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THE EFFECT OF STEREOSCOPIC PRESENTATION ON A SIMULATED AIR TRAFFIC CONTROL TASK

J. Walraven
A.D. Hekstra

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Netherlands organization for applied scientific research

TNO Institute for Perception

P O Box 23
3769 ZG Soesterberg
Kampweg 5
Soesterberg, The Netherlands

Phone +31 34 63 62 11

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Authors: Dr. J. Walraven and A.D. Hekstra

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SUMMARY

Collision prediction in a simulated Air Traffic Control (ATC) task was compared for conditions in which the aircraft displacements on the radar display were shown in either two or three dimensions. The image separation that is required for stereoscopic (3D) viewing was achieved by both anaglyphic presentation (red-green glasses) and sequential field stereoscopy (electro-optical shutters). The stimuli consisted of traffic scenarios that varied in density and complexity. One of the aircraft was singled out to represent the one to be under control. The observer's task was to judge whether it was on a collision course or not. In the 2D condition, the (necessary) altitude information was provided in numerical form. In the 3D conditions, experiments both with and without numerical information were performed.

The results indicate that stereoscopic information by itself, that is, without numerical altitude information, may already be sufficient for the task under consideration. However, in the condition with combined stereoscopic and numerical altitude information, the performance was not significantly better than in the 2D condition employing numerical information only. Nevertheless, subjects preferred the stereoscopic display over the (normal) two-dimensional format.

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Het effect van stereowaarneming op de uitvoering van een gesimuleerde luchtverkeersleidingstaak

J. Walraven en A.D. Hekstra

SAMENVATTING

In een gesimuleerde luchtverkeersleidingstaak werden de vliegtuigbewegingen op het beeldscherm in twee of drie dimensies getoond. Vergeleken werd of de taakprestatie, v.w.b. het voorspellen van een botsing, door deze verschillen in presentatiemethode werd beïnvloed. Bij de stereoscopische weergave (3D) werd de separatie van linker en rechter stereobeeld bewerkstelligd met zowel de anaglyf methode (rood-groen bril) als met electro-optische hulpmiddelen (PLATO knipperbril). De simulatie betrof verkeersscenario's met verschillende aantallen vliegtuigen, waarvan er één fungeerde als het te controleren vliegtuig. Beoordeeld moest worden of dit vliegtuig wel of niet op botsingskoers lag met de overige vliegtuigen. In de 2D conditie werd de informatie over vlieghoogte uitsluitend in numerieke vorm gegeven. In de 3D conditie werden experimenten verricht waarbij de botsingsvoorspelling zowel met als zonder numerieke informatie werd uitgevoerd.
De resultaten laten zien dat stereoscopische plaatsinformatie, zonder toegevoegde numerieke hoogtegegevens, al nauwkeurig genoeg is voor de hier onderzochte taak. In condities met zowel stereowaarneming als numerieke informatie bleek de taakprestatie echter niet significant beter dan bij twee-dimensionaal presentatie met uitsluitend numerieke informatie. Desalniettemin bleken proefpersonen de voorkeur te geven aan de stereoscopische beeldpresentatie.

1 INTRODUCTION

Due to the still increasing density and complexity of air traffic, the work load in Air Traffic Control (ATC) has become a matter of great concern. One of the factors that adds to the difficulty of a controller's task is that his main (radar) display, showing the positions of the aircraft under his control, only provides a plan view. The aircraft altitude, an important variable that has to be continuously monitored during the ascent and descent of the aircraft, is available only as numerical information. It is to be expected that reconstructing (rather than seeing) the vertical separations of the aircraft, will require quite some mental effort from the controller (Sperandio, 1975). So, anything that might help to support the controller's mental grip on the three-dimensional space he is working in, should be welcome. One possibility would be colour coding, an application that has finally become well accepted in the ATC community (Narborough-Hall, 1985; Walraven, 1987), and which already has been shown to aid in identifying and memorizing aircraft at the same altitude (Wedell and Alden, 1973). A more direct approach would be, of course, to show the air traffic in three rather than in two dimensions.

It is possible to present a complete three-dimensional ATC picture by using stereoscopic techniques. However, despite the obvious relevance of 3D presentation for ATC application, such proposals have not been met with a favourable response in ATC circles. A possible reason for that adversity is given by Neeland (1982). Reporting on the FAA's (Federal Aviation Administration) viewpoint regarding 3D displays he stated: "The consensus was that the accuracy of tabular data was needed for the responsibility of the air traffic controller. For him to grant separation, issue clearances, and authorize descents, he needs to have the accuracy that he gets from actually reading altitude on the plan view that he uses right now. If he still has to have that, there is not much sense in going to a 3D display. I think that this has been one of the major problems. This idea of precision requirements, which controllers feel are too tight to allow human perceptual capabilities to give them that data".

The main message from the above quote is that air traffic controllers consider only numerical altitude information as precise enough, and further, that there is apparently no further benefit to be expected from a 3D display. This may or may not be true, but the fact is, that this opinion is not based on a quantitative evaluation of the possible benefit of a 3D ATC display, either with or without the addition of numerical altitude information. This study is a first attempt at such an evaluation.

2 METHODS

2.1 Apparatus

The stimulus pattern used for simulating aircraft on an ATC display was generated on either a colour CRT (Conrac 7211, 66 Hz interlaced, 512 x 512 pixels) or a monochrome display (Tetraco 220, 50 Hz interlaced, 512 x 512 pixels). The colour CRT was used for displaying stereoscopic pictures with the anaglyphic image separation method, employing red-green glasses adapted to the phosphors of the display (Mulligan, 1986). The monochrome CRT was used in conjunction with the method of field-sequential stereoscopy. This was achieved with electro-optical shutters, i.e. the PLATO goggles (Portable Liquid-crystal Apparatus for Tachistoscopic Occlusion) developed at the TNO Institute for Perception (Milgram and Van der Horst, 1986).

The images were generated by an IP 8400 Gould/DeAnza graphical image processor supported by a Gould-MPX computer system. Real-time software was written in Fortran 77+, employing the graphical image processor with standard GKS subroutine calls. The bit-mapped RGB multiple memories were used for manipulating and storing the stereo images. The equations for generating the latter are given in the Appendix.

2.2 Stimulus

The test stimuli consisted of aircraft representations according to the conventions used on ATC displays, i.e. a position indicator (a circle) connected to a speed/direction vector (Fig. 1).

Fig. 1 Anaglyph of an ATC traffic scenario. The red-green viewer should be used to see the picture in depth. For ease of viewing, that is, with the stereo image floating above rather than below the page, the left eye should look through the red filter. (It may take some time before the eyes lock in on the raised image plane.) The filled circle identifies the test aircraft (A). In this example the latter is on a collision course with the descending aircraft (C). An impression of the 2D stimulus presentation can be obtained by looking through the viewer with one eye closed.

The tail-end of the latter was connected to a smaller circle (a third of the size of the position indicator), to improve the perception of its three-dimensional location. The length of the speed/direction vector (or memory trace) was proportional to the speed of the aircraft, varying between 50 and 25 mm on the screen (which was viewed from a distance of 70 cm). Scaling was also applied to the diameter of the position circle (12-15 mm) and the tail circle (4-5 mm). The circles decreased and increased in size, consistent (although not quite proportional) with their displacement from or towards the observer.

Next to each aircraft an identification letter (A, B, C etc.) was shown and, in the majority of the experiments, a three-digit number indicating its altitude. One of the aircraft, the one under control, was shown with a filled, rather than open leading circle. Within a given traffic scenario each aircraft followed a fixed flight path at a fixed speed. In total 70 different flight scenarios were available, including 50 that resulted in a collision with the test aircraft, after a flight time that could vary from 25 to 80 s. The traffic scenarios were not just random combinations of individual aircraft flight paths, but were programmed to have different directions of encounter including "decoy" collisions, i.e. flights that barely missed the test aircraft.

2.3 Experimental task

The traffic scenarios were viewed from a distance of 70 cm. The subject's task was to judge whether the test aircraft (labelled A) was on a collision course or not. The instruction was to make the judgment as quickly as possible, but without "endangering" the aircraft (precision was considered more important than speed). After reaching a decision, the subject pressed the space bar of the display terminal, thus timing their own decision time and stopping the aircraft in their tracks. After two seconds the stimulus was replaced by a text asking "Collision?" and "Which one?", to which the response was given by keyboard input: that is, Y for yes, N for no, and one of the characters B to P, indicating the aircraft that was expected to collide with the test aircraft. Task performance was scored both by measuring the percentage correctly predicted collisions and also, in the first experiments, by the decision time. In later experiments the stimulus was stopped at a preset moment, i.e. 5 to 20 s before collision time, resulting in (enforced) decision times, varying also between 5 to 20 s.

The various experimental conditions will be detailed separately, when presenting the results of the experiments in question. In all experiments the subject x stimulus blocks were designed in accordance with digram-balanced Latin squares (Wagenaar, 1969), in order to reduce stimulus interaction and learning effects to a minimum.

2.4 Subjects

The subjects were students, between 18 and 28 years old, selected from the Institute's subject "pool", on the basis of good general vision (acuity, colour) and depth perception. Stereoscopic depth discrimination was tested with the TNO Stereopter (Walraven and Boogaard, 1970), an instrument for the precise measurement of stereo-acuity. In addition, the subjects were screened with the TNO Test for Stereoscopic Vision (Walraven, 1975), a test for the more global assessment of stereoscopic vision. This test, which consists of anaglyphs, was used to check whether the subjects would have problems with seeing depth through red-green glasses, i.e. the kind of stimulus presentation also used in part of the experiments.

3 RESULTS

The experiments differed somewhat with respect to stimulus presentation (red-green glasses or PLATO goggles), complexity of traffic scenarios (number and density of aircraft), and experimental design (number of sessions and subjects). The specific experimental conditions will be detailed separately for each of the four experiments discussed below.

3.1 Experiment 1

This experiment addresses two questions, that is:

1 Is 3D presentation preferable over 2D?

2 Can the numerical altitude information be omitted in the stereoscopic presentation mode?

The experimental set-up was as follows:

- stimulus presentation: anaglyphic red-green display either with (3D) or without (2D) binocular disparity
- number of aircraft in each scenario: 10
- number of different scenarios: 35
- number of collision scenarios: 24
- conditions: 2D or 3D, in the latter condition either with (+) or without (-) numerical altitude information

- procedure: 4 sessions per subject; one session consisted of 4 presentations 2D/3D/2D/3D; with 3D as either 3D(+) or 3D(-); one presentation consisted of 35 scenarios
- number of subjects: 8 (one per 2D/3D session)
- performance criteria: % correct collision predictions and decision time.

The experimental results, averaged per subject (over two 2D and two 3D sessions) are shown in Table I.

Table I Performance scores, i.e. % correct judgments and decision time, compared for the viewing conditions 2D vs 3D(-) and 2D vs 3D(+), for eight different subjects.

	% correct		decision time (s)	
subj	2D	3D(-)	2D	3D(-)
1	77.1	85.7	49.6	44.8
2	72.9	75.7	41.4	36.5
3	70.0	62.9	48.0	43.8
4	62.9	82.9	61.2	49.6
mean	**70.8**	**76.8**	**50.5**	**43.7**
	2D	3D(+)	2D	3D(+)
5	54.3	74.3	57.9	56.1
6	65.8	64.3	80.9	74.5
7	81.4	82.9	65.2	65.5
8	75.7	72.9	75.1	74.4
mean	**69.3**	**73.6**	**69.8**	**67.6**

The results of this first experiment show a slightly better performance in all 3D conditions, both with respect to error score and decision time (i.e. shorter decision times). However, it was rather puzzling that performance in the 3D(-) condition was actually somewhat better than in the 3D(+) condition (mean scores of 76.8% vs 73.6%). This was even more evident in terms of decision time, these being quite a bit shorter in the condition without numerical information (mean time of 43.7 s, as compared to 67.6 s in the other condition).

We suspected that the altitude information might have interfered with the task, due to the increase in (numerical) clutter in the 3D(+)

condition. In addition, there might have been a difference in subject population. This is suggested by the fact that the 2D/3D(+) group (Ss 5-8) not only require longer decision times in the 3D(+), but also in the 2D condition. A within-subjects rather than between-groups design would have been more appropriate to compare the 3D(+) vs 3D(-) condition.

Since it was felt that, apart from the above flaw in design, the experiment could be improved upon in other ways, a new experimental set-up was tried.

3.2 Experiment 2

In this experiment only the condition 2D/3D(+) was studied. Thus, the added clutter due to numerical information was a factor present in both presentation modes. The clutter was somewhat reduced, however, by using smaller characters.

The fact that in the previous experiment the improvement in performance in the 3D(+) condition was unexpectedly small, might possibly reflect a too simple task, too easy anyway to profit from the addition of 3D depth information. It was decided therefore, to vary the degree of complexity by employing traffic scenarios with either 5, 10 or 15 aircraft. The task was also made more difficult by no longer allowing the subject the freedom to watch the scenario as long as they felt necessary. Decision time was set by the computer, thereby stopping the aircraft displacement 5-20 s before a collision would take place. Further experimental variables are summarised below:

- stimulus presentation: red-green anaglyphs either without (2D) or with (3D) binocular disparity
- number of aircraft: variable (5, 10 or 15)
- number of different scenarios: 72
- number of collision scenarios: 48
- conditions: 2D or 3D with numerical altitude information, i.e. 3D(+)
- procedure: 6 sessions per subject, i.e. 2 display modes (2D or 3D) x 3 densities (5, 10, 15) aircraft; one session consisted of 12 different scenario presentations
- number of subjects: 10
- performance criterion: % correct collision predictions
- decision time: 5-20 seconds before collision, as set by the computer.

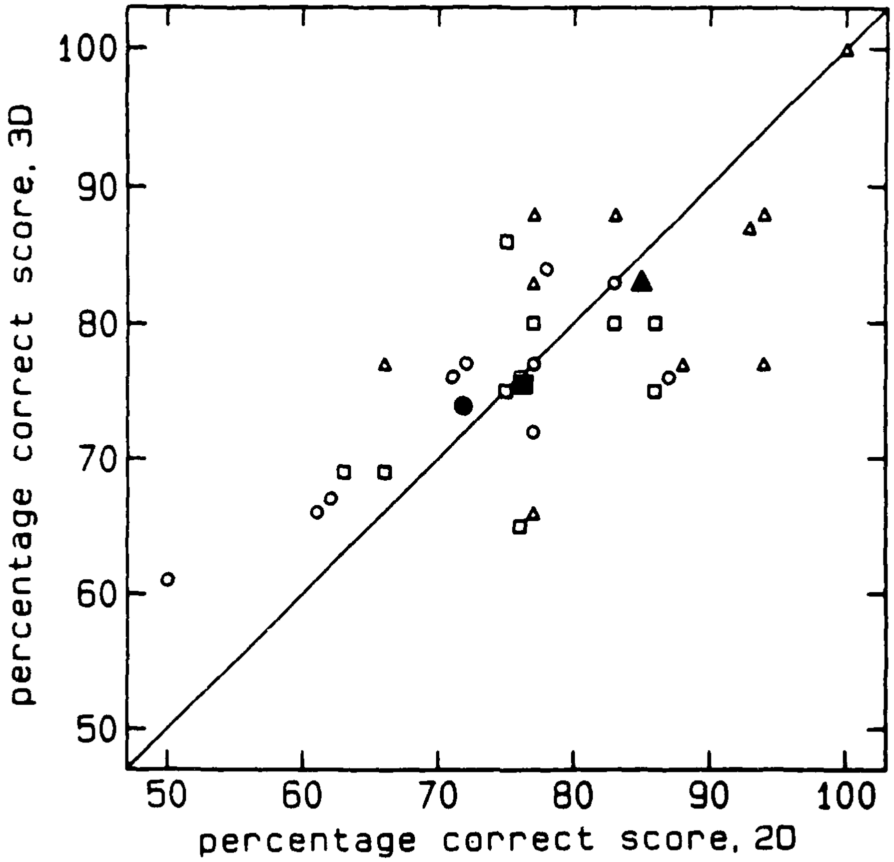

Fig. 2 Comparison of task performance (% correct scores) for the 2D and 3D display mode. Open symbols relate to individual subject scores for traffic scenarios with 5 (Δ), 10 (□), or 15 (O) aircraft. Filled symbols represent the mean scores for each traffic density.

The results of Experiment 2, plotted in Fig. 2, do not show a difference in performance in favour of either the 2D or 3D presentation mode. The overall score, generalising over the different traffic densities, is 77.7% and 77.5% correct predictions for the 2D and 3D condition, respectively. As can already be expected from Fig. 2, the statistical analysis (ANOVA) only shows a fairly strong subject effect, i.e. 27% explained variance ($Fp < 0.002$), and consequently only a small effect of aircraft density, i.e. 3.2% explained variance ($Fp < 0.02$). No effect at all was found for 2D vs 3D. Still, in the most complex condition (15 aircraft), where one might expect to profit most from the 3D display, the data show a slight tendency for higher 3D scores. In general, the 3D/2D score ratio increases with increasing traffic density.

When the subjects were asked for their preference with respect to 2D or 3D viewing, the general feeling was that 3D was better, but there were complaints that it was not always easy to maintain depth perception. This might reflect problems with binocular rivalry due to the different colours of the stereo half-images. It was decided, therefore, to do a new experiment, in which the stereo images would be generated with the method of sequential field stereoscopy (PLATO goggles). In addition, the traffic scenarios were made more complex.

3.3 Experiment 3

The PLATO goggles used in this experiment precluded the problem of binocular colour rivalry, but had the disadvantage that, due to the alternation of odd and even interlaced half-frames, the display showed more flicker. By sufficiently reducing the picture brightness and contrast, this effect could be kept within acceptable limits. All subjects agreed that the 3D picture was improved as compared to the anaglyphic presentation.

For this experiment the traffic scenarios were made more complex by having more aircraft closing in on the test aircraft, and also by forcing the subjects to long-term predictions (10-20, rather than 5-10 s before collision). Further details are given below:

- stimulus presentation: field-sequential (PLATO goggles) in combination with the monochrome display.
- number of aircraft: 10, with the majority closing in on the test aircraft
- number of different scenarios: 100
- number of collision scenarios: 50
- conditions: 2D or 3D(+)
- procedure: sessions (1 per subject) consisting of alternating 2D and 3D presentation (10 of each); each presentation consisted of 10 scenarios
- number of subjects: 5
- performance score: % correct collision predictions
- decision time: 10-20 seconds before collision.

Fig. 3 shows the 2D/3D comparison of task performance for the 5 subjects that participated in Experiment 3.

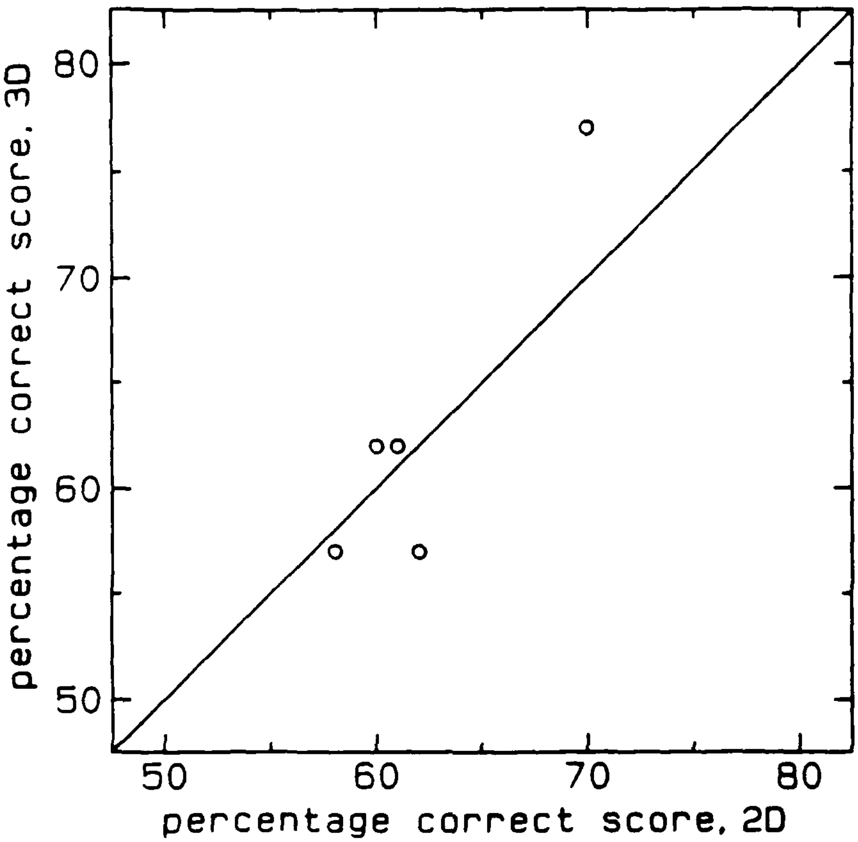

Fig. 3 Comparison of task performance (% correct predictions) for the 2D and 3D display mode. The data represent single subject score averaged over the same set of 100 different traffic scenarios presented in 2D and 3D mode, respectively.

The results of Experiment 3 confirm, again, the findings of Experiment 2; that is, task performance is the same in the 2D and 3D presentation mode. Still, in this, as in the previous experiment, the subjects expressed their preference for the 3D display. It would seem however, and this was confirmed by their reports, that the subjects rely on numerical rather than on perceptual information.

A possible reason for not utilizing perceptual 3D information could be that it does not much add to the numerical information, or that it is simply ignored while keeping track of the numbers indicating the aircraft altitudes. The next, and last, experiment addresses this possibility by providing still better visual information (predicted tracks), so as to make the visual cues more competitive with respect to the cognitive approach (i.e. relying on numbers only).

3.4 Experiment 4

In this experiment the ATC display showed aircraft equipped with predictor rather than memory tracks. Using this information, which is actually also used in modern ATC displays, the extrapolation task involved in collision prediction should become easier; one can better foresee, literally, whether aircraft are on a collision course or not (see also the insets of Fig. 4).
The predictor lines, pointing in the direction the aircraft is going, were computed for the aircraft's position 15 s ahead in time. In this experiment the small tail circles (see Fig. 1) were omitted in order to get a less cluttered picture. The other experimental variables were the same as in Experiment 3, except that now 4 instead of 5 subjects were used, one of which had also participated (three months earlier) in Experiment 3.

The results of Experiment 4 are shown in Fig. 4, which also shows the results obtained earlier in Experiment 3. Here again, there was no significant improvement (not in a statistical sense either) of task performance in the 3D display mode, despite an outspoken preference of the subjects for 3D.
We can but conclude, therefore, that none of the obtained experimental evidence sofar, provides evidence for a beneficial effect of stereoscopic presentation on performance. At least, as far as the collision prediction task is concerned.

An interesting side result of Experiment 4 is the large gain in performance that is obtained when employing a predictor track rather than a memory trace. Even the one subject for which a comparison of these two display modes would be justified on a statistical basis (see the crossed symbol in Fig. 4), shows the difference to be highly significant. Generalising over 2D and 3D presentations, a simple Wilcoxon test already shows the improvement (from 73.5% to 88% correct predictions) to be significant at a level of less than 0.5%. The advantage of the prediction track already can be appreciated by the example shown in the inset of Fig. 4. It shows two pairs of aircraft, that are both on a near-collision course (the lower member of the pair is slightly too slow to catch up with the upper member). That there will be no collision is obvious for the pair on the right, but far from clear for the pair on the left.

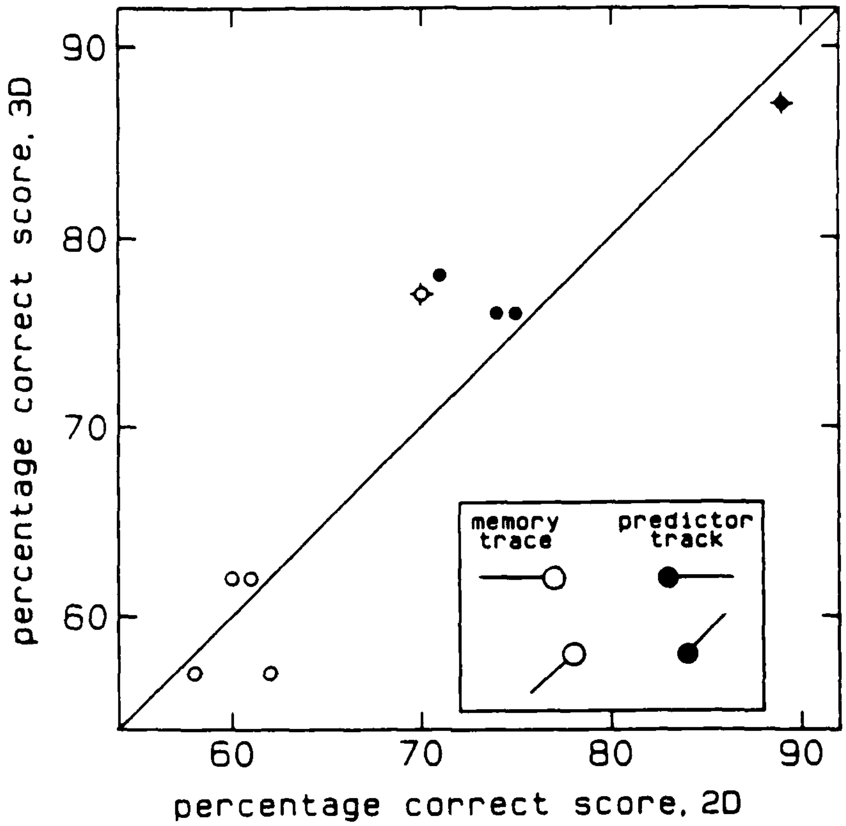

Fig. 4 Comparison of task performance (% correct predictions) for the 2D and 3D display mode, employing either memory traces (O) or predictor tracks (●). The data represent single subject scores averaged over the same set of 100 different traffic scenarios, presented in 2D and 3D, respectively. The two crossed symbols relate to a subject that had also participated in Experiment 3.
Inset: Example showing two aircraft equipped with either a memory trace or track predictor. Both pairs of aircraft follow the same near-collision course. For the left pair this is less easy to judge than for the pair on the right.

4 DISCUSSION

The results of this study are rather surprising in that they show no indication of a beneficial effect of stereoscopic vision in a task that actually would seem to invite such an effect. The subjective impression of the simulated ATC display used here seemed so much more informative in the 3D than in the 2D presentation made, that one would expect a dramatic improvement in task performance in the 3D condition.

Considering the pilot nature of this study, it is still too early to conclude that ATC operators would not benefit from a stereoscopic display. The experiments were not designed to test factors like visual fatigue and learning. It is noteworthy in this respect that the general feeling of the subjects in this study was that 3D made it easier to perform the task, although they reported that they let numerical information prevail in their collision prediction task. The fact that in the absence of numerical information, the 3D(-) condition, the task performance was at least as good as in the 2D condition with numerical information (Experiment 1), indicates that the spatial information conveyed by stereopsis may be potentially as useful as numerical information. It would be worthwhile to test whether this finding can de substantiated under more realistic task conditions.

As has been discussed by Merrit (1982), the potential benefit of stereoscopic displays has often been difficult to evaluate, due to the poor quality of the stereo display (e.g. flicker, low resolution). Thus, Kama and DuMars (1964) found no difference in 2D vs 3D in a simple remote-manipulation task (peg-in-hole) when using 2D and 3D TV. However, since this result might be due to the fact that the 2D TV had only half the resolution of the 3D TV, Chub (1964) repeated the experiment with monocular and binocular (i.e. stereoscopic) viewing. He found a significant improvement (20% faster execution) and less variance in the 3D condition. A similar example of unrevealed 3D potential, due to the experimental set-up, i.e. a between-groups design of unpractised subjects rather than a within-subjects design of trained subjects, was reported by Smith et al. (1979). Still, if the reality is such that a stereoscopic device does not allow the (full) benefit of stereoscopic vision, there is of course, no reason for considering its use. A case in point is a study by Walraven (1980), showing no advantage of stereoscopic vision (due to inferior image quality) when viewing through a binocular image intensifier.

The negative result of the present study with respect to a clear advantage of 3D over 2D information is not likely to have been caused by (stereo)equipment problems. The same display and viewing attributes (red-green spectacles, PLATO goggles) were used in the 2D and 3D presentation, the only difference being that in the 2D condition the stereo half-images were presented without binocular disparity (i.e. zero depth difference). In real ATC applications, however, the 2D display might have the edge over 3D displays, when not employing 3D techniques that avoid the loss of image quality that may occur with some of the conventional techniques. However, there are already high-resolution, 120 Hz flicker-free colour CRT's commercially available, that employ cordless light-weight viewing glasses (Fuller & Phillips, 1989; Johnson, 1989). In future displays, even the glasses may be dispensed of (Lane, 1982; Collender, 1986, 1987).

The present study was instigated with the stereo display of the future in mind. Whether that display would be useful for ATC applications may not be that evident from the results obtained in this limited study. In view of the subject reports a beneficial effect should still not be excluded. Maybe the trials in our laboratory study were too short, and the task, watching only a single aircraft, too simple. Future research should aim, therefore, at a more realistic task, in which the operator is kept busy with monitoring various aircraft at the same time and also with the communications involved. Under such conditions, in which the operator's attention has to switch continuously from one aircraft to the other, stereoscopic depth perception might be quite helpful in the parallel processing of the aircraft altitudes. Alleviation of the mental load involved would be expected, since it allows the controller an instantaneous and global check on the aircraft movements. This should be particularly true in military applications where the aircraft movements are less predictable than in civilian air traffic.

A noteworthy side result of this study is the finding that a predictor track is so much more effective than a memory trace, as an aid to collision prediction. This is not an unexpected result (see Fig. 4), but the size of the effect, an improvement of almost 20%, is substantial enough to recommend it for "old-fashioned" ATC displays or other applications, like (tactical) combat and navigation displays.

5 CONCLUSIONS

Keeping in mind that the results of this study apply to just a single task (collision prediction), in conditions that are only distantly related to the ATC working environment, the following tentative conclusions can be drawn:

- Stereoscopic depth perception does not add significantly to performance in a simulated ATC task (collision prediction) when numerical altitude information is available.

- Task performance on a 3D display without numerical altitude information is at least as good as on a 2D display with numerical information.

- Subjects prefer 3D over 2D data presentation.

- The use of a predictor track rather than a memory trace may improve task performance by about 20%.

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Soesterberg, December 1, 1989

Dr. J. Walraven

APPENDIX Stereoscopic image generation

Stereopsis results from merging the slightly different (disparate) images that are formed on the retina of the right and left eye when viewing a three-dimensional object or scene. So, in order to create a stereoscopic picture on a display, a left and right-eye image have to be generated that produce the retinal images associated with the three-dimensional picture in question. The x,y coordinates of the stereo pair can be derived from the x,y,z coordinates of the corresponding three-dimensional image, given the point of view and the eye base. The geometry in question is shown in Fig. 5.

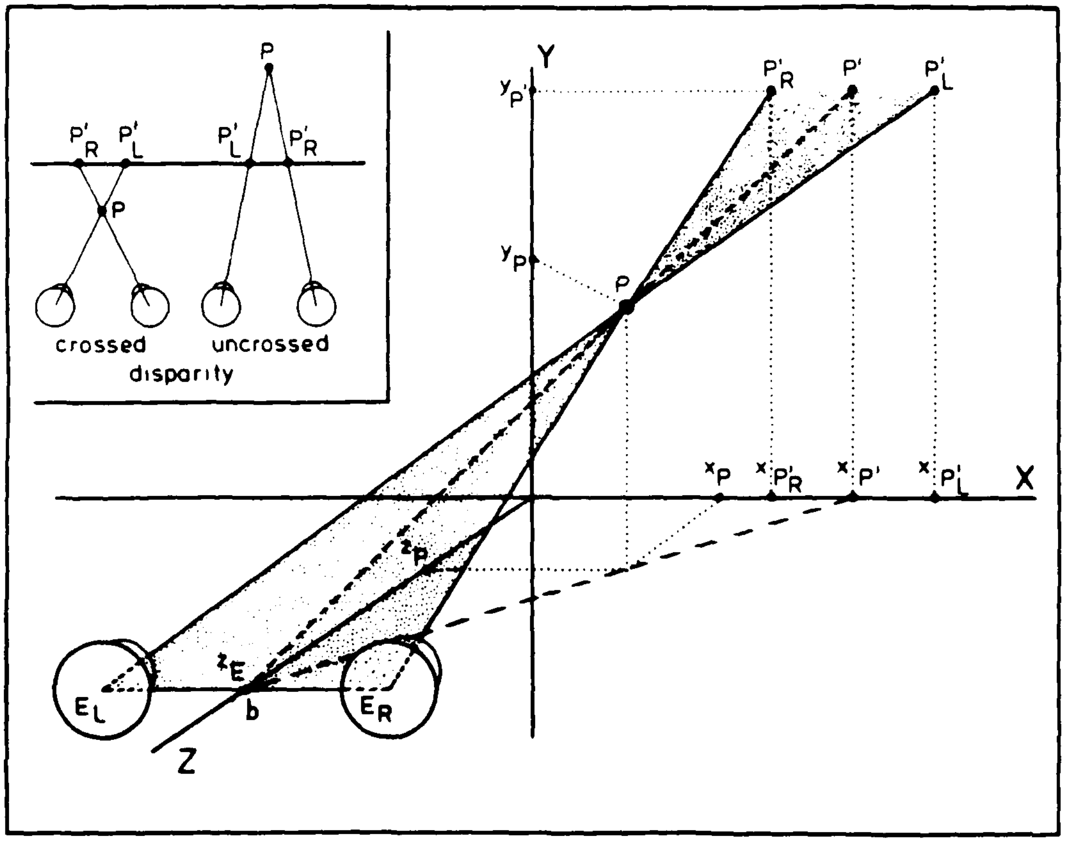

Fig. 5 Geometry of stereoscopic image generation. The point P, with coordinates x_P, y_P, z_P, is generated by the left and right-eye projections P'_L and P'_R. The corresponding x,y (display) coordinates are the x-coordinates $x_{P'L}$ and $x_{P'R}$, and the common y-coordinate $y_{P'LR}$. The two eyes (E_L, E_R) are separated by the eye-base b, which is bisected by the Z-axis at z_E.
Note that increasing or decreasing the separation between P'_L and P'_R (by varying Δx) causes P to shift away or towards the display, respectively. The inset illustrates the difference between crossed and uncrossed disparity (see text for further explanation).

Fig. 5 portrays the situation where the two eyes (E_L and E_R) are converged on a (virtual) point P, which is generated by its projections P'_R and P'_L on the display surface. These projections are located at equal distances (Δx) from the point P', where the line of sight, i.e. the line through P and the center z_E of the eye base b, intersects the x,y plane (screen). Note that changing Δx causes P to travel along the line of sight. For $P'_L > P'_R$ point P will be seen in front of the screen, a condition referred to as crossed (retinal) disparity. When $\Delta x = 0$, P'_L and P'_R merge into a single point P' (=P), as is the case when P is located in the x,y plane (no disparity). For $P'_L > P'_R$, P will be seen behind the x,y plane, and the visual axes will no longer cross in front of the screen (uncrossed disparity).
Because of the horizontal position of the eye base (b), the normal viewing condition, there is no vertical disparity ($y_{P'L} = y_{P'R} = y_{P'}$). If, unwittingly, vertical disparities are introduced on the screen, the eye will not be able to properly converge on P, and the images P'_R and P'_L will no longer be seen as a single, fused, image of P.

In order to generate P one has to calculate the coordinates $x_{P'L}$ and $x_{P'R}$ and $y_{P'LR}$ of the stereo pair P'_L, P'_R. As for the x-coordinates, these can be expressed as

$$\begin{aligned} x_{P'L} &= x_{P'} + \Delta x \\ x_{P'R} &= x_{P'} - \Delta x \end{aligned} \tag{1}$$

On the basis of simple geometric considerations one can show that

$$\Delta x = \frac{1}{2} \frac{b.z_P}{z_E - z_P} \tag{2}$$

and

$$x_{P'} = \frac{x_P . z_E}{z_E - z_P} \tag{3}$$

Eqs. (2) and (3) apply to both crossed and uncrossed disparity. In the latter case Δx takes negative values (because Z_P is negative), with the result that $x_{P'R} > x_{P'L}$, as it should be in the case of uncrossed disparity.
By substituting Eqs. (2) and (3) into Eq. (1) the x,y coordinates of the stereo pair can be calculated from the coordinates specifying the point P and the viewing point E. That is,

$$x_{P'L} = \frac{x_P . z_E + 1/2b(z_E - z_P)}{z_E - z_P} \quad (4)$$

$$x_{P'R} = \frac{x_P . z_E - 1/2b(z_E - z_P)}{z_E - z_P} \quad (5)$$

Further it can be shown that the common y-coordinates of the stereo pair are given by:

$$y_{P'L} = y_{P'R} = \frac{y_P . z_E}{z_E - z_P} \quad (6)$$

The subscripts of the coordinates represent:

P'_L = left-eye image
P'_R = right-eye image
P = stereoscopic image
E = eye position

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The effect of stereoscopic presentation on a simulated Air Traffic Control task

11. AUTHOR(S)

J. Walraven and A.D. Hekstra

12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

TNO Institute for Perception
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

TNO Division of National Defence Research
Koningin Marialaan 21
2595 GA DEN HAAG

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

Collision prediction in a simulated Ai.· Traffic Control (ATC) task was compared for conditions in which the aircraft displacements on the radar display were shown in either two or three dimensions. The image separation that is required for stereoscopic (3D) viewing was achieved by both anaglyphic presentation (red-green glasses) and sequential field stereoscopy (electro-optical shutters). The stimuli consisted of traffic scenarios that varied in density and complexity. One of the aircraft was singled out to represent the one to be under control. The observer's task was to judge whether it was on a collision course or not. In the 2D condition, the (necessary) altitude information was provided in numerical form. In the 3D conditions, experiments both with and without numerical information were performed.

The results indicate that stereoscopic information by itself, that is, without numerical altitude information, may already be sufficient for the task under consideration. However, in the condition with combined stereoscopic and numerical altitude information, the performance was not significantly better than in the 2D condition employing numerical information only. Nevertheless, subjects preferred the stereoscopic display over the (normal) two-dimensional format.

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