

Dynamic Form Templates Determine Sensitivity To Biological Motion

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Abstract. Visual perception of biological motion shows a remarkable robustness against noise, fundamentally different from sensitivity to other moving stimuli. This is evidence for specialized mechanisms for biological motion perception that are more sensitive to biological motion than to other stimuli. Yet, the specifics of biological motion stimuli or the mechanisms which might explain the qualitative discrepancy between coherent motion and biological motion in terms of sensitivity remain elusive. In a combination of neurocomputational modeling and psychophysical experiments we investigated how form and motion signals influence sensitivity to biological motion in noise. With stimuli that vary in the amount of motion signals we tested the ability to detect and discriminate biological motion in human observers and in a dynamic neuro-cognitive model of biological motion perception. These results suggest that the sensitivity to human movements is caused by a specialization to the dynamic and complex pattern of the changing form of the body over time.

1 Motion Integration For Simple and Biological Motion

Global motion perception is achieved by spatio-temporal integration of local motion signals. The sensitivity to simple translational motion is influenced by noise in such a way that the tolerance to the noise increases linearly with the number of stimulus dots [1, 2]. Point light displays of biological motion consist of stimulus dots that move smoothly during a walking sequence. For short time intervals the dot motion is approximately linear and provides a brief local motion signal. Theoretically, integration of these local motion signals over space and time might therefore result in a global impression of the stimulus, similar to the integration mechanisms proposed for simple translational motion. Unlike for simple coherent motion, however, the limited lifetime-technique, in which point motion is confined only to a limited number of successive frames, showed that sensitivity to discriminate the walking direction of biological motion increased in a non-linear way, much stronger than expected from simple mechanisms that integrate motion over space and time [2].

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2 Template Model for Biological Motion Perception

Our model uses a template-matching algorithm based on distance measures between stimulus dots and stick-figure templates [3, 4]. When tested with stimuli that were identical to the stimuli used experimentally, i.e. a limited lifetime-technique that lead to local motion signals in the stimuli [2], the increase in sensitivity in the model matched that of the published experimental data [3]. However, the model operates by simply analyzing the sparse form information in the point-light stimuli while ignoring the local motion signals. It predicts, therefore, that sensitivity to direction discrimination of biological motion should be independent of local motion signals. Confirmation of this prediction would corroborate the exceptionality of biological motion perception, and demonstrate that human perception of biological motion is not necessarily an adaptive mechanism but could be explained by simple template matching mechanisms.

A detailed description of the model can be found in [3]. Here, we give a short qualitative description of the two stages of the model. The first stage uses an algorithm that matches each stimulus frame independently to a set of stored static templates extracted from the walking sequences of nine persons. Half of the templates face to the left the others face to the right. By computing a distance measure between a specific stimulus frame and each of the template frames, the model extracts the template frame that matches best to the stimulus frame. This template is then used for a decision whether the stimulus frame shows a walker oriented to the left or to the right. Subsequently, this procedure is repeated for all stimulus frames and the model achieves an overall decision by averaging over all decisions obtained for the single frames. This stage, therefore, analyzes only the global form information available in the single stimulus frames. Subsequently, the information is forwarded to a second stage that analyzes the temporal order of the single stimulus frames, i.e. this stage analyzes the global motion information. We have shown that the output of the first stage correlates with behavioral results of human observers in discrimination task like the one presented in this study [3, 4]. Since we applied in the present study a direction discrimination task, only the first stage of the model is used.

3 Human Experiments and Model Simulations

The stimulus used for combined model simulation and experimental studies depicted a human body viewed from the side walking in place as on a treadmill [5]. It contained of a fixed number of dots that varied from 2 to 8. The positions of the dots were chosen randomly on the limbs [6]. The dots were either relocated to a new, again random position on the limbs after each frame (“lifetime 1”) or they moved on this position with the limb for two frames before being relocated on a new location on the limbs (“lifetime 2”). The “lifetime 2” condition contained apparent motion signals, the “lifetime 1” condition did not. The stimulus was walking forwards and oriented either to the right or to the left, presented embedded in a field of random noise dots. The noise dots changed their position each frame to a new, randomly chosen position.

Four subjects (age 25 - 30) participated in the experiment. Their task was to indicate the orientation (left or right) of the stimulus. The stimulus was presented on a computer screen (refresh rate 100 Hz), covered a field of $5 \times 10^\circ$, and consisted of white dots (5×5 pixels) on a black background. A single stimulus frame lasted 50 ms (five monitor frames). Stimulus velocity was 0.67 walking cycles/s. Stimuli lasted up to three walking cycles. The experiment was split into blocks of a constant number of stimulus dots and constant lifetime of the stimulus dots (1 or 2). In each block, a 2-up 1-down staircase determined the 70.7% correct noise threshold for discriminating the walking direction. Thresholds were plotted in a log-log-plot and fitted by linear regression.

The model simulations started by determining the recognition rate of 100 stimulus sequences with 2 dots per stimulus frame and a dot lifetime of 1. Subsequently, we added in a window (6.5×4 times the stimulus size) a fixed number of noise dots and again determined the recognition rate. We repeated the procedure until the recognition rates dropped to chance level. Then we plotted the recognition rates as a function of number of noise dots and fitted these data points with a sigmoid function in order to determine the noise thresholds for 70.7% correct responses. We repeated this procedure for all combinations of number of stimulus dots and lifetimes. The results were plotted in log-log-diagrams and fitted by linear regression.

Fig. 1 shows the noise thresholds measured for the four subjects (A-D) and the model (E) for both dot lifetimes. The model results are characterized by a linear increase in the log-log-plots for the noise thresholds for both lifetimes. The slopes of the linear regression are steeper than 1. Moreover, slopes for both conditions are virtually identical, i.e. the slopes did not show significant differences. In agreement with the model, all subjects revealed slopes that are steeper than 1 for dot lifetime 2. Furthermore, the data from the subjects confirmed the model predictions for lifetime 1: all slopes are steeper than 1 and all slopes are virtually identical to slopes obtained for dot lifetime 2, i.e. there are no significant differences in terms of slope steepness. All slopes are in the same range as the published data [2] for a walker with a dot lifetime of 2.

4 Discussion and Conclusion

We tested our model prediction that local motion signals are irrelevant for sensitivity to direction discrimination of biological motion. First, we reproduced prior experimental results [2] in simulations of the form-based model. The linear regression for stimuli with a dot lifetime 2 revealed a slope of 3.18, thus confirming the nonlinear increase of sensitivity to biological motion stimuli. Second, the model predicted the same results for dot lifetimes of 1 as for dot lifetime 2 (slope of 2.53), i.e. that sensitivity to direction discrimination of biological motion should be unaffected by local motion signals. We confirm this prediction by showing that our subjects noise thresholds were virtually identical in both lifetime conditions. We conclude that our form-based model well describes the direction discrimination of biological motion.

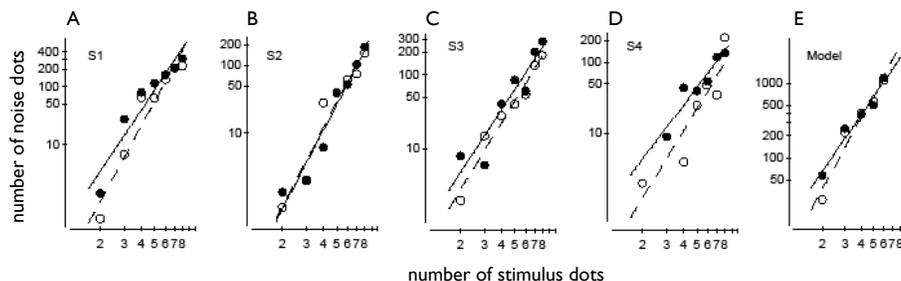


Fig. 1. Noise thresholds for 70.7% correct identification of the walking direction of the stimulus as a function of number of stimulus dots per stimulus frame. Filled dots represent data for conditions with a dot lifetime of 1, open dots for a lifetime of 2. Data are plotted in a Log-Log-diagram and fitted by linear regression (solid line for dot lifetime of 1, dashed lines for dot lifetime of 2). A-D show the psychophysical results for four subjects, E shows the data for the model simulations.

In contrast to the direction discrimination tasks, for the task of *detection* in noise a linear relationship between number of stimulus dots and detection thresholds was shown for translational motion as well as for biological motion [2]. We suggest that detecting biological motion and discriminating its walking direction are two distinct processes which are not necessarily coupled. To detect biological motion in noise local motion signals may be important to segregate the stimulus from the noise [7, 3]. This process is linearly dependent on local motion signals but unspecific for biological motion. Our results suggest that a template-matching process is sufficient to achieve the second step of the recognition process, i.e. the discrimination of walking direction, which is specific for biological motion stimuli.

References

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