

# Crowding of biological motion stimuli

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**It is difficult to identify a target in the peripheral visual field when it is flanked by distractors. In the present study, we investigated this “crowding” effect for biological motion stimuli. Three walking biological motion stimuli were presented horizontally in the periphery with various distances between them, and observers reported the walking direction of the central figure. When the inter-walker distance was small, discriminating the direction became difficult. Moreover, the reported direction for the central target was not simply noisier, but reflected a degree of pooling of the three directions from the target and two flankers. However, when the two flanking distractors were scrambled walking biological motion stimuli, crowding was not seen. This result suggests that the crowding of biological motion stimuli occurs at a high-level of motion perception.**

## Introduction

Identification of closely spaced objects is more difficult than for isolated objects, especially in the periphery. This impairment is known as crowding (Bouma, 1970; Flom, Weymouth, & Kahneman, 1963), and the effect increases greatly the further the objects are in the peripheral visual field (Toet & Levi, 1992) and also increases when objects have high similarities (Kooi, Toet, Tripathy, & Levi, 1994). Crowding impairs a wide variety of tasks, ranging from the identification of low-level features like orientation (Andriessen & Bouma, 1976; Westheimer, Shimamura, & McKee, 1976), vernier acuity (Levi, Klein, & Aitsebaomo, 1985; Westheimer & Hauske, 1975), color (van den Berg, Roerdink, & Cornelissen, 2007), stereo acuity (Butler & Westheimer, 1978), and motion (Aghdaee, 2005; Harp, Bressler, & Whitney, 2007;

Rajimehr, Vaziri-Pashkam, Afraz, & Esteky, 2004; Whitney & Bressler, 2007), to mid-level recognition of letters (Bouma, 1970; Flom et al., 1963; Toet & Levi, 1992) and faces (Louie, Bressler, & Whitney, 2007; Martelli, Majaj, & Pelli, 2005), to high-level properties like emotions (Kouider, Berthet, & Faivre, 2011). Crowding has been attributed to the integration of features over an inappropriately wide area (Parkes, Lund, Angelucci, Solomon, & Morgan, 2001; Toet & Levi, 1992), which is set either preattentively (Pelli, Palomares, & Majaj, 2004) or by the selection region of attention (He, Cavanagh, & Intriligator, 1996; Intriligator & Cavanagh, 2001). When two or more items are within the integration area, their features are combined or exchanged, resulting in degraded performance (He et al., 1996; Nandy & Tjan, 2007; Pelli et al., 2004). Previous articles have shown this crowding effect for motion properties, for example, discriminating direction of apparent motion (Rajimehr et al., 2004), rotational direction (Aghdaee, 2005), and direction of second-order motion (Whitney & Bressler, 2007). It is not clear from these studies at which level the motion properties are degraded by crowding.

To examine this circumstance, we studied crowding with biological motion stimuli. Biological motion involves limited human motion cues, for example the displacement of the joints, without static form cues (Johansson, 1973). Despite the absence of recognizable form, observers can see what the actor is doing. Our first aim was to determine if crowding occurs for biological motion stimuli.

Our second aim was to examine whether crowding of biological motion stimuli, if it occurred, showed pooling of values over the target and the flankers. Such pooling is seen for voluntary averaging over widely spaced biological motion stimuli in the displays showing several biological motion stimuli walking in

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different directions simultaneously (Sweeny, Haroz, & Whitney, 2011). Several studies have suggested that crowding itself is an involuntary, compulsory averaging of target and flanker features (Greenwood, Bex, & Dakin, 2009; Parkes et al., 2001). We constructed our stimuli to have a graded response (direction of motion) that would allow us to examine whether crowding in biological motion perception showed averaging.

To examine whether crowding resulted from interactions of low-level or high-level motion signals, we replaced the biological walkers that were our two flankers with scrambled walkers. These scrambled walkers had similar low-level motion profiles but differed, of course, in their high-level motion interpretation.

Finally, we examined the effect of the relative phase of the walking cycle of the target and flankers. In our first experiment, the flankers and target were all walking in synchrony, although in different directions. In the second experiment, the flankers and target had random phase in their walking cycles relative to each other. The same synchronous or random phase relations were used for the scrambled control walkers in the two experiments.

## Experiment 1

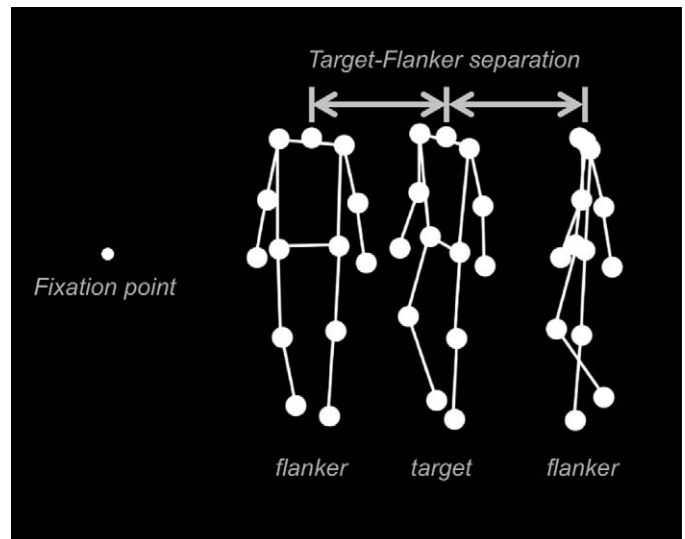
### Methods

#### Observers

Four adults participated in this experiment (three female, one male). One observer was an author. All had normal or corrected-to-normal vision and were given informed consent. The experiments were carried out according to ethical standards specified in the Declaration of Helsinki.

#### Stimulus

A biological motion stimulus was composed of 13 moving white dots on a black background (Figure 1). The 13 dots showed the 13 main joint positions (neck, shoulders, elbows, wrists, waist, knees, and ankles). Head position was not included to avoid posture cues for direction. The motion performed was walking. Ten actors' walks, stimuli in Ma, Paterson, and Pollick (2006) created from motion capture data of nonprofessional actors walking, were used in this experiment. There were five walking directions (left 90°, left 40°, face front, right 40°, or right 90°). Stimulus size, top to bottom, was 4° of visual angle. The three walking figures were presented horizontally to the right of fixation with the target stimulus in the

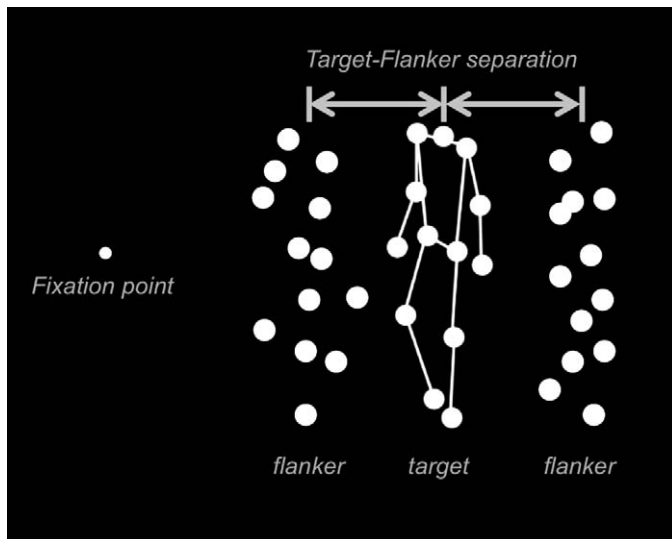


**Figure 1.** Sample stimulus when target and both flankers are all biological motion stimuli. The lines connecting the dots were not present in the experiment display. Head position was excluded to avoid static posture cues to direction.

middle. Target eccentricity was fixed 5° of visual angle throughout the experiment. In a preliminary experiment, the accuracy to discriminate the target's walking direction was higher than 80% (chance is 20%) when a target was presented alone at this eccentricity.

There were two conditions that differed in the type of flanker stimuli. In the first condition, the two flankers were walking biological motion stimuli like the target (the Walking Flankers condition) with walking directions randomly chosen for each from among the five directions with the constraint that each participant saw all 125 combinations of directions of the three stimuli. Flankers were presented at five different distances (2°, 2.5°, 3°, 3.5°, or 4°) from the target, chosen randomly on each block, having equal frequencies across the session.

The second condition was identical to the first with the exception that the biological motion of the flankers was scrambled (Figure 2: the Scrambled Flankers condition). This was done by rotating the biological motion figure to one of 5 “walking” directions and randomizing the starting positions of each of the 13 dot trajectories. Each dot followed the same physical trajectory as in the original walking version, but they all had different phases. These scrambled flankers were presented again at five different spacings (2°, 2.5°, 3°, 3.5°, or 4°) from the target. Observers reported that the scrambled figures were not seen as human movement. However, it should be noted that the local motion cues were identical for the normal and scrambled sequences.



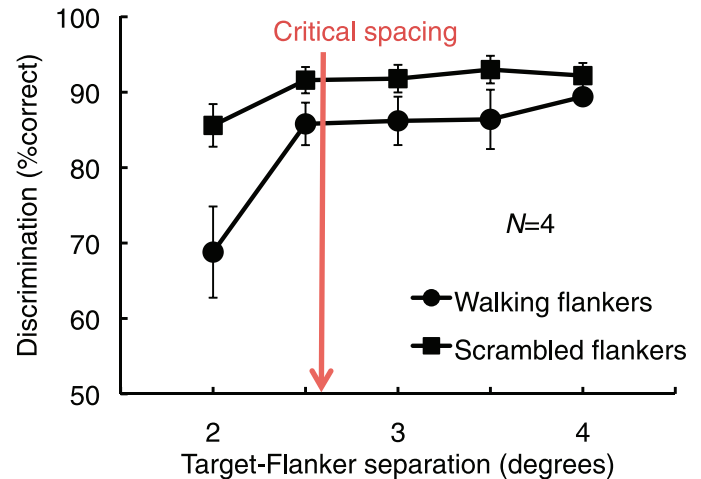
**Figure 2.** Sample stimulus when target is flanked by scrambled biological motion figures. The lines connecting the dots were not present in the experiment display.

### Task and Procedure

Observers binocularly viewed a fixation point in the center of the display from a distance of 57 cm throughout the whole experiment. On each trial, three figures were presented simultaneously for 1000 ms, and observers reported the direction of the target walker. To evaluate any practice effects, two observers performed the sessions with normal walkers as flankers after performing the sessions with scrambled flankers whereas the two other observers performed the session with normal flankers first and the scrambled flankers second.

### Results

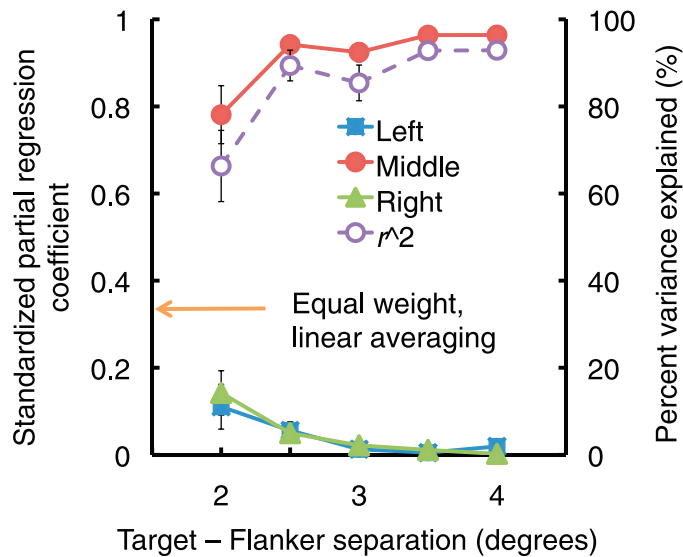
Figure 3 shows results from both conditions (Walking Flankers and Scrambled Flankers). This graph shows the percentages of correct rates for discriminating the direction of the target's walking plotted as a function of the distance between the target and the adjacent flankers. When the flankers were more than 2.5° from the target in the Walking Flankers condition, the average correct response rate reached about 80%. Accuracy declined with closer spacing of the flankers. In the Scrambled Flankers condition, all observers performed above 80% correct at all separations of the target and flankers. A two-way ANOVA on the percent correct rates of the Walking and Scrambled Flankers conditions showed a significant interaction between spacing and flanker condition, ( $F(4, 12) = 8.29$ ,  $p < 0.01$ ). In addition, the analysis of the simple effect of spacing in the Walking Flankers condition indicated



**Figure 3.** Discrimination performance (percent correct) as a function of target to flanker separation for the Walking and Scrambled Flankers conditions. Responses were the direction of the target walker (among five possible directions). Vertical bars show  $\pm 1.0$  SEM. The red arrow shows the critical spacing at 2.6° where the slope of rising performance, if extended, would intersect the asymptotic value for the Walking Flankers condition. We used the “Two-lines method” (Yeshurun & Rashal, 2010) to get the critical spacing. Since the target was at 5° eccentricity, the critical spacing is within the normal range for crowding (Bouma, 1970).

that the correct response rate decreased significantly as the target to flankers spacing decreased, ( $F(4, 12) = 16.12$ ,  $p < 0.01$ ), demonstrating a crowding effect for biological motion stimuli. The correct response rate in the Scrambled Flankers condition also decreased significantly at closer spacings, ( $F(4, 12) = 6.12$ ,  $p < 0.01$ ), but the significant interaction indicated that stronger crowding occurred in the Walking Flankers condition. Thus, the low-level motion of the scrambled flankers interfered less with the perception of the target walker's direction, suggesting that the crowding effect was not due solely to the low-level motion patterns of the flankers which were the same in the Scrambled and Walking flanker conditions.

We next evaluated how the signals from the flankers interacted with the signal from the target in the Walking Flankers condition. To do so, we used a multiple regression analysis of the three walkers' directions (two flankers and one target) as predictors of the reported direction. If there was no crowding, the responses should depend only on the central target's direction. If there was complete averaging of the three figures' directions, then there should be equal contributions from all three to the response. The standardized partial regression coefficients were averaged across all observers and plotted to estimate the influence on response of each of the three figures (target and two

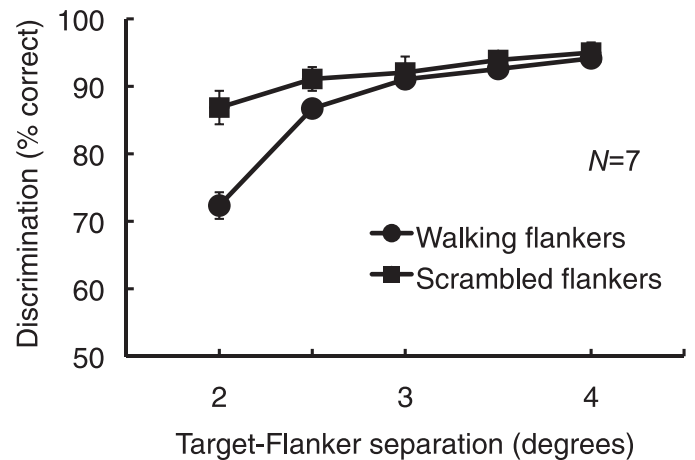


**Figure 4.** Multiple regression analysis of response directions in Experiment 1 as a function of the three stimulus directions: target, left, and right flankers. The standardized partial regression coefficient of each predictor is given on the left hand ordinate. If there were linear pooling of the three stimulus directions, the coefficients would all be 0.33. The adjusted coefficient of determination, the  $r^2$  value for the multiple regression, is given on the right hand ordinate. Vertical bars show  $\pm 1.0$  SEM.

flankers) in Figure 4. In addition, we used the adjusted coefficient of determination ( $r^2$ ) to show the percent explained variance given by the regression model (the combined prediction of the three regression coefficients). These values were averaged across observers and plotted as the percent of response variance explained in Figure 4. These values indicate that at the widest spacing, the response direction was almost entirely determined by the target's direction; but at closer spacings, the influence of the target decreased somewhat. In contrast, the flankers had little or no influence at wider spacings, but their influence increased at closer spacings, indicating some degree of pooling across the three figures.

## Experiment 2

In the first experiment, the dots of the target walker and the flankers were moving synchronously, all having the same phase in their walking cycle. This regularity may have induced some grouping effects across the target and flankers that influenced the direction judgments. To check this possibility, we ran a second experiment with random phases for all three figures, target and flanker.



**Figure 5.** Discrimination performance (percent correct) as a function of target to flanker separation for the Walking and Scrambled Flankers conditions in the experiment with random phase. Responses were the direction of the target walker (among five possible directions). Vertical bars show  $\pm 1.0$  SEM.

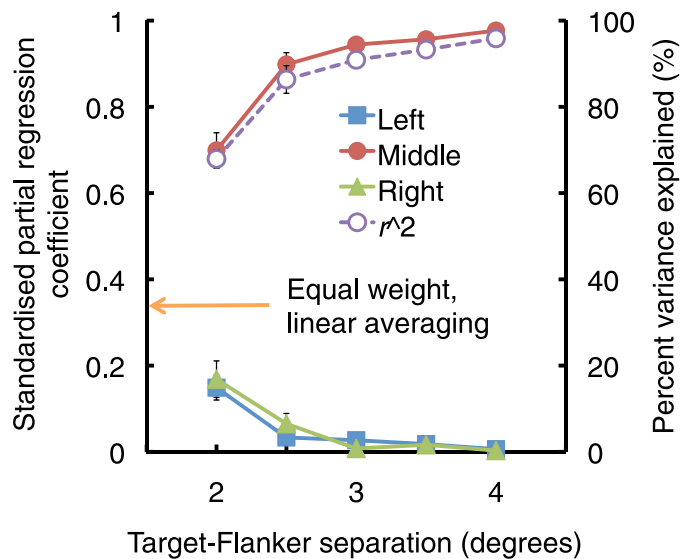
## Methods

Methods were identical to the first experiment with the following exceptions. Seven observers participated in the experiment, one of whom had been in Experiment 1 (an author, HI). The walking cycles (which last on average 800 ms across the 10 actors) were offset for each of the two flankers by a value from 167 to 1000 ms relative to the target walker's cycle, chosen randomly for each and randomly on each trial.

## Results

Figure 5 shows correct rates for discriminating the direction of the target's walking plotted as a function of distance between the target and the adjacent flankers. These results are similar to those of Experiment 1, indicating no effect of the synchrony between flankers and the target on the results. A two-way ANOVA on the percent correct rates of the Walking and Scrambled Flankers conditions again showed a significant interaction between spacing and flanker condition, ( $F(6, 24) = 6.38, p < 0.01$ ). In addition, the analysis of the simple effect of spacing in the Walking Flankers condition indicated that the correct response rate decreased significantly as the target to flankers spacing decreased, ( $F(6, 24) = 25.31, p < 0.01$ ), demonstrating a crowding effect for biological motion stimuli. The correct response rate in the Scrambled Flankers condition also decreased significantly at closer spacings, ( $F(6, 24) = 5.60, p < 0.01$ ), but the significant interaction indicated that stronger crowding occurred in the Walking Flankers condition even when the three stimuli had different time phases.





**Figure 6.** Multiple regression analysis of response directions in the experiment with random phase in the Walking Flankers condition as a function of the three stimulus directions: target, left and right flankers. The standardized partial regression coefficient of each predictor is given on the left hand ordinate. If there were linear pooling of the three stimulus directions, the coefficients would all be 0.33. The adjusted coefficient of determination, the  $r^2$  value for the multiple regression, is given on the right hand ordinate. Vertical bars show  $\pm 1.0$  SEM.

We again computed the standardized partial regression coefficients averaged across all observers to estimate the influence on response from each of the three figures (target and two flankers). In addition, we used the adjusted coefficient of determination ( $r^2$ ) to show the percent variance explained by the regression model (Figure 6). These results, like those for the synchronized stimuli (Figure 4) again show some degree of pooling across the three figures for the random-phase stimuli.

We again conclude that the crowding effect is not due solely to the low-level motion patterns of the flankers but must involve some interference at a high level of motion organization. Moreover, this high-level crowding was not reduced when the walking cycles of the target and the flankers were asynchronous.

## Discussion and conclusions

The results demonstrated an effect of crowding between adjacent biological motion stimuli in the periphery. Accuracy in reporting the direction of the target decreased as distances between stimuli decreased. A multiple regression analysis suggested that the reported direction for the central target showed some degree of pooling across the three directions from the

target and flankers at the closer spacings. When the biological motions of the flankers were scrambled, they produced less crowding despite having the same low-level motions as the biological motion stimuli. This result suggests that the crowding was not solely due to the adjacent low-motion patterns, but also because of the similarity of the high-level motion patterns of the target and the flankers. In conclusion, we found a crowding effect between adjacent biological motion stimuli that depended on their high-level motion properties and showed some degree of cross-item pooling.

*Keywords:* crowding, biological motion, motion perception, peripheral vision

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