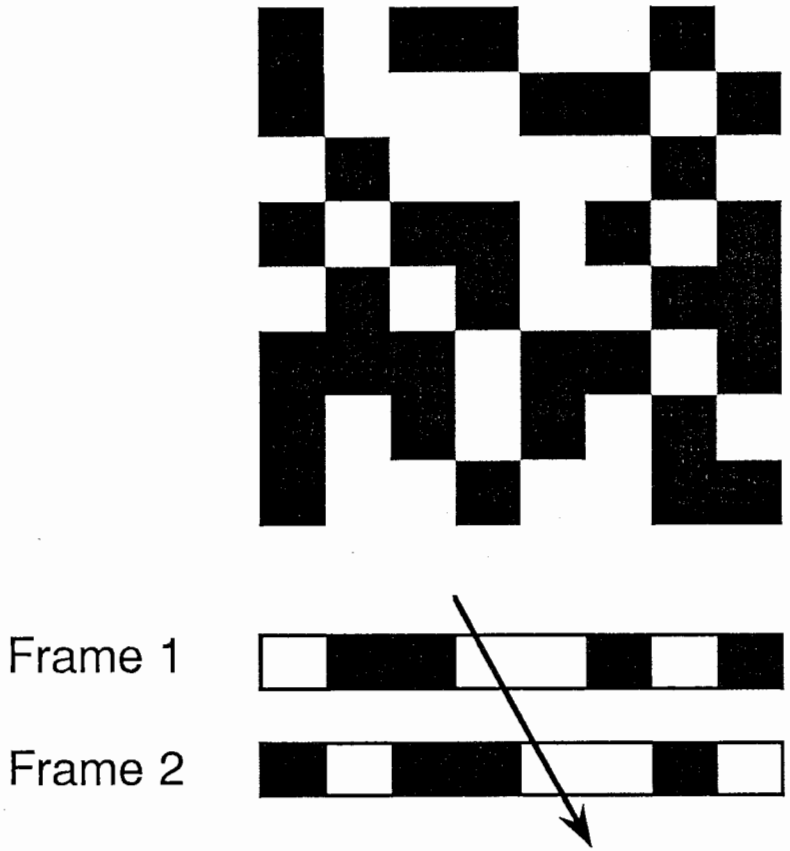
Similarity of luminance and contrast motions

[1] The minimum aperture width of direction perception for a drifting sinusoidal grating (Cavanagh & Mather, 1989).
[2] Contrast and velocity dependencies of velocity discrimination (Turano & Pantle, 1989).
[3] Motion after-effect (Mather, 1991; von Grünau, 1986).
[4] Plaid motion perception (Cavanagh & Mather, 1989).
[5] Motion transparency (Cavanagh & Mather, 1989).
[6] Kinetic depth effect (Prazdny, 1986).

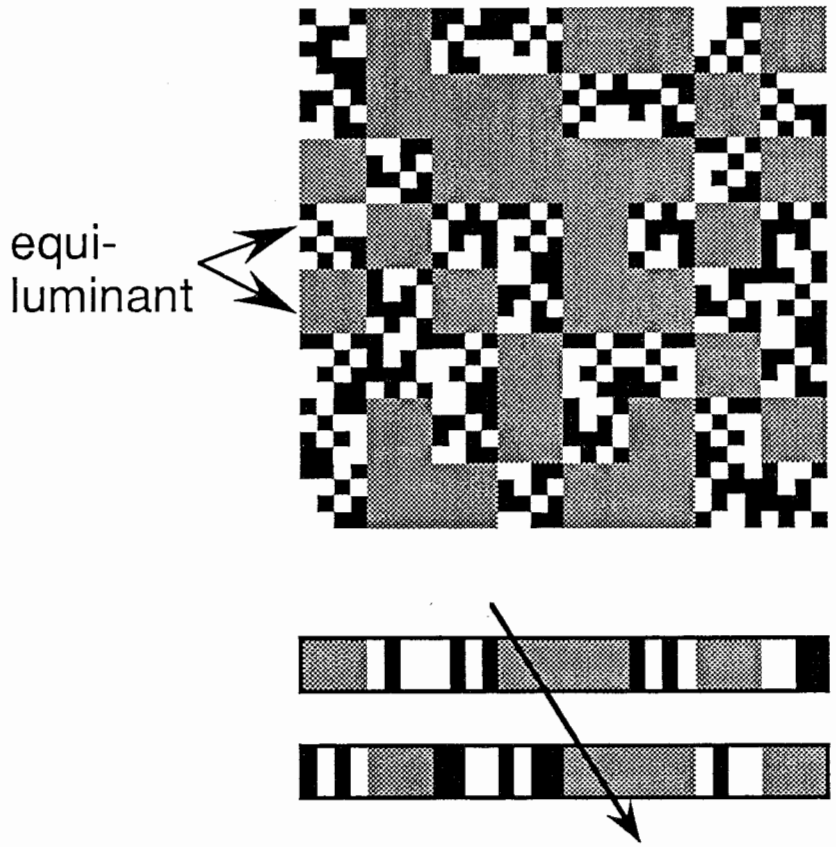
Difference of contrast motion from luminance motion

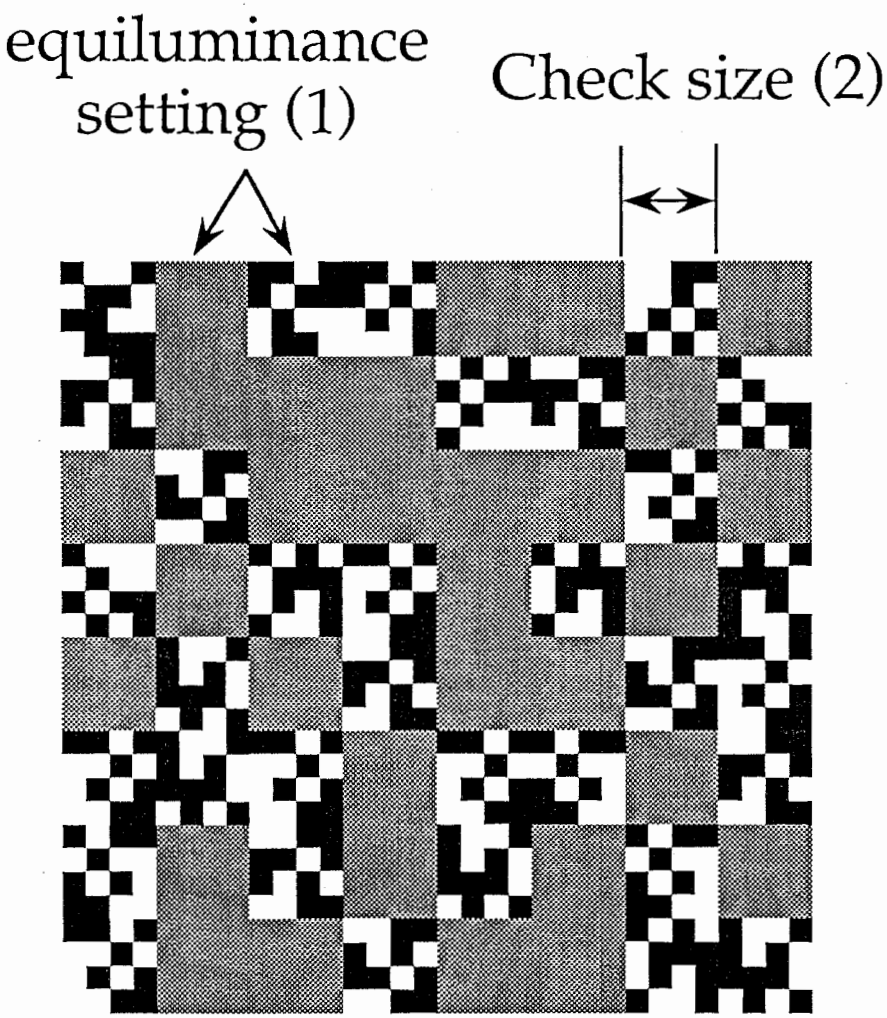
[1] High contrast threshold (Dosher et al., 1989; Sperling, 1989).
[2] Difficulty in perceiving motion for small elements (Cavanagh & Mather, 1989; Landy et al., 1991) .
[3] Difficulty in perceiving motion for peripherally presented stimuli (Dosher et al., 1989; Turano & Pantle, 1989).
[4] Ineffective in inducing motion after-effect (Derrington & Badcock, 1985).
[5] Ineffective for motion segregation (Cavanagh & Mather, 1989).
[6] Ineffective for kinetic depth effect (Dosher et al., 1989; Landy et al., 1991).

RDK
(Random Dot Kinematogram)

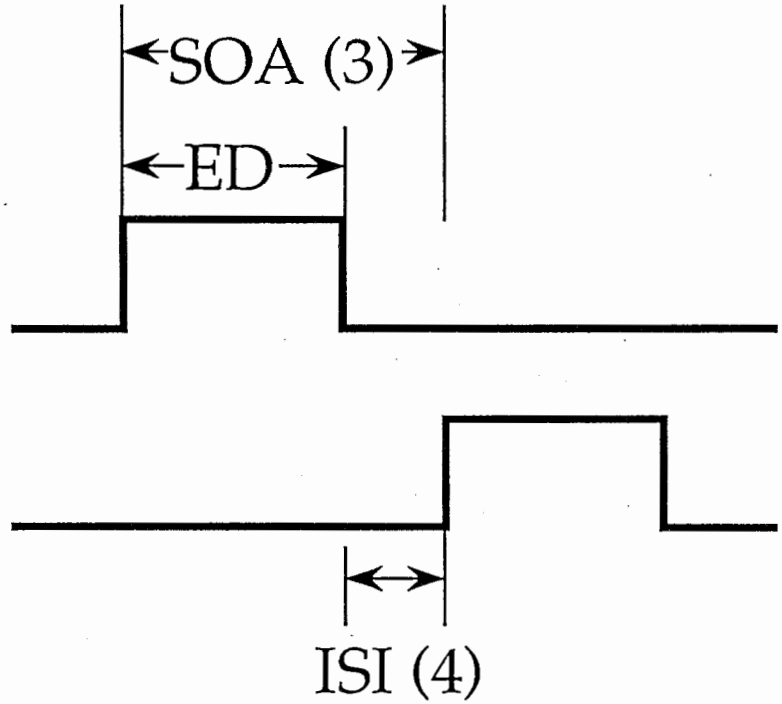


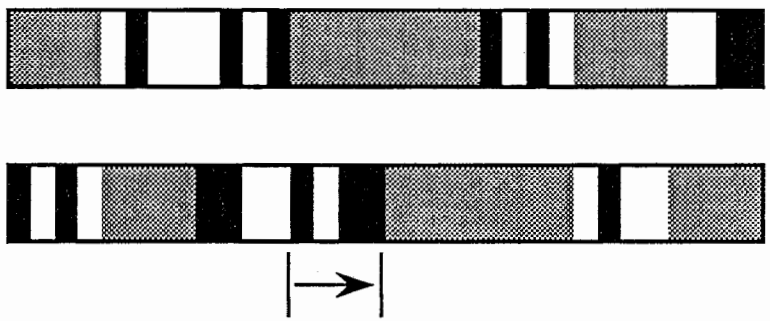
RWK
(Random Window Kinematogram)



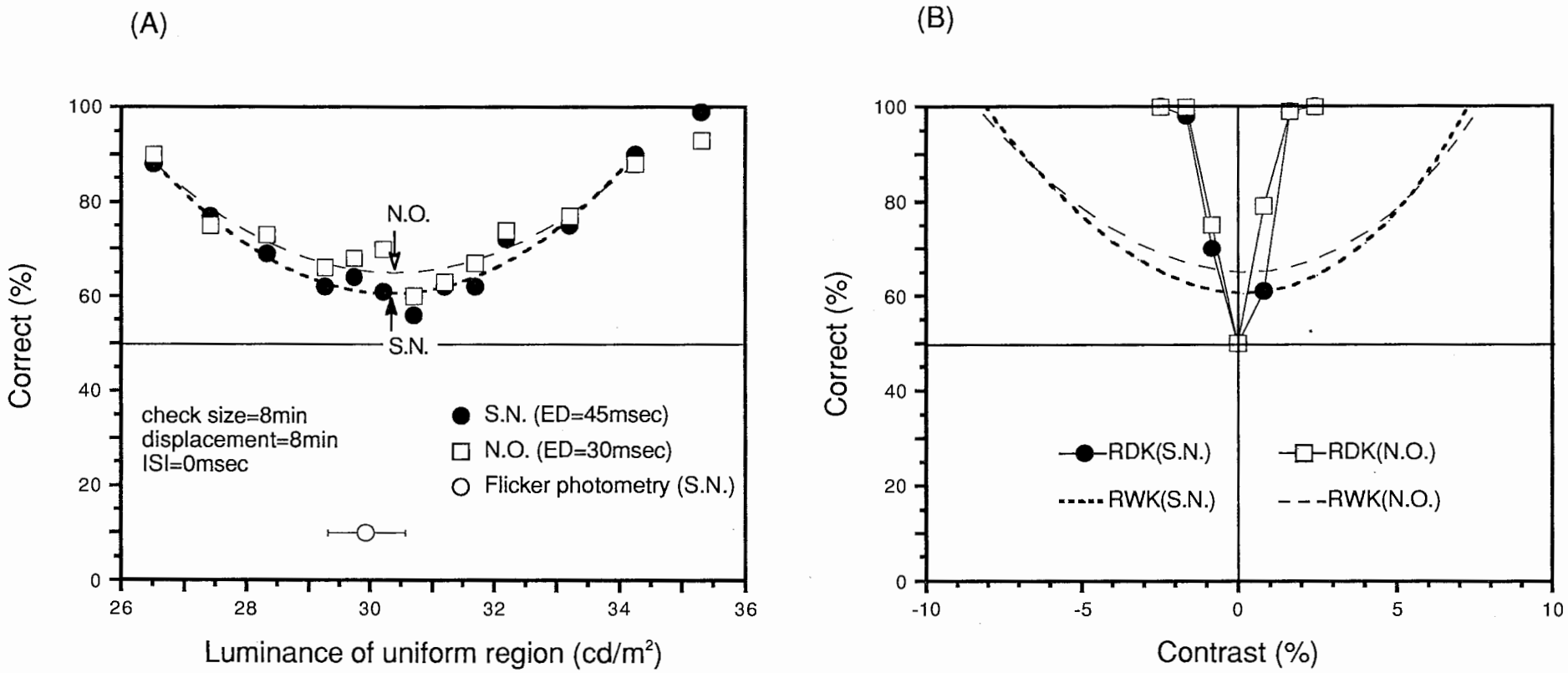


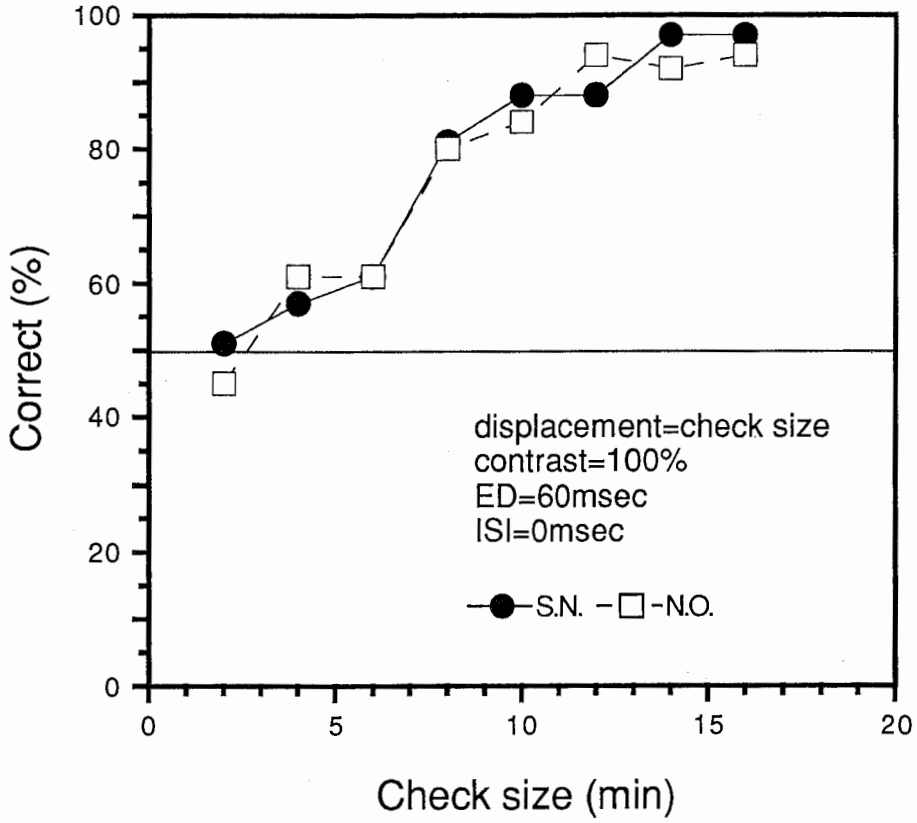
Reversed phi (5)

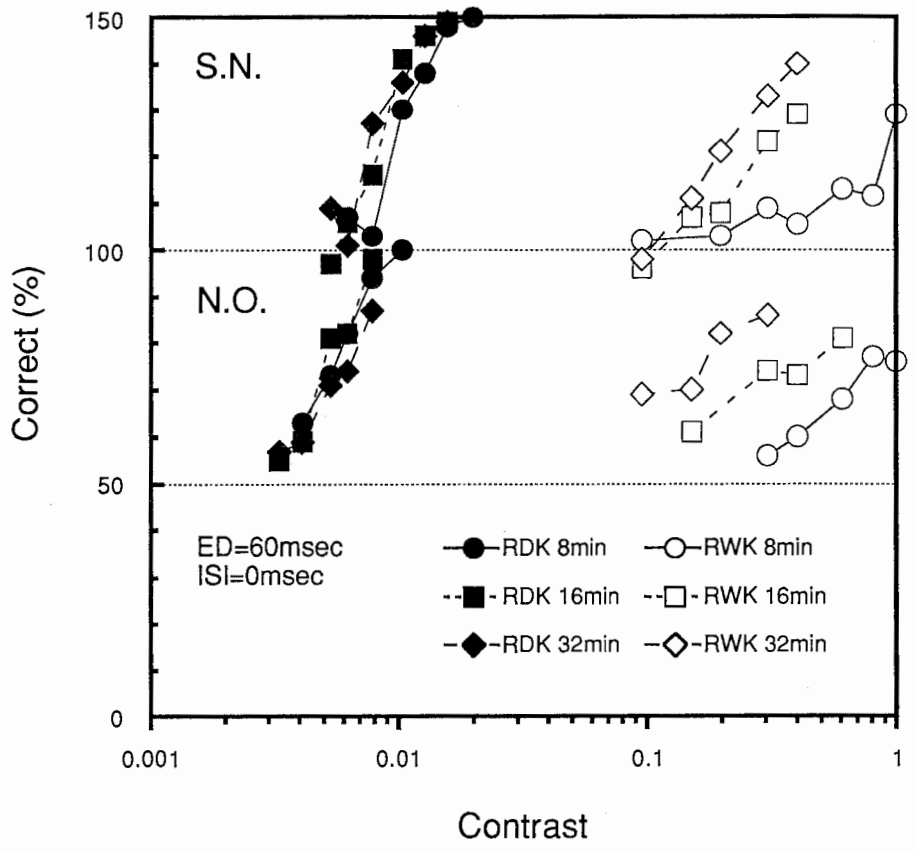


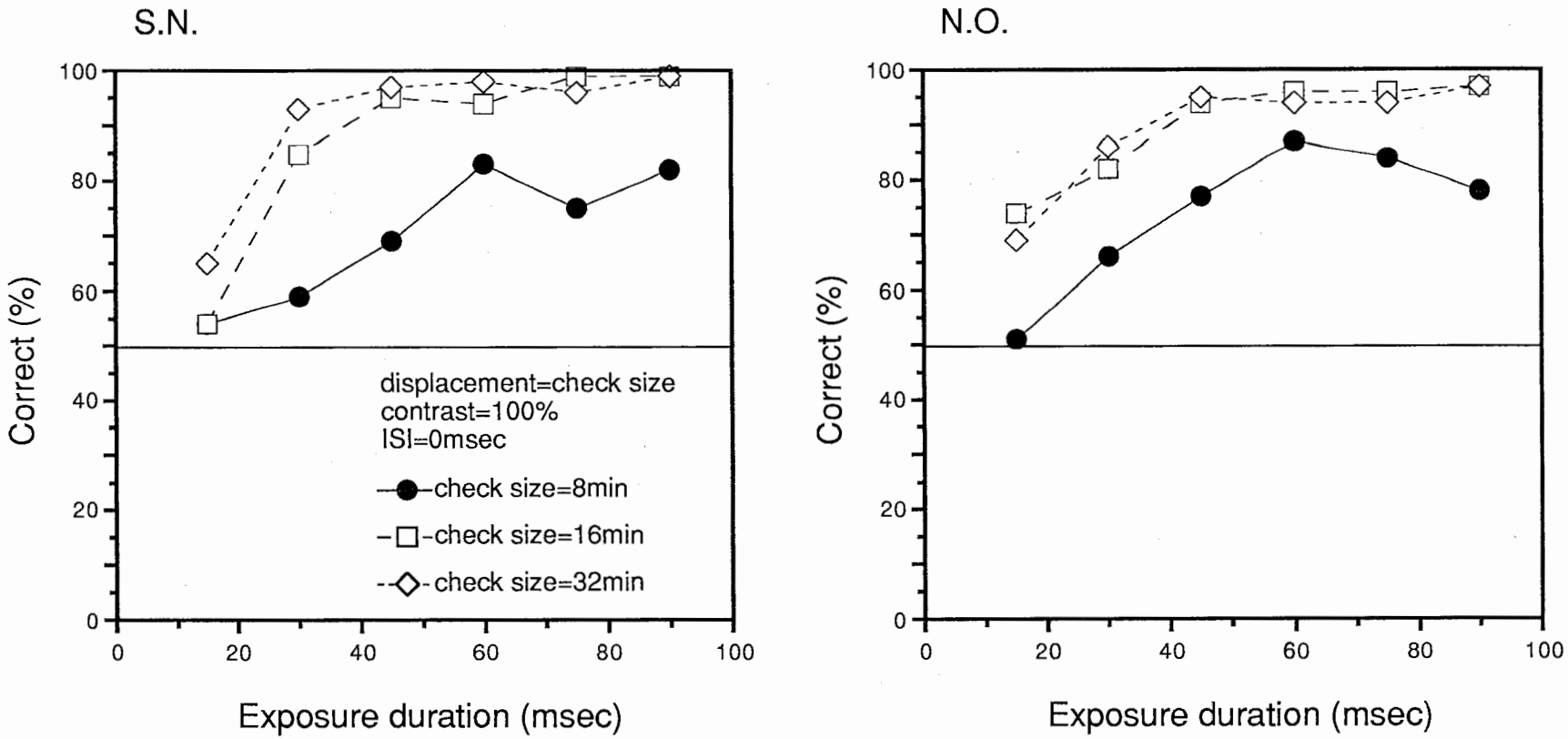


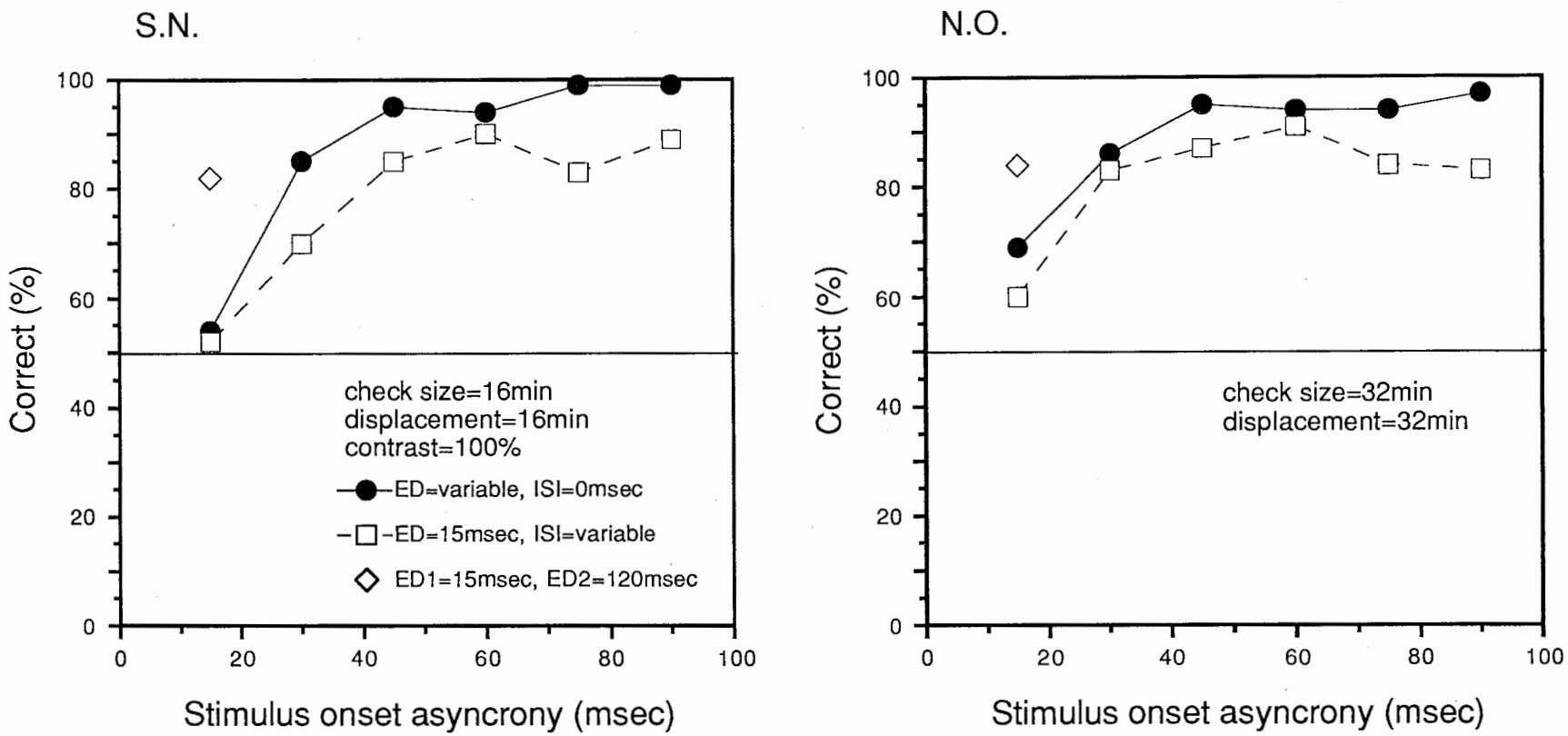
Displacement (6)


(A)
Correct (%)
100
80
60
40
20
0
N.O.
S.N.
check size=8min
displacement=8min
ISI=0msec
S.N. (ED=45msec)
N.O. (ED=30msec)
Flicker photometry (S.N.)
26
28
30
32
34
36
Luminance of uniform region (cd/m²)
(B)
Correct (%)
100
80
60
40
20
0
RDK(S.N.)
RDK(N.O.)
RWK(S.N.)
RWK(N.O.)
-10
-5
0
5
10
Contrast (%)


100
80
60
40
20
0
Correct (%)
0
5
10
15
20
Check size (min)
displacement=check size
contrast=100%
ED=60msec
ISI=0msec
S.N.
N.O.


150
100
50
0
Correct (%)
S.N.
N.O.
ED=60msec
ISI=0msec
RDK 8min
RWK 8min
RDK 16min
RWK 16min
RDK 32min
RWK 32min
0.001
0.01
0.1
1
Contrast


S.N.
N.O.
Correct (%)
Exposure duration (msec)
displacement=check size
contrast=100%
ISI=0msec
check size=8min
check size=16min
check size=32min
0
20
40
60
80
100


S.N.
N.O.
Correct (%)
Stimulus onset asyncrony (msec)
check size=16min
displacement=16min
contrast=100%
ED=variable, ISI=0msec
ED=15msec, ISI=variable
ED1=15msec, ED2=120msec
check size=32min
displacement=32min
0
20
40
60
80
100

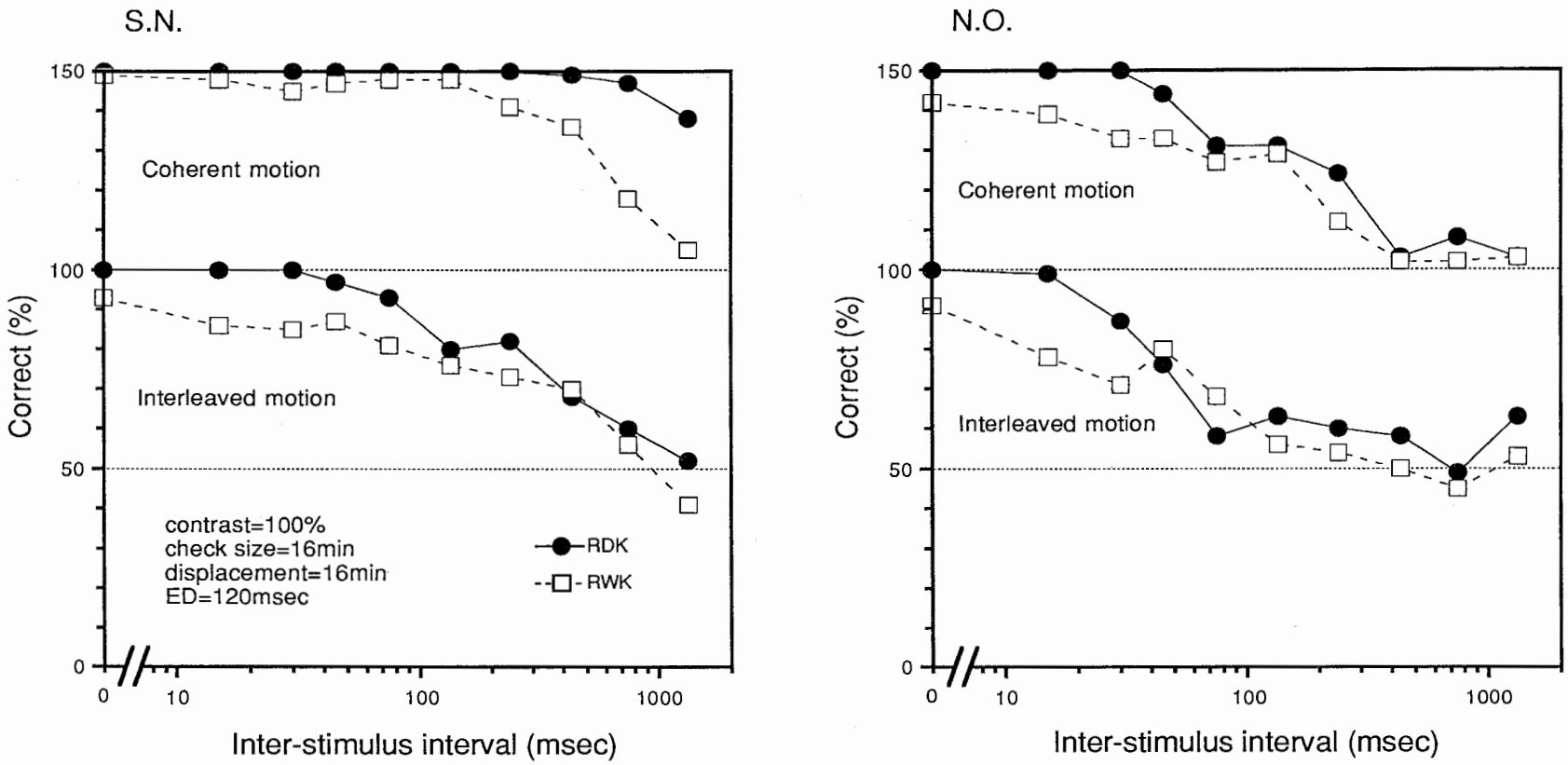
ED and SOA

For short EDs, the performance for RWK increased with increasing ED. The effect of ED could be described as SOA dependency when the EDs of the frames were the same, but the performance was better than predicted from SOA when the first ED was short while the second was long.

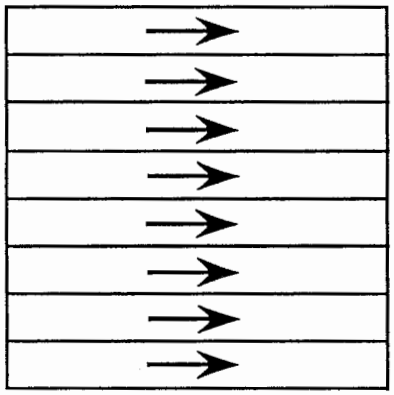
Baker & Braddick (1985) found similar tendencies for RDK, and claimed that these temporal properties are easily understood in terms of a correlation type of motion detection model.

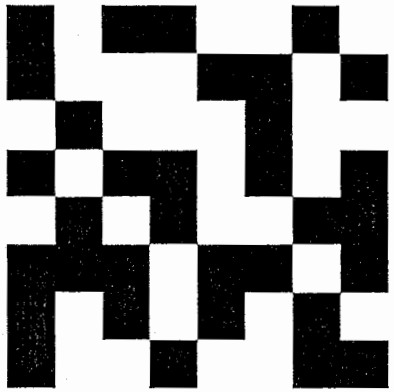
↓

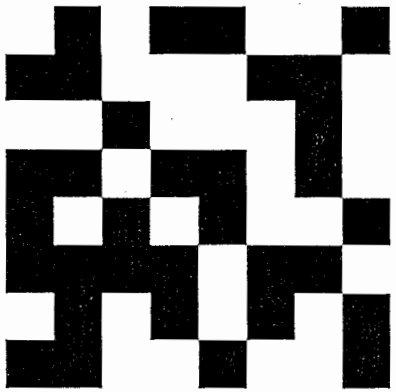
The motion extraction process of the contrast motion mechanism can be modeled as a correlation-type detector.


S.N.
N.O.
Correct (%)
150
100
50
0
Coherent motion
Interleaved motion
contrast=100%
check size=16min
displacement=16min
ED=120msec
RDK
RWK
0
10
100
1000
Inter-stimulus interval (msec)

Coherent motion

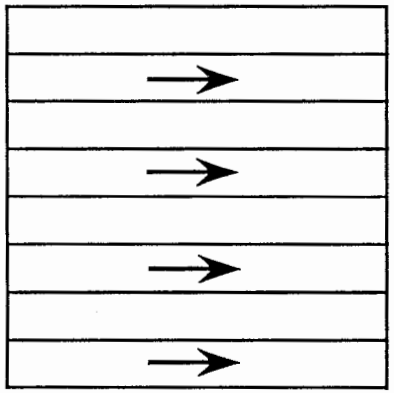


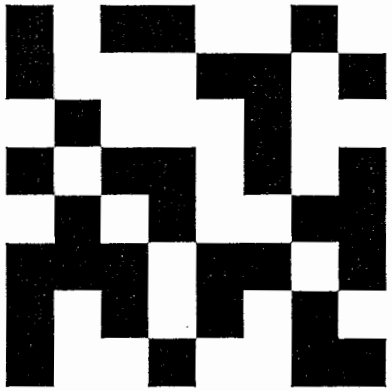


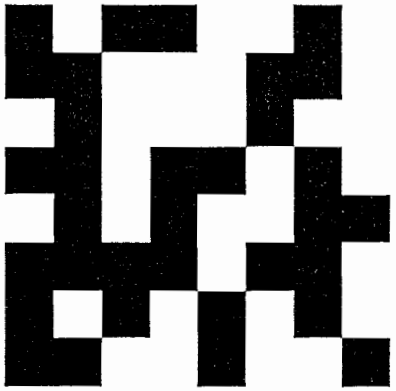


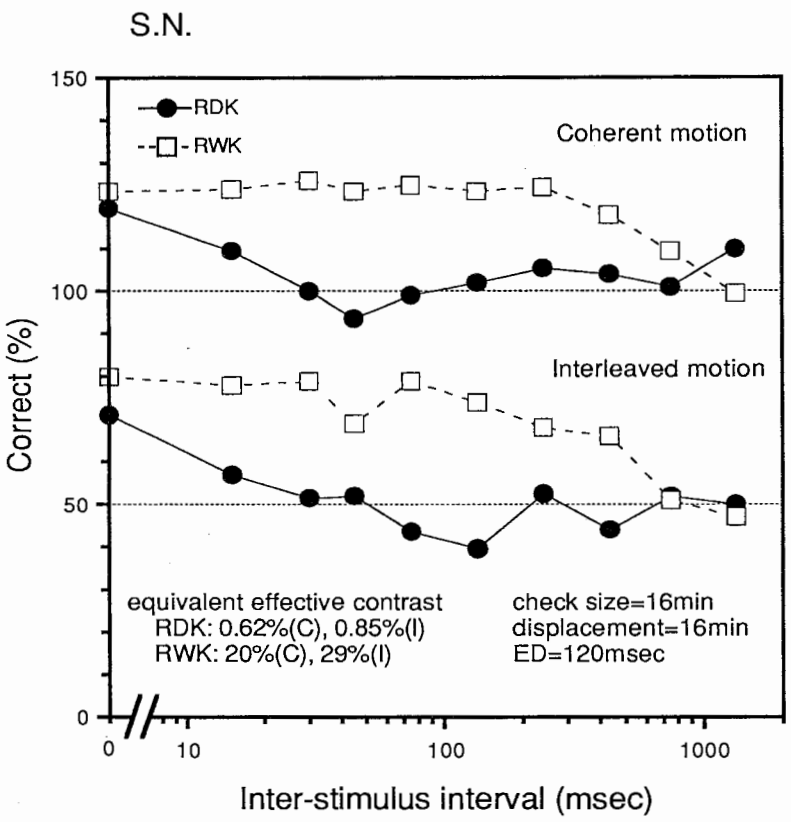
1st frame *2nd frame*

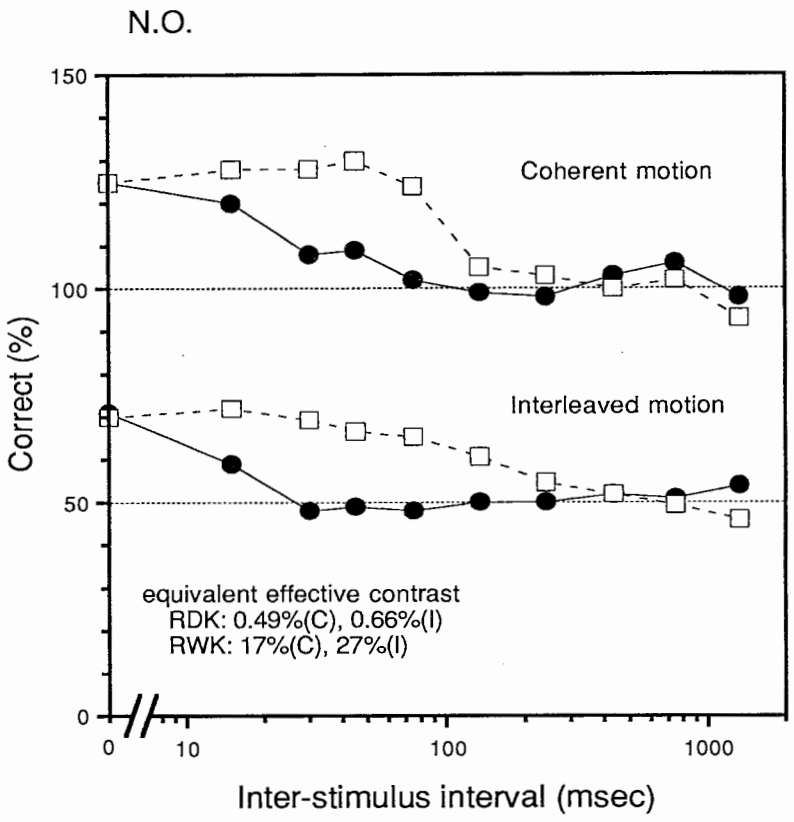
Interleave motion








S.N.
RDK
RWK
Coherent motion
Interleaved motion
Correct (%)
150
100
50
0
equivalent effective contrast
RDK: 0.62%(C), 0.85%(I)
RWK: 20%(C), 29%(I)
check size=16min
displacement=16min
ED=120msec
0
10
100
1000
Inter-stimulus interval (msec)


N.O.
Coherent motion
Interleaved motion
Correct (%)
150
100
50
0
equivalent effective contrast
RDK: 0.49%(C), 0.66%(I)
RWK: 17%(C), 27%(I)
0
10
100
1000
Inter-stimulus interval (msec)

Inter-stimulus interval (ISI)

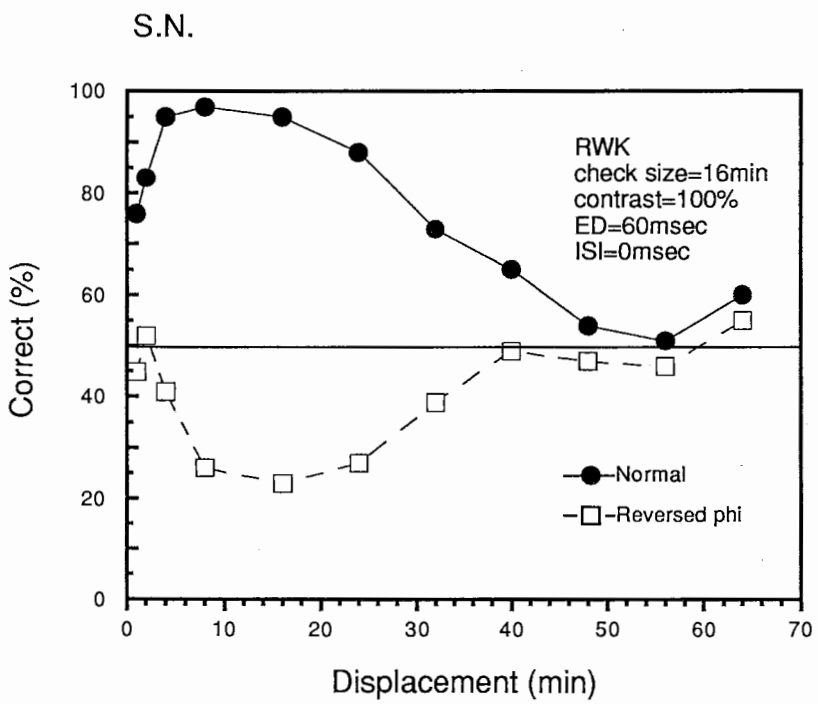
Under equivalent effective contrast, the discrimination performance decreased more gradually with ISI for RWK than for RDK.

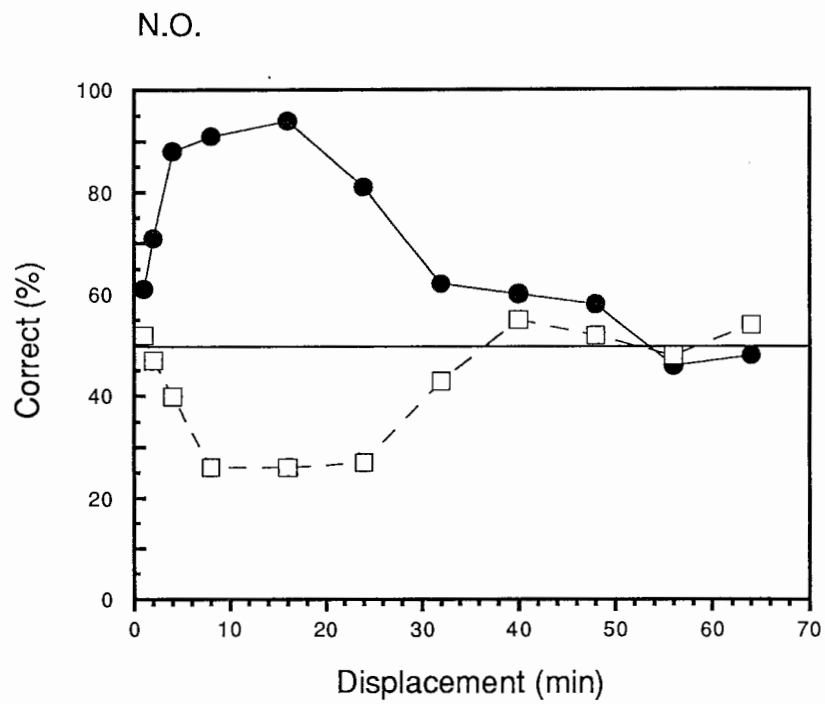
The ISI dependency of direction discrimination for the high contrast RDK was quite similar to the ISI dependency of RWK discrimination.

↓

The contrast motion detector operates over a greater range of ISI than the luminance motion detector.

Direction discrimination for the high contrast RDK may be mediated by contrast motion detectors, at least for large ISIs.


S.N.
RWK
check size=16min
contrast=100%
ED=60msec
ISI=0msec
Normal
Reversed phi
Correct (%)
Displacement (min)
0
20
40
60
80
100
0
10
20
30
40
50
60
70


N.O.
Correct (%)
Displacement (min)
0
20
40
60
80
100
0
10
20
30
40
50
60
70

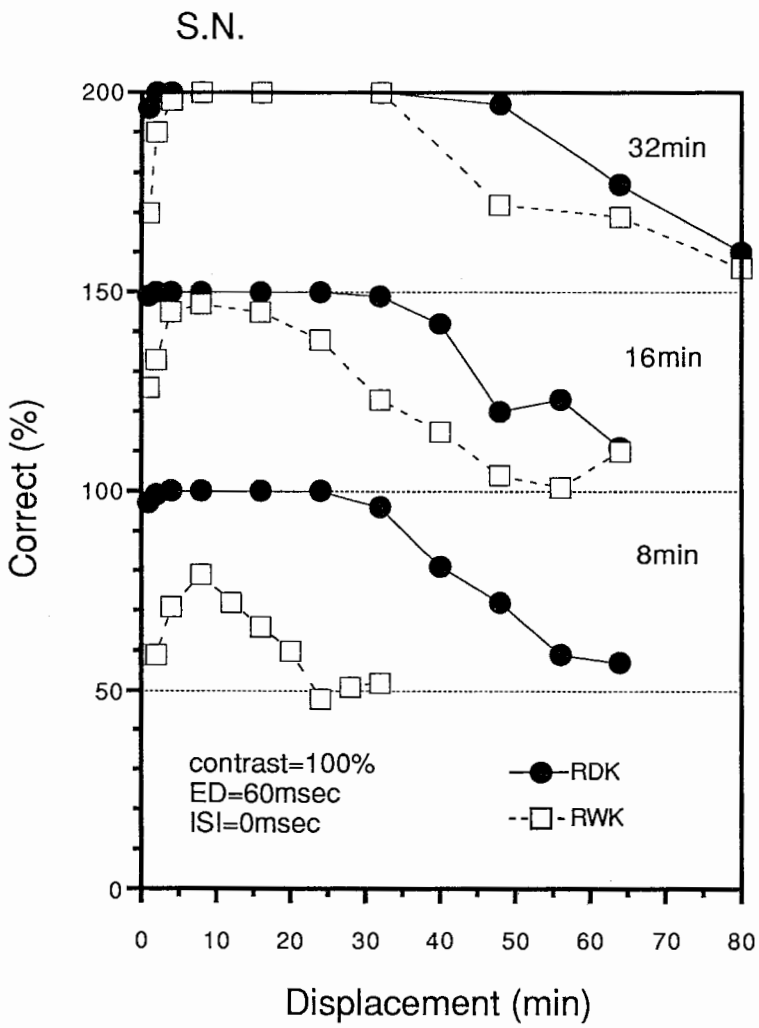
Incoherent motion

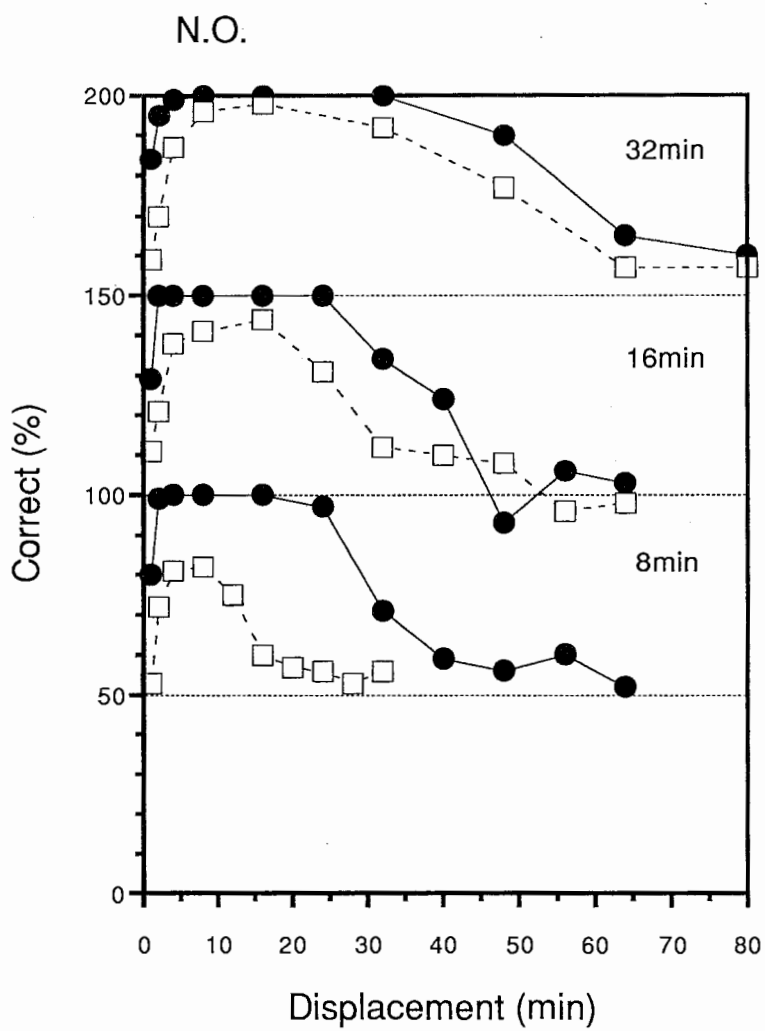
Contrast motion was perceived for stimuli in which the pattern was not shifted coherently between frames
(Interleaved motion & Reversed phi).

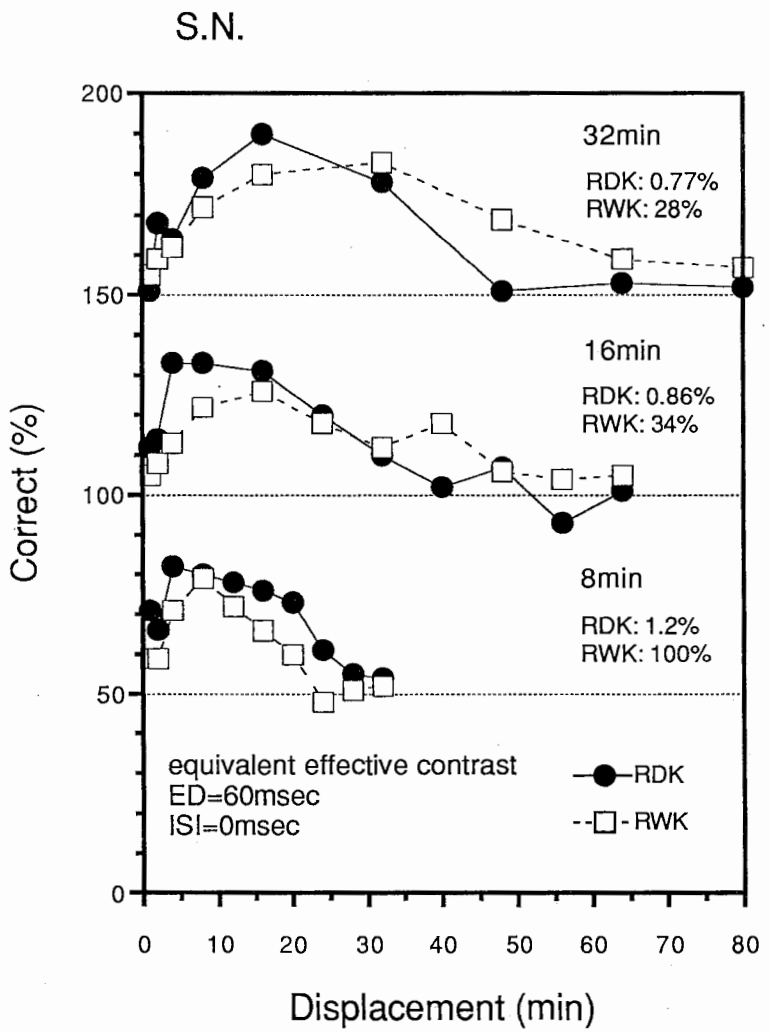
These incoherent motions can be derived from local correlations of contrast value across time and space.

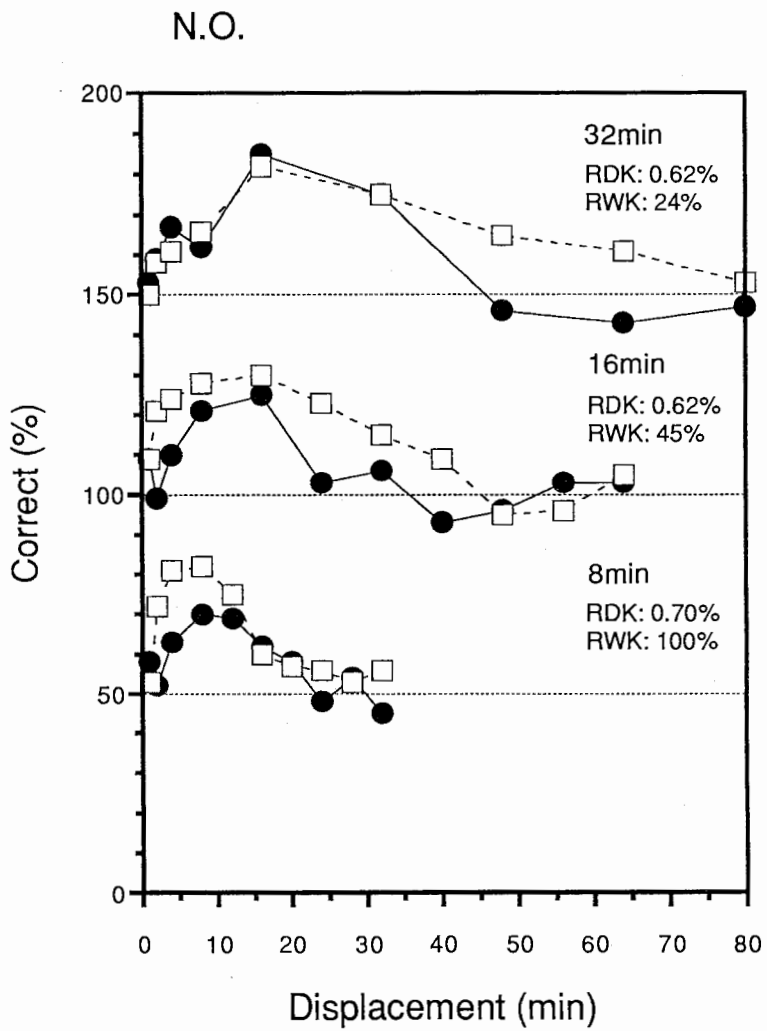
↓

A contrast motion detector operates on a local spatial area, as does a luminance motion detector.


S.N.
Correct (%)
Displacement (min)
32min
16min
8min
contrast=100%
ED=60msec
ISI=0msec
RDK
RWK
0
50
100
150
200
0
10
20
30
40
50
60
70
80


N.O.
Correct (%)
Displacement (min)
32min
16min
8min
0
50
100
150
200
0
10
20
30
40
50
60
70
80


S.N.
32min
RDK: 0.77%
RWK: 28%
16min
RDK: 0.86%
RWK: 34%
8min
RDK: 1.2%
RWK: 100%
equivalent effective contrast
ED=60msec
ISI=0msec
RDK
RWK
Correct (%)
Displacement (min)
0
50
100
150
200
0
10
20
30
40
50
60
70
80

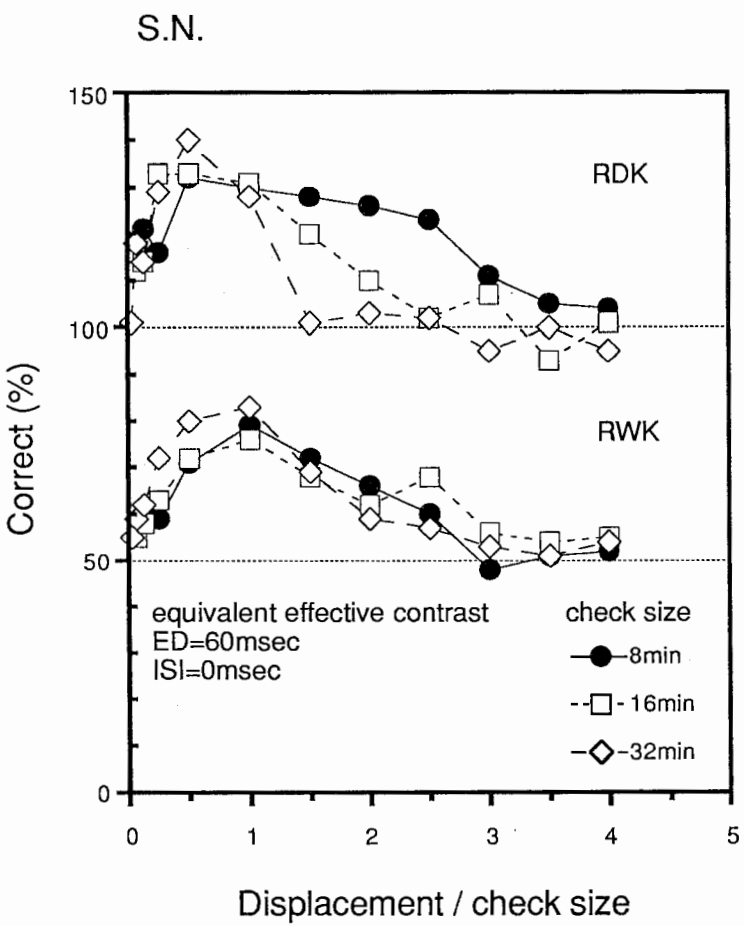

N.O.
32min
RDK: 0.62%
RWK: 24%
16min
RDK: 0.62%
RWK: 45%
8min
RDK: 0.70%
RWK: 100%
Correct (%)
Displacement (min)
0
50
100
150
200
0
10
20
30
40
50
60
70
80

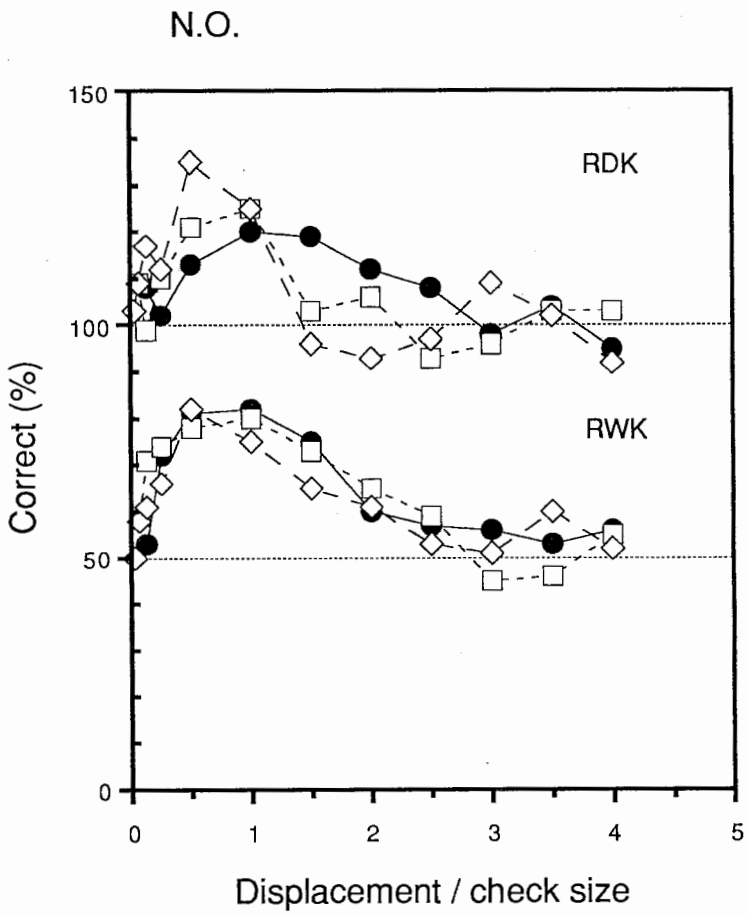
Displacement

When the effective contrast was the same for RDK and RWK, the Dmax values for RDK and RWK were roughly the same.

↓

Contrast motion detectors operate over spatial ranges comparable to those of luminance motion detectors when the spatial configurations and the effective contrasts of the stimuli are the same.


S.N.
150
100
50
0
Correct (%)
RDK
RWK
equivalent effective contrast
ED=60msec
ISI=0msec
check size
8min
16min
32min
0
1
2
3
4
5
Displacement / check size


N.O.
150
100
50
0
Correct (%)
RDK
RWK
0
1
2
3
4
5
Displacement / check size

Displacement - check size interaction

The Dmax for RWK increased in proportion to check size, while the Dmax for RDK did not.

The rectification model of Chubb & Sperling (1988) cannot account for this finding.

If one assumes that the motion in RWK is extracted after representation of edges and/or blobs of contrast modulations, it is not surprising for Dmax to increase in proportion to check size.

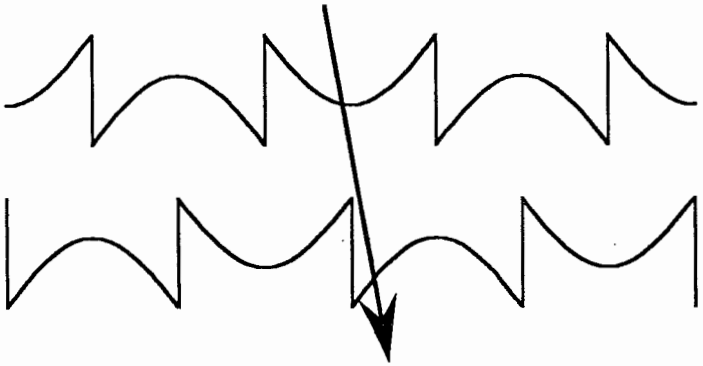
↓

The preprocessing of the contrast motion detector is different from, and probably more complex than, that assumed in the model currently proposed.

Motion perception for missing-fundamental square-wave grating

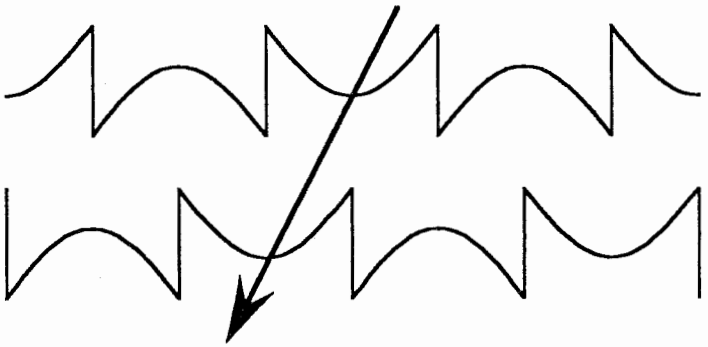
(Georgeson & Shackleton, 1989; Georgeson & Harris, 1990)

ISI < 40 msec



negative motion
→ first-order

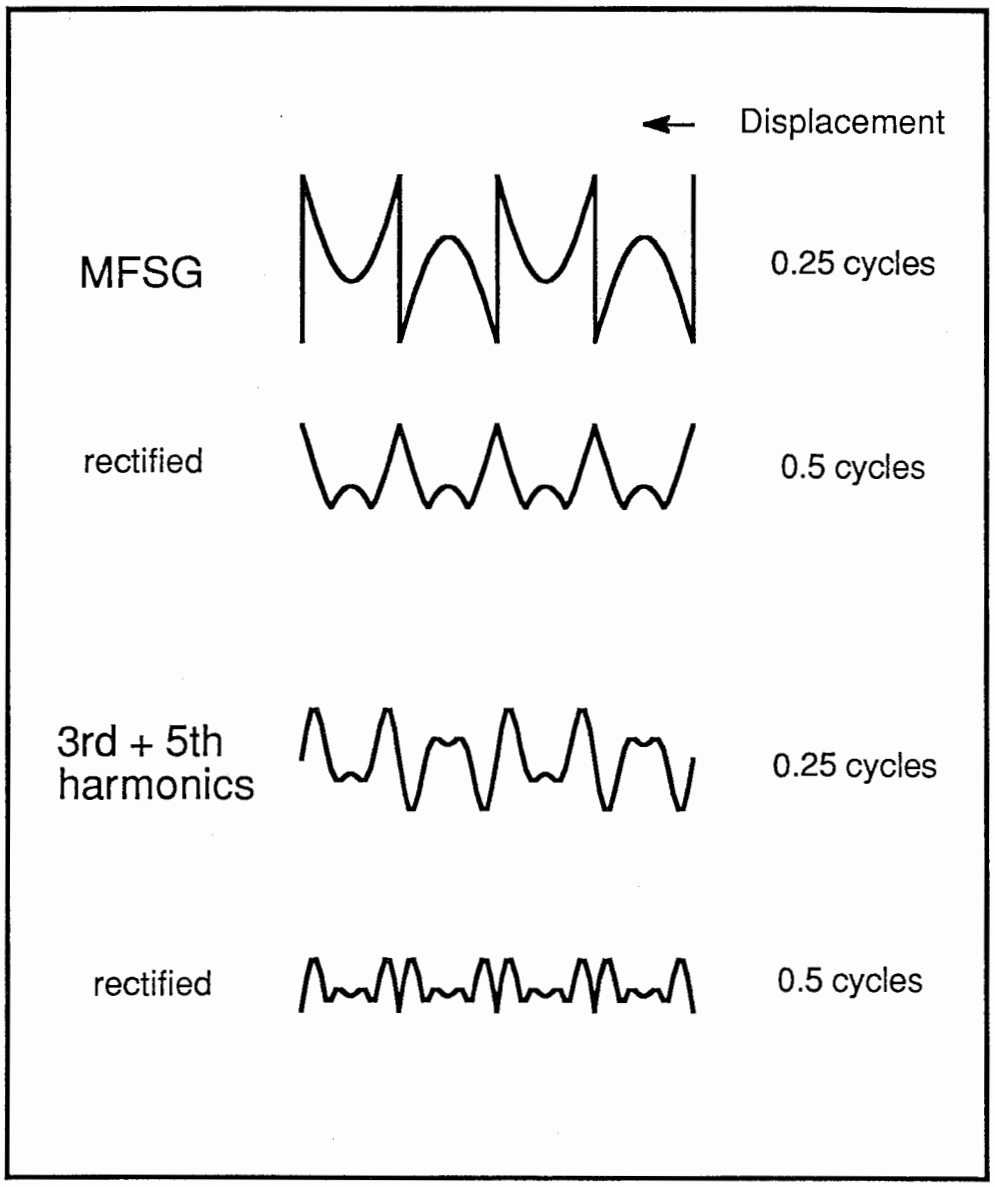
Dichoptic presentation
or ISI > 40 msec



positive motion
→ second-order?

↓

But, unaccountable in terms of the
rectification model (Chubb & Sperling,1988)


Displacement
MFSG
0.25 cycles
rectified
0.5 cycles
3rd + 5th
harmonics
0.25 cycles
rectified
0.5 cycles

Two possibilities

(1) Motion perception for the missing-fundamental square-wave grating is detected by the same mechanism as that of detecting contrast and flicker motions.

↓

The rectification model should be modified.

(2) Motion perception for the missing-fundamental square-wave grating is detected by the third kind of motion mechanism.

↓

Attention-based feature-tracking process (Cavanagh, 1991) ?

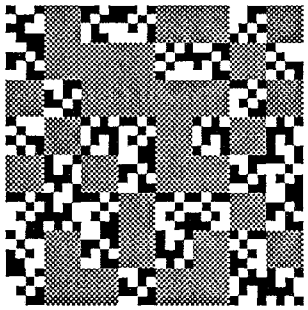
Summary

Like the luminance motion mechanism,
(1) the contrast motion mechanism extracts motion locally. and
(2) its motion extraction stage can be modeled as a correlation-type detector.

These points are consistent with the model currently proposed (Cavanagh & Mather, 1989; Chubb & Sperling, 1988).

(3) The spatial ranges of the contrast motion detectors are comparable to those of the luminance motion detectors, but
(4) their temporal range is larger.
(5) The preprocessing of the contrast motion mechanism before motion extraction is probably more complex than assumed in the model of Chubb & Sperling (1988).

A putative mechanism of contrast motion detection



Spatiotemporal bandpass filtering

↓

Analysis and representation of features in contrast modulations

↓

Motion extraction

Too vague

More complex than rectification

A correlation-type detector with a large temporal constant