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Detecting changes of velocity of smoothly moving objects

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Introduction.

We report the results of a set of experiments to test the sensitivity of the human visual system to smooth and abrupt changes in the base velocity of objects. These experiments are the temporal equivalent of spatial contrast sensitivity experiments performed using sine wave gratings many years ago.

Using 2AFC and PEST we determined the minimal amplitude of periodic velocity modulation (ie, the threshold of detection) of the base velocity of an object for several periodic waveforms, frequencies of modulation from 1 to 10 Hz and base velocities between 3 and 9 degrees/second.

Goals

We believe that temporal limits of attention determine the longer time constant traditionally associated with the integration phase of the motion perception system.

If the traditional model is accepted, the motion perceptual system could be sensitive to:

- frequencies present in the velocity of a stimulus
- integral of the velocity over short durations
- distribution of the velocities

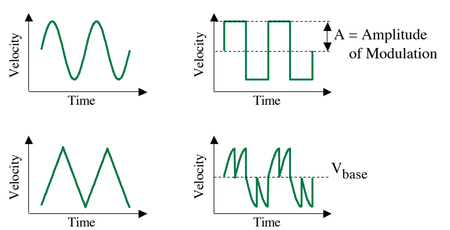
by using velocity modulations which vary one of these parameters while holding the other two constant we seek to determine the attentional limits of the visual system with respect to motion.

Modulation of Stimuli Velocity

Several velocity functions were used in our experiments. For example, sinusoidal modulation was created by using:

$$V(t) = V_{\text{base}} + A\sin(ft)$$

We replaced the sin() function with the triangle, square and scrambled sine functions:

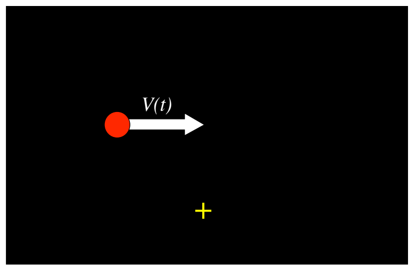


Method

The stimulus was a red circle of diameter 0.8 degrees that moved horizontally first to the left and then to the right across the black display of an Apple eMac. The display was set to 1024x768 pixels with a refresh rate of 89 Hz. The CRT in an eMac uses P22 phosphors.

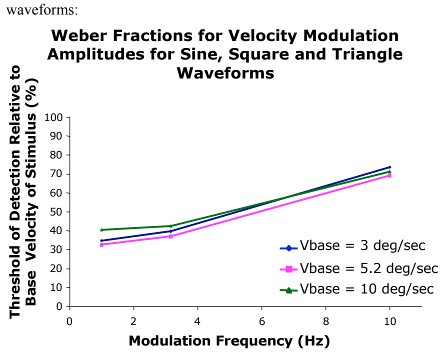
Participants fixated a cross centered about 6 degrees below the target trajectory. Participants were instructed to indicate by pressing a key which movement interval (left to right or right to left) was not smooth.

Parameter Estimation by Sequential Tracking (PEST) was used to adjust the amplitude of the velocity change so that participants were 80% correct. Five reversals of performance were used to terminate the trial after collecting the amplitude of the velocity change for an additional sixteen "tail trials."



Reproduction of Prior Results

As a verification of our apparatus we reproduced the prior results of Simpson (1994), Snowden, and Braddick (1991), and Werkhoven, Snippe, and Toet (1992) using the sine, square, and triangle waveforms:

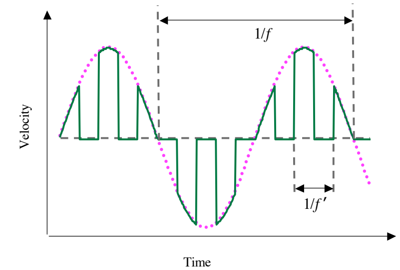


Novel Results

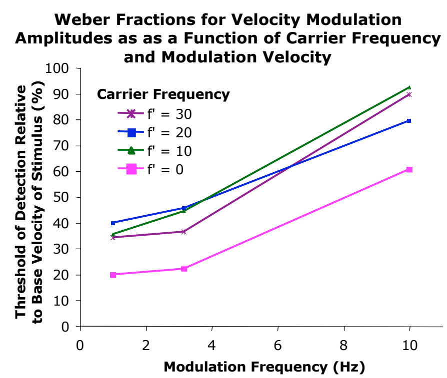
As the visual system behaves as a low pass filter in the temporal frequency domain it should suppress higher frequencies in the velocity signal. In order to test integration of the velocity signal we also used a "carrier frequency" stimulus:

$$V(t) = V_{\text{base}} + A\sin(ft)\text{cf}(f't)$$

where cf() is a square wave with range [0,1] and f' is a frequency much higher than f. This generates:



As expected, this stimulus - with base waveforms of sine, square, and triangle waveforms - resulted in a lower sensitivity to the velocity modulation. Specifically, about a twice as large modulation is required for detection.



Acknowledgements

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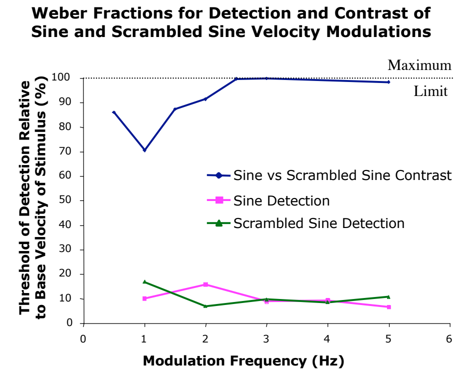
Really Novel Results

We also tested the relative contrast of the sine and scrambled sine waveforms. The Weber fractions clearly show a temporal limit of the attentional system away from 1Hz. This is in agreement with Verstraten, Cavanagh and Labianca (2002).



Previous Work

It has been shown that without the smooth pursuit of moving object, humans are insensitive to changes in the velocity of the moving object. The most popular model for the visual system capable of detecting acceleration is a two stage system that integrates and squares the output of a low pass filter operating on the output of the primary motion sensors (Simpson, 1994; Werkhoven, Snippe & Toet, 1992).

Prior experiments have used alternating velocities (Snowden and Braddick, 1995) - equivalent to our use of square wave modulation; instantaneous changes in position (Simpson, 1994); and modulation of a base velocity using sine, triangle, and square waveforms (Werkhoven, Snippe & Toet, 1992).

Summary

We have found new limits on the visual system for detecting changes in velocity at low temporal frequencies. We believe these limits are attention based. Experiments are planned to extend these experiments to line segment rotations and rotations of the joints of articulated figures.

References

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