Binocular depth perception takes 50-80 ms for data processing

A psychophysical analysis of the “Delayed Stereopsis Illusion” (DSI)

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• Question

How much time does our brain need to perform stereopsis?

Viewed pseudoscopically, an opaque square floating in front of a random-dot pattern appears depth-reversed as a rectangular cut-out. When that pattern is moved upwards or downwards, an *illusory gap* is perceived above the upper edge of the square, or below the lower one, respectively (Delayed Stereopsis Illusion DSI, Fig. 2B). This gap shows the same pattern as the rest of the moving part, its position in depth, however, is undefined: It is perceived somewhere between the plane of the motionless square, which steadily uncovers parts of the surrounding moving pattern, and the plane of that pattern.

In analogy with Julesz’ “no-man's-land” we called this DSI-gap “trailing edge no-man's-land”. Its width, marked by subjects under well-defined conditions, indicates the 3-D processing time needed to determine the spatial depth of the pattern, which virtually appears “from nowhere”.

• Method

Data were collected psychophysically with a mechanical apparatus and a computer-generated model system based on the software „Bino 2.4“ (written 1999 by Frank Scheiner, Rechenzentrum, University of Würzburg). There are two different “modes” for the 3-D presentation of the DSI: Mode “2RD” creates two half images lying side by side which have to be fused by squinting (Fig. 2). Mode “S” creates the impression of depth by shutter goggles and synchronously alternating half images on the monitor.

The velocity v of the moving pattern perceived in the foreground is adjusted by the operator by keyboard. The subjects measure the DSI-gap by marking the subjectively perceived width z of the trailing edge no-man´s-land with a short red line. Different values of v were presented in randomized order.

Spatial frequency and other parameters of the moving pattern and the square could be varied by software before starting an experiment.

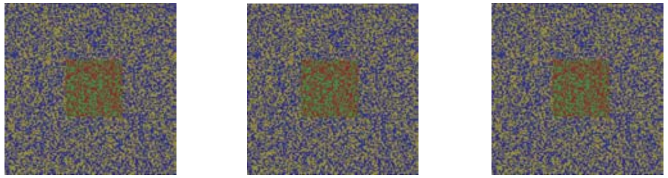

Fig. 1: How to perceive Julesz´ “topological” no-man´s-lands: *When fused by squinting or staring, the adjoining random dot patterns are perceived as a square “floating” in front of or behind the surrounding plane. To the right and to the left of the floating square the topological no-man´s-lands can be seen. They are three pattern elements wide and form a rectangular cut-out.*

• Results

Three series of experiments (E1-E3) were conducted with a total of 16 subjects capable of stereopsis. In E1 the results from three subjects indicated inter-individually different 3-D processing times which averaged ***80 ms** for velocities below v_{max} = 2.9 deg/s* (as represented by the slope of the regression line through all data points, Fig. 3).

E2 was performed with eight randomly selected subjects at *velocities up to v_{max}= 8.8 deg/s*. E1 and E2 unexpectedly revealed considerable *interindividual differences*.

So in E3 we tested three stereo- and DSI-experienced subjects under the *same conditions as in E2*, but with *each data point representing the average of five seperate measurements*. Thus, data from E3 (Fig. 4) are the most reliable, whereas in E1 and E2 each data point represents one measurement only.

The results of E1 and E2 indicate two ranges of velocities characterized by different slopes with the cut-off point at about 3 deg/s (Fig. 3), suggesting the presence of two different 3-D processing channels of different time characteristics. Both E1 and E2 show a steeper increase of z at velocities below 3 deg/s (yet not significant in E2).

This assumption, however, could not be confirmed in E3. Again, our data show inter-individual differences (Fig. 4), but all of them build up graphs of similar shape: They represent straight lines with slopes indicating 3-D processing times of *58ms* in subject 1, *82 ms* in subject 2 and *62 ms* in subject 3 in E3.

As the regression lines do not pass the origin, our data indicate a *systematic, individually different overestimation of z* by the subjects which may be due to our discrete measurement method, and/or the elusiveness of the DSI. This systematic error may cause all z-data to be shifted upwards, yet without altering the slopes, thus yielding *average 3D-computation times of **78 ms*** in E1, ***50 ms*** in E2 and ***67 ms*** in E3 (Figs. 4,5).

E1 and E2 also showed that *variations in spatial frequencies* of the patterns, or the *ratio of black and white dots* in the random dot pattern, had *no significant effect* on the DSI-gap. Furthermore, our data were *not indicative of systematic learning effects*.

• Conclusions

Our preliminary assumption that there are different processing pathways for fast and slow motion, which are characterized by different 3-D processing times, could not be confirmed. *The established processing times rather vary from 50 to 80 ms, due to inter-individual differences.*

In any case, the minimum presentation time of 17ms, at which Julesz´ dynamic random-dot stereograms are just recognizable, is much too short to determine the position in depth from each single frame. Our 3-D system rather seems to check - perhaps by sampling - whether the depth situation has changed, and if it has not, our percept of the floating square is maintained.

Fig. 2
(A) *Screenshot of the software “Bino 2.4”, mode “2RD” with two half images to be fused by squinting. In the experiment the surrounding pattern moves upwards, and the motionless square is perceived spatially behind the foreground - as shown in **(B):** The DSI-gap appears at the upper edge of the square. Its width is marked by the subject with a red line.*

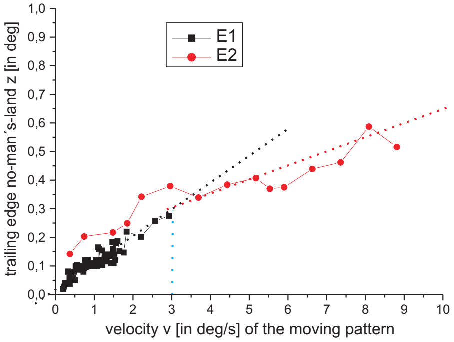

Fig. 3: *The first experimental series E1 and E2 suggest two ranges 0 < v < 3 deg/s and v > 3 deg/s with different slopes of the regression lines. However this could not be confirmed (Fig. 4,5).*

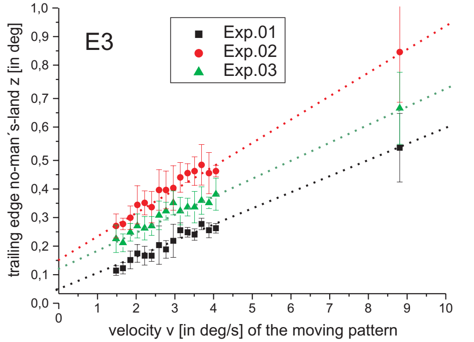

Fig. 4: *Averaged data from three subjects in E3 show inter-individual differences in the size of z and the slope. Each subject contributed 5 measurements per data point.*

• Outlook

As the DSI-gap is due to delayed stereopsis, it should be expected to increase when light intensity is reduced, according to the well-known Pulfrich effect. Indeed, preliminary data gained at an illuminance of 3 lux suggest that during scotopic vision 3-D processing is delayed by the 2-3fold, which fits well with the maximum delay of about 100 ms of the darkened eye in Pulfrich experiments (Howard & Rogers: Binocular Vision and Stereopsis. Oxford 1995, Fig. 13.7).

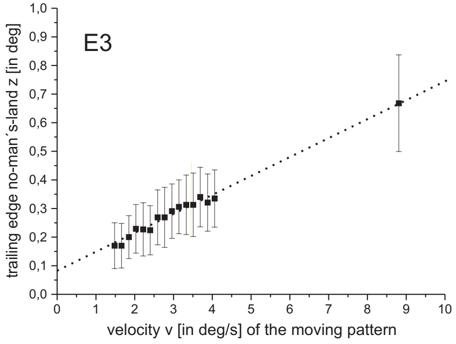

Fig. 5: *The average of all data collected in E3 indicates that there seems to be only one single processing pathway with an average 3-D processing time of about 70 ms, as represented by the slope of the regression line.*