Effects of the noise level on induced motion

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Abstract

Motion in a part of the field induces motion in an adjoining region. In this study, it was investigated how the noise level affects induced motion of a counterphase-flickering (target) grating due to adjacent drifting (inducer) gratings. It was shown that at low noise levels, motion contrast occurred, and at high noise levels, motion assimilation occurred. When the noise level was randomly set for each trial, the adaptive change with the noise level was also observed. The result suggests that the adaptive change occurs for a short period. It was also found that noise for the target as well as noise for the inducers contributes to the effect of noise on motion induction. It suggests that the overall noise level is crucial for the effect. The study provided evidence that motion integration changes from a spatially band-pass operation to a low-pass operation as the signal-to-noise ratio (SNR) decreases.

1 Introduction

Motion in a part of the field induces motion in an adjoining region. For example, when a stationary object is surrounded by moving objects, the center object appears to be moving in the direction opposite to the motion direction of the surrounding objects (see Reinhardt-Rutland, 1988 for review). Under some conditions, however, a surrounded object appears to move in the same direction as surrounding objects move. For example, Ohtani, Ido and Ejima (1995) reported that when a surrounding sinusoidal grating is displaced by a 90-deg phase and simultaneously a center grating is displaced by a 180 deg phase (that is, contrast of the center grating is reversed), the center grating appears to move in the same direction as the surrounding gratings move. Also, when surrounding luminance-defined dots move, nearby stationary dots with the same luminance as the background luminance appears to move in the same direction as adjacent dots move (Murakami and Shimojo, 1993; Ramachandran, 1987). The phenomenon is usually called motion capture. Nawrot and Sekuler (1990) reported that motion in one direction induced a similar direction of illusory motion in adjoining dynamic noise. They used cinematograms comprised of alternating strips. Random dots in one strip tended to move in a direction or moved in random directions. The dynamic noise appeared to move in the direction of the adjacent region under some conditions. We will use the term motion assimilation to denote phenomena that a stimulus moving in one direction causes another stimulus to appear to move in the same direction, and will use motion contrast to denote phenomena that a stimulus moving in one direction causes another stimulus to appear to move in the opposite direction.

Why does motion contrast occurs in some conditions and motion assimilation occurs in other conditions. One factor in determining perceived direction for induced motion is the size of stimuli (Nawrot and Sekuler, 1990; Murakami and Shimojo, 1993, 1996). For a small central region surrounded by moving stimuli, motion assimilation tends to occur and for a large center motion contrast tends to occur. For example, Murakami and Shimojo (1993) examined effects of the size of the stimulus on motion assimilation and found that motion assimilation occurs when the stimulus is small. Also, Nawrot and Sekuler (1990) reported that motion assimilation arises when the induced strips are narrow, and motion contrast occurs when they are wide. They proposed that the result may be explained by center-surround antagonistic motion contrast detectors in motion processing, which consist of an excitatory area surrounded by an inhibition area. The center subregion is selective to motion in one direction and the surround subregion is tuned to the opposite direction. When the stimulus size is small, both central stimulus and peripheral one lie in the central excitatory region of the motion detector. Hence the motion unit is excited by peripheral motion, and motion assimilation occurs. On the other hand, when it is moderately large, the induced central stimulus lies in the center excitatory area and the peripheral inducing stimuli lie in the inhibitory region. Hence the motion unit is inhibited by the peripheral motion. Thus, motion contrast occurs. However, Ido, Ohtani and Ejima (1997) reported that motion assimilation occurs for a contrast reversing center grating synchronized with two-frame motion of surrounding gratings, and with the same stimulus configuration motion contrast occurs for a static target and smoothly moving inducing gratings. Also, they reported that both motion contrast and motion assimilation occurs for the same stimulus configuration of random-dot patterns (Ido, Ohtani and Ejima, 2000). The findings are not explained by the center-surround motion contrast detectors.

When an induced luminance grating is stationary, motion contrast usually occurs and motion assimilation does not (e.g. Ido et al., 1997). Motion assimilation often occurs when an induced stimulus is dynamic noise or ambiguous motion like a computer-phase flickering grating (Chang and Julesz, 1984; Nawrot and Sekuler, 1990; Nishida, Edwards and Sato, 1997; Murakami and Shimojo, 1996). Also, motion assimilation tends to occur when inducing motion is jerky and motion contrast occurs when inducing stimuli move smoothly (Ohtani et al., 1995; Ido et al. 1997, 2000). Motion assimilation occurs when induced dots are isoluminant color-defined or when luminance contrast of induced dots is low (Murakami and Shimojo, 1993). Motion signals for isoluminant stimuli in the human visual system may be weak since the human visual system is poor at processing isoluminant moving stimuli. It seems that when noise is large or when signal is weak, motion assimilation tends to arise. On the other hand, motion contrast occurs when noise is small. In this study, we tested the hypothesis that as SNR (signal to noise ratio) is increased, the mode of induced motion changes from motion contrast to motion assimilation by varying SNR of the stimulus directly.

2 Experiment 1

We examined effects of the noise level on induced motion in this experiment. A counterphase flickering grating was used for a central target stimulus since it can elicit both motion contrast and motion assimilation (Nishida et al., 1997).

2.1 Methods

Apparatus. Stimuli were generated by an AT compatible computer using a graphic card (Elsa ERAZOR III Lt) which had a 8 bits resolution for each of the R, G, and B channels, and displayed in a CRT display. The viewing distance was 50 cm. The refreshrate of the display was 75 Hz. The display size was 1024 pixels × 768 pixels, subtending 33 deg × 25 deg. Observers binocularly viewed the display in a dark room with their head supported on a chin rest.

Observers. Three observers participated in this experiment. One was the author (observer 3). The others were naive as to the purpose of the experiment. All the observers had normal or corrected normal acuity.

Stimuli. The stimulus consisted of three rows of vertical gratings as shown in Fig. 1. The top and bottom inducing gratings were identical and moved in the same direction. The central target was a counterphase flickering grating. The counterphase grating is decomposed into two sinusoidal gratings moving in the opposite directions. The directional bias of the target was controlled by changing the contrast of the two components. The luminance profile of the grating at the image point (x, y) and at the time of t was:

$$\text{Ł}(x, y, t) = L_{mean}\,[1 + \lambda\ c\ \sin\{2\pi(fx + \omega t) + \theta\} - (1 - \lambda)\ c\ \sin\{2\pi(fx - \omega t) + \theta\}] \tag{1}$$

where L_{mean} is the mean luminance of the grating (the same as the background luminance), c is the luminance contrast, λ is a parameter for controlling the relative strength of leftward and rightward moving gratings, and f

Figure 1: Insert the figure about here.

and ω are the spatial and temporal frequencies, respectively. 0.5 of λ means the counterphase flickering, values more than 0.5 indicate leftward motion bias and values less than 0.5 indicate rightward motion bias, and λ for the inducers was 0 (rightward motion) or 1.0 (leftward motion). The stimuli were presented for 1.0 sec. The mean luminance of the stimulus was 30 cd/m^2, which was the same as the luminance of the background. The luminance contrast was 0.25. The spatial frequency of the inducers and the target was 0.4 cycle/deg. The temporal frequency of the inducers was 8 Hz and that of the target was 2 Hz. Noise was added to the center and surrounding gratings. The noise for the top and bottom inducing grating was the same, but the noise for the center was independent of the noise for the inducers. The vertically uniform random noise, which was distributed uniformly between $L_{mean} - b$ and $L_{mean} + b$, was generated for a one-cycle grating at each frame. The one-cycle noise was repeated to the stimulus width, and then the noise was added to the gratings. (In fact, the stimuli were moved by palette animation. The noise was added to the palettes for the inducers and target.) Noise magnitude was defined as b/L_{mean}. Four noise magnitudes were used: 0, 0.25, 0.5 and 0.75. Even for a noise magnitude of 0.75, we can easily judge the motion direction of the inducers.

Procedure. The observers were asked to indicate in which direction the target grating presented in the center field appeared to move by pressing an appropriate key button.

Eleven values of λ (0.35, 0.38, $\cdots$, 0.65) were used to obtain psychometric functions. The inducing gratings moved leftward or rightward. Four noise magnitudes were used. Hence there were 88 conditions. The noise levels were varied between sessions, and the other conditions were varied within a session. For each condition 20 trials were conducted. A single session consisted of 440 trials.

2.2 Results and discussion

Fig. 2 shows the percentage of 'left' responses (P_{left}) as a function of λ for an observer. For noise magnitude of 0, there were more 'left' responses for the rightward moving inducers than for the leftward moving ones when $\lambda = 0.5$. On the other hand, for noise magnitude of 0.75, there were more 'right' responses for the rightward moving inducers than for the leftward moving ones when $\lambda = 0.5$. It implies that motion contrast tended to occur in the noiseless case, and motion assimilation tended to occur in the noisy case. The shift of the psychometric curve for the rightward inducers from that for the leftward ones indicates the effect of the inducers' motion on perception of the target's motion.

Figure 2: Insert the figure about here.

We fitted a logistic function to the data for each condition by the Logit analysis, and estimated the values of the two parameters by the most-likelihood method (α and β).

$$P_{left} = \frac{1}{1 + \exp(-\alpha(\lambda - \beta))} \times 100 \quad [\%] \tag{2}$$

where α and β represent the slope and the uncertainty point (the point at which the percentage of the 'left' responses would be 50 [%] according to the fitted curve). We define 'motion induction index' I as

$$I = \beta_{right} - \beta_{left} \tag{3}$$

where β_{left} and β_{right} are the uncertainty points for the inducers moving leftward and rightward, respectively. The motion induction index implies signed shift of the psychometric function for the rightward moving inducers from that for the leftward moving ones. A negative value indicates motion contrast and positive one implies motion assimilation. The motion induction index is plotted as a function of noise magnitude in Fig. 3. The motion induction index changed from a negative value to positive one as the noise magnitude was increased for all the three observers. It implies that motion assimilation tended to occur when noise was large, and motion contrast

Figure 3: Insert the figure about here.

tended to occur when noise was small. The results support the hypothesis that the mode of induced motion changes from motion contrast to motion assimilation as the noise level increases.

3 Experiment 2

In Experiment 1, the noise level was fixed in an experimental session. We could not know whether the adaptive change in motion processing according to the noise level in Experiment 1 was long-term adaptation for a session or short-term adaptation for a single stimulus presentation. To examine whether the adaptation to the noise level occurs for a short period, we varied the noise level in a session.

3.1 Methods

The stimuli and the apparatus were the same as in Experiment 1. The noise magnitude for each trial was set randomly out of the four values used in Experiment 1 to prevent observers from predicting the noise level in advance. Hence all the conditions were varied in a session. Five trials were conducted for each condition in a session. The same observers as in Experiment 1 participated in four sessions. The total number of the trials in each condition was the same as in Experiment 1. The other points of the procedure were

Figure 4: Insert the figure about here.

the same as in Experiment 1.

3.2 Results and discussion

Motion induction indices were calculated as in Experiment 1, and they were shown in Fig. 4. The motion induction index increased as the noise magnitude for all the observers. However, observer 1 and observer 3 showed only positive motion induction indices for all the noise magnitudes. On the other hand, observer 2 showed negative or almost zero motion induction indices for all the noise magnitudes.

Overall tendency that the motion induction changed from motion contrast to motion assimilation was also observed in this experiment. It suggests that adaptation of motion processing to the noise level occurred for a short period (within the presentation time of 1 sec). However, either motion contrast or motion assimilation occurred for an individual in this experiment, while both phenomena occurred for an individual in Experiment 1. The difference suggests that some long-term adaptation to the noise level might also occur.

4 Experiment 3

In Experiments 1 and 2, noise was added to the target as well as the inducers, and we did not know from the results which noise affected motion induction.

Figure 5: Insert the figure about here.

In this experiment, we examined whether noise added either to the target or to the inducers causes the mode change in the motion processing system.

4.1 Methods

The methods were the same as in Experiment 1 except for the regions to which noise was added. The noise was added to either the top and bottom inducing gratings or the target grating. In this experiment, we did not collect data for a condition of noise magnitude 0 since the condition was included in Experiment 1.

4.2 Results and discussion

Motion induction indices obtained in this experiment are shown in Fig. 5. The data for a condition of noise magnitude 0 were those obtained in Experiment 1. The motion induction index increased as a function of noise magnitude even when noise was added to either the inducers or the target, though the increase rate of motion induction index for observer 2 was small. The results imply that the noise levels of both the center and surrounding regions contribute to the mode change of induced motion.

5 General discussion

It was shown that at low noise levels, motion contrast occurs, and at high noise levels, motion assimilation occurs. The result suggests that motion integration in the visual system changes adaptively according to the noise level. It was found in Experiment 2 that when the noise level was varied between trials, the adaptive change was also observed. It implies that the adaptive change occurred for a short period, though some long-term adaptive change seemed to occur. In Experiment 3, it was shown that noise for the target as well as noise for the inducers contributes to the adaptive change. The result suggests that the overall noise level is crucial for the adaptive change for motion processing. The experimental results support the hypothesis that the mode of induced motion changes from motion contrast to motion assimilation as the signal-to-noise ratio (SNR) decreases.

5.1 How does the visual system estimate the noise level?

The visual system must estimate the noise level to adapt to the noise level. How does the visual system estimate the noise level? In a local region, one can consider that the image velocity is approximately constant. It implies that in frequency domain power should concentrate on a plane passing to the origin (the DC point), whose normal is dependent on the image velocity.

Power outside the plane should be regarded as power due to noise. Hence we can estimate noise power if the velocity plane is known. The plane passing to frequency points with large power is easily estimated by a standard linear optimization method. It is suggested that a local frequency analysis (or a Gabor-Wavelet analysis) is conducted in the early stage of the visual processing. From the outputs of the local frequency analysis, the visual system may extract noise and signal power, and may calculate SNR. Note that for the noise estimation a flickering stimulus is considered to be rather noisy because the flickering target is decomposed into rightward moving sinusoidal gratings and leftward moving ones, and rightward or leftward moving components would be categorized into noise. It explains why motion assimilation for a luminance-defined target occurs only when the target is flickering. The static target has little noise, while the flickering target has substantial noise according to the proposed noise estimation. Since motion assimilation tends to occur for low SNR, motion assimilation may occur for a flickering target and motion contrast may occur for a static target.

5.2 Spatial interaction for luminance and motion information

Contrast sensitivity function changes to low-pass to band-pass as the light level increases (e.g., van Ness and Bouman, 1967; De Valois, Morgan and

Snodderly, 1974). The fact suggests that the filtering characteristic in the early visual processing is low-pass when it is dark, and band-pass when it is light. Furthermore it is reported that receptive fields of the ganglion cells in the retina are center-surround antagonistic when it is light, and low-pass when it is dark (Barlow, Fitzhugh and Kuffler, 1957; Enroth-Cugell and Robson, 1966). The adaptive change reflects a general principle of signal processing that for low SNR at a low light level nearby signals should be integrated additively to collect information in a large area, while for high SNR at a high light level difference of nearby signals should be transmitted to reduce redundancy (Atick, 1992; Atick and Reclich 1990; van Hateren, 1993). The general principle can be also denoted by information maximization principles according to SNR. We have shown in this study that the same principle may also be applicable to motion signal processing in the visual system. When the noise level is high (for example, the flickering targets or jerkily moving gratings), or when the signal is low (for example, for isoluminant color motion), the visual system integrates motion signals additively. When SNR is high, the visual system differentiates motion signals. The processing may also be formulated by information maximization for transmission of motion signals.

Figure 6: Insert the figure about here.

5.3 Adaptive filtering to velocities

Phenomena of induced motion suggest post-filtering to velocities estimated by the early motion processing. The results of this study imply that weights of the post-filter are adaptive to SNR estimated by the visual system. The schematic model of velocity filtering is shown in Fig. 6. First the visual system calculates velocities on the image points. Then the SNR is estimated in some ways. Finally the velocities on the image are filtered. The weights of the post-filter are changed by the estimated SNR. Although we focus on the weight change by SNR, the weights may be affected by the light level since the light level affects SNR. Furthermore internal states such as arousal and attention may have some effects on the weight since attention affects motion integration (Hock, Park & Schoner, 2002). Differences in internal states might explain some individual differences in induced motion observed in the experiments. In this study, we have shown qualitative tendency of the change of the weights according to the noise level. Further computational and empirical studies are needed to model quantitative aspects of the adaptive velocity filter.

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Figure captions

- Figure 1. The stimulus consisted of the three fields, each of which subtended 13.0 deg $\times$ 1.3 deg. The three fields were separated by 0.13 deg. The target stimulus in the center field and the inducing stimuli in the upper and lower fields were vertical sinusoidal gratings of 0.4 c/deg. Vertically uniform, and horizontally and temporally random noise was added to the inducers and/or and the target.

- Figure 2. The percentage of the trials in which the target was perceived to move to the left (P_{left}) is plotted as a function of λ (ratio of contrast of a leftward moving component grating to total contrast (contrast of a rightward moving component + that of a leftward moving component)). The upper panel shows the functions for noise magnitude of 0 for an observer. The lower panel shows the functions for noise magnitude of 0.75 for the same observer. Circles and triangles show the data for the leftward and rightward moving inducers, respectively. Curves represent the best-fitted logistic functions.

- Figure 3. The results of Experiment 1. Motion induction indices for three observers are shown. Positive motion induction index indicates motion assimilation, and negative one indicates motion contrast. The error bars represent the $\pm$ standard errors. They were calculated as follows. First, the uncertainly point (β in Eq. (2)) for each condition was calculated by the Logit analysis of SPSS 9.01. Assuming that the estimate was approximately normally distributed, we calculated the standard error for an uncertainty point as the 95% confidence interval of the uncertainty point divided by 3.92. The standard error for motion induction index ($\beta_{right} - \beta_{left}$) was calculated as the root of the sum of the square standard errors for β_{left} and β_{right}.

- Figure 4. The results of Experiment 2. Motion induction indices for three observers are shown. The error bars represent the ± standard errors as calculated in Fig. 3.

- Figure 5. The results of Experiment 3. Motion induction indices for three observers are shown. Different panels show the data for different observers. Noise was added either to the field of the inducers or to that of the target in Experiment 3. Circles show the data for noise to the target, and triangles indicate the data for noise to the inducers. The error bars represent the ± standard errors as calculated in Fig. 3.

- Figure 6. Schematic diagram of motion information processing in the visual system. Initial estimates of velocity fields are filtered. Weights of the filter are adaptive to the estimated noise level.

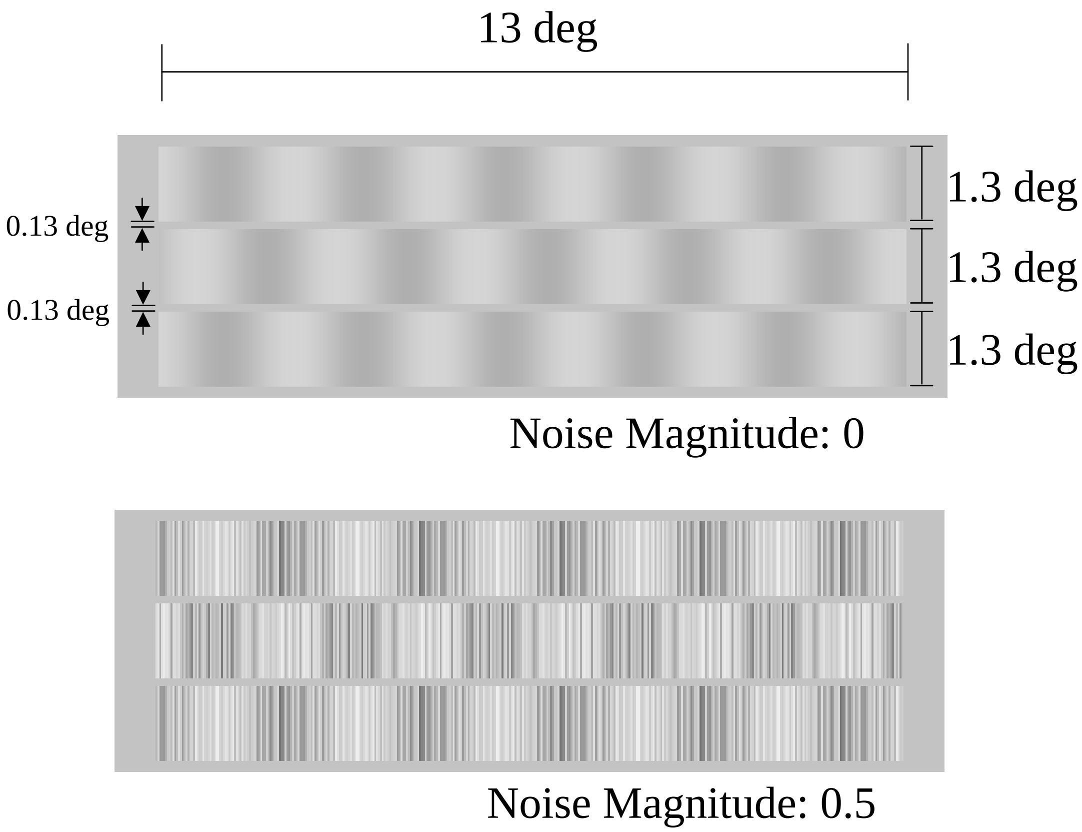

13 deg
0.13 deg
0.13 deg
1.3 deg
1.3 deg
1.3 deg
Noise Magnitude: 0
Noise Magnitude: 0.5

Figure 1

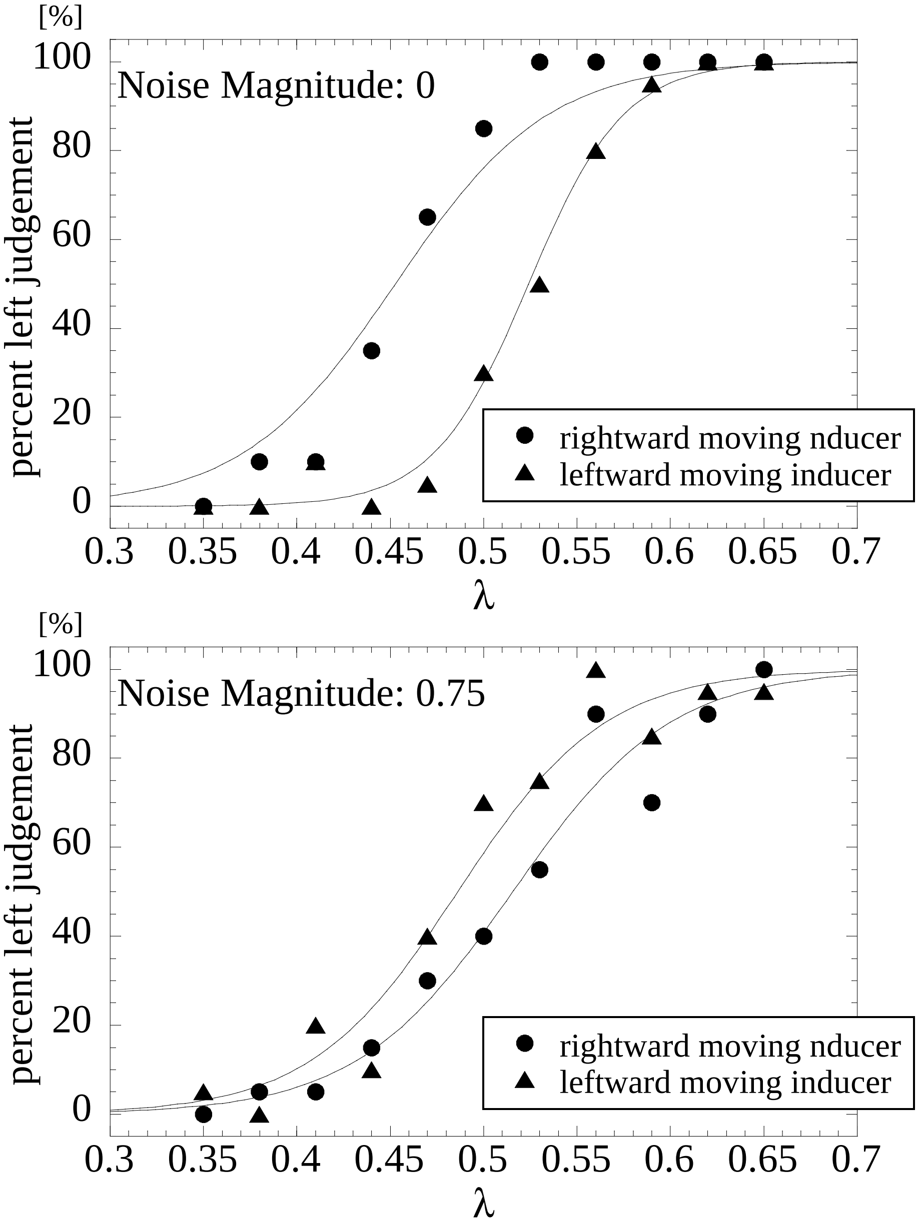

[%]
Noise Magnitude: 0
percent left judgement
rightward moving nducer
leftward moving inducer
λ
[%]
Noise Magnitude: 0.75
percent left judgement
rightward moving nducer
leftward moving inducer
λ

Figure 2

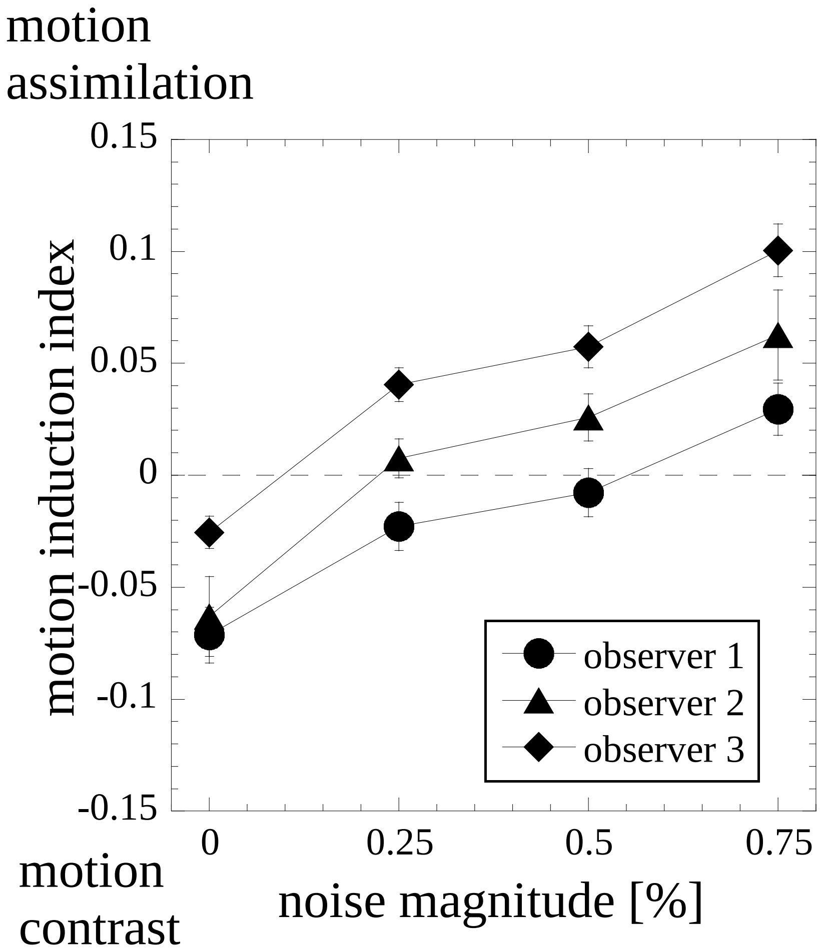

motion
assimilation
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
motion induction index
motion
contrast
0
0.25
0.5
0.75
noise magnitude [%]
observer 1
observer 2
observer 3

Figure 3

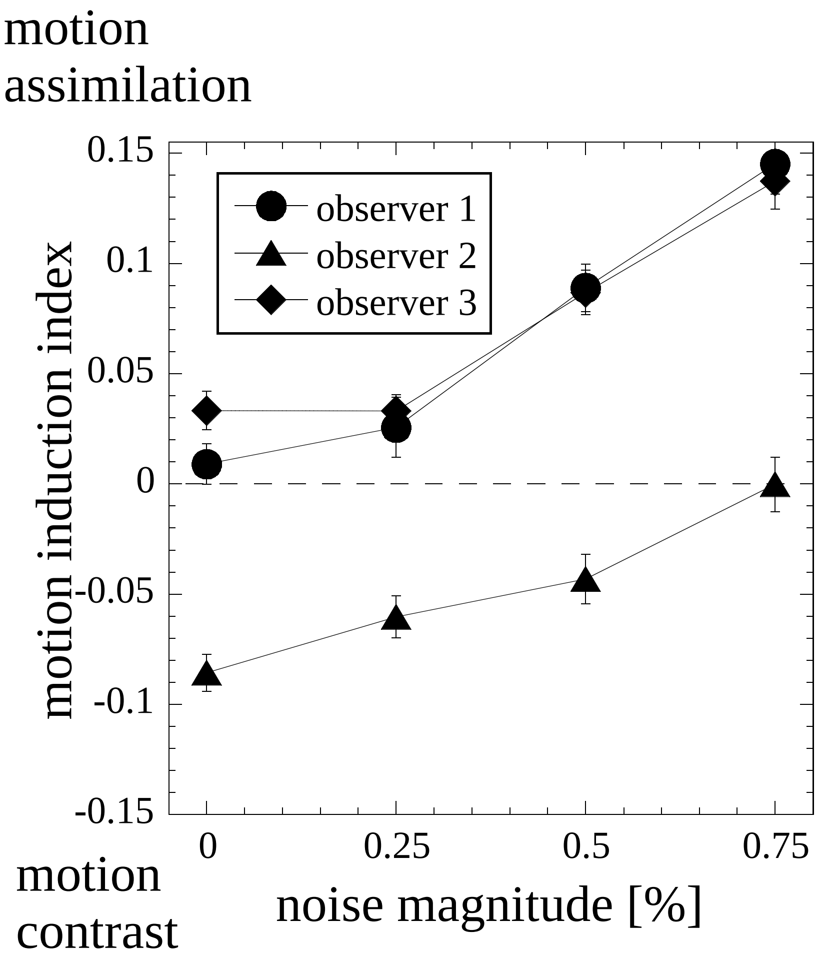
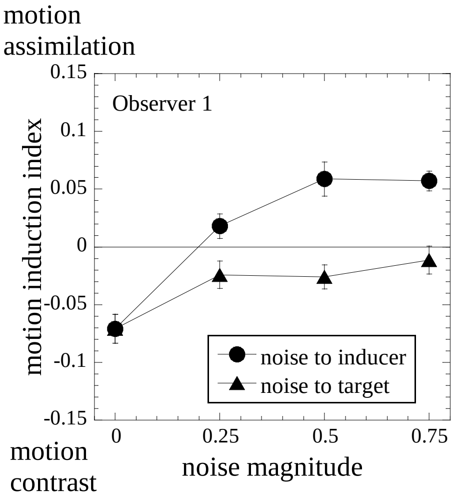
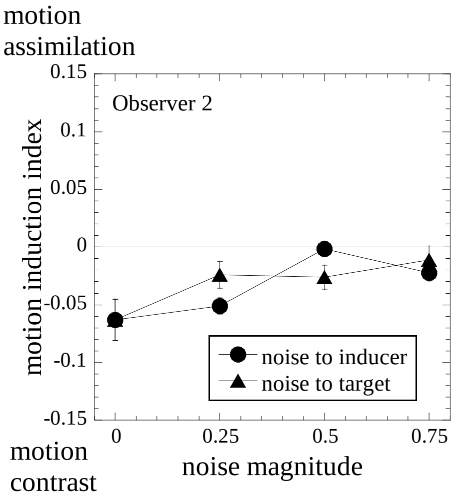

motion
assimilation
motion
contrast
motion induction index
noise magnitude [%]
observer 1
observer 2
observer 3
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
0
0.25
0.5
0.75

Figure 4


motion
assimilation
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Observer 1
motion induction index
noise to inducer
noise to target
0
0.25
0.5
0.75
motion
contrast
noise magnitude


motion
assimilation
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Observer 2
motion induction index
noise to inducer
noise to target
0
0.25
0.5
0.75
motion
contrast
noise magnitude

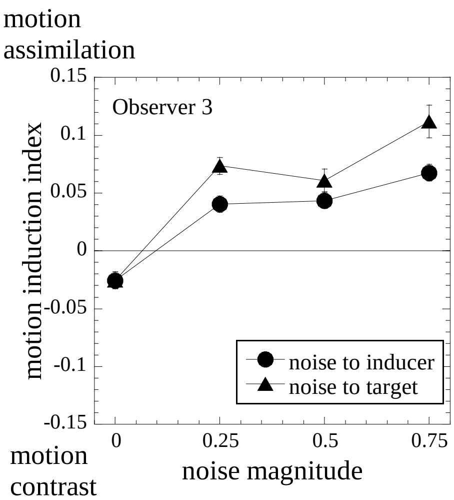

motion
assimilation
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Observer 3
motion induction index
noise to inducer
noise to target
0
0.25
0.5
0.75
motion
contrast
noise magnitude

Figure 5

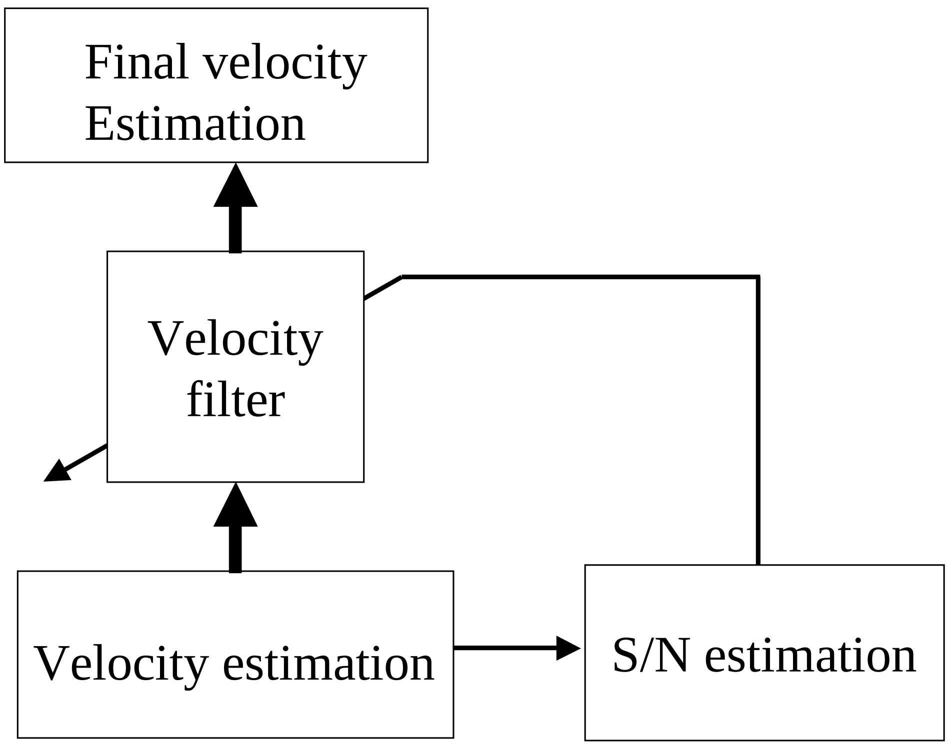

Final velocity
Estimation
Velocity
filter
Velocity estimation
S/N estimation

Figure 6