Report LR-403

PERCEPTION OF ROLL RATE FROM AN ARTIFICIAL HORIZON AND PERIPHERAL DISPLAYS

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Delft - The Netherlands
November 1983
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Presented at the 19th Annual Conference on Manual Control

Delft - The Netherlands

November 1983
SUMMARY

It was shown earlier that peripheral side displays can help to improve the performance of subjects in tracking tasks. The work reported in the present report was undertaken to find out whether this improvement was due to an increase in 'arousal level', a more accurate or a faster perception of roll rate.

The experiment described investigates the perception accuracy of roll rate by subjects from a central CRT-display (simulated artificial horizon), peripheral side displays (moving checkerboard pattern) and both displays combined. Discrete values of roll rate were presented to the subjects during exposure times between 0.1 and 0.8 second.

Immediately after stimulus exposure the displays were either plainly blanked or masked by a dithering line on the central display or dithering of the checkerboard pattern on the peripheral displays.

Results show that the roll rate perception process from peripheral displays is more accurate and up to 0.1 second faster than from the central display. Masking shows to have a different influence on the central visual perception than on the peripheral visual perception.
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1. INTRODUCTION

The tests described in this report are a part of a larger research program in the field of pilot's motion perception, presently in progress at the Department of Aerospace Engineering of the Delft University of Technology. It is well known that simulator or airplane motion visible in the peripheral visual field have an influence on pilot's control behaviour. See Refs. 1, 2, 3 and 4.

In Refs. 3 and 4 an experiment was described where all combinations of a central CRT-display (simulating an artificial horizon) two peripheral side displays and simulator cockpit motion were used to establish the influence of the separate and combined ways of motion perception on subject's tracking performance and control behaviour. The results of that experiment showed a strong performance improvement due to the addition of peripheral visual cues and motion cues. Further a considerable change of subject's control behaviour in terms of increased cross-over frequency and/or phase margin, was demonstrated.

due to the fact that these improvements were achieved only by changing the display configuration (i.e. adding peripheral visual cues and or motion cues) it was assumed that the above mentioned improvements resulted only from improvements of the first step of the subject's information processing i.e. the perception process. Due to the lack of information on the accuracy of perception and the time needed to observe and process the different sensory stimuli in a typical piloting situation, a more detailed investigation on motion perception was started.

It will be obvious that visual stimuli presented on a CRT-display or on a TV-monitor are much easier manipulated than the motion stimuli generated by a simulator motion system. Therefore it was decided to study motion perception from central and peripheral visual displays first.

In Ref. 5 first results of two experiments on roll attitude and roll rate perception were presented. A number of important differences between roll attitude perception and rol rate perception emerged from these first attempts, the most important being perhaps that attitude perception is more accurate and is done quicker than rate perception.

The present report describes an extended study on roll rate perception only in which the same central and peripheral displays were used. Just as in the previous experiment, discrete roll rate stimuli were presented to the subject. Subject's were requested to make an accurate estimation of the rates and to answer by pressing the appropriate key of a keyboard. One important aspect of a
closed loop task was retained by displaying the subject the error magnitude immediately after the response. In the present experiment the range of exposure times was shifted to exposure times shorter (down to 0.1 sec.) than the ones in the experiment reported in Ref. 5. In one experimental configuration the displays were masked. This was done in order to investigate, if as for attitude perception, there is a so-called 'iconic memory' for rate perception. With these two extensions a wider range of perception accuracy could be assessed. The influence of redundant observations, resulting from the combination of central and peripheral displays, on the roll rate perception accuracy, were studied in some detail.

Apart from the extensions to the tests of Ref. 5, the number of subjects was extended from two to three in such a way that all three test subjects completed all tests of the extended experiment.

The main output variables of the experiment are the perceived roll rate and the response time. The question has to be raised whether changes in response time due to changes in display configuration and exposure time should be attributed to the perception process alone. The further steps of the information processing however are not changed. It has been argued in Ref. 6 that the effects of disturbances of parts of the information processing on the response time are additive, if the disturbances each act on a different step of the information processing.

Thus if the perception process in the present experiment needs a longer or shorter time interval the response time will correspondingly be longer or shorter and there is no need to expect any interaction on the decision and response steps of the information processing.
2. TEST FACILITY AND DATA REDUCTION

All measurements were performed in a low noise room where, in front of the subject's seat, a central (foveal) CRT-display (Tektronix 604 monitor), was mounted in an instrument panel. Peripheral visual cues were provided by two TV-monitors (Bosch Fernseh Monitor) placed on each side of the subject's seat, see Fig. 1. Subjects gave their responses via a digital keyboard, see Fig. 2.

The relative positions of central and peripheral displays and the subject's eye reference point are shown in Fig. 3.

Also shown in Fig. 3 is the image on the central display, simulating an artificial horizon. The repetition rate was 250 times/sec. and the position of the horizon line was updated at a rate of 50 times/sec.

The peripheral displays showed a moveable checkerboard pattern with squares of 5 x 5 cm generated by a moving pattern generator (developed at the Delft University) at a repetition rate of 30 frames per second.

All experimental runs were controlled by a hybrid computer (EAI Pacer 100). A rather complete description of the test facility hardware and the computer programs is given in Ref. 7.

During the experiments, each run consisted of 100 stimuli at fixed intervals, the sequence during one interval was as follows, see Fig. 4.

At the beginning of an interval a new value \( e_{n_1} \) of roll rate was presented and this event was marked by an audiotone in the subject's headset. After observation the subject was required to respond by pressing the appropriate key of the keyboard. The response magnitude is designated by \( \Delta_0^n \). Immediately after the response the error value

\[
e_{n_2} = e_{n_1} - \Delta_0^n
\]

was shown on the display, thus giving the subject an immediate knowledge of the result. The exposure time \( \Delta t_{\text{exp}} \) could be varied and was set at a constant value by the experimenter prior to each run. In one particular experimental condition, the exposure was retained until the subject's keyboard response. In all other conditions the stimulus \( e_{n_1} \) was made to disappear at the end of the preset exposure time. In that case subjects were required to give responses only after termination of the exposure, responses during exposure time were neglected by the computer program in all test runs with limited exposure time.

Termination of the exposure could be programmed in either of two ways. Apart from simply 'blanking' the display after exposure, an additional feature of the
test facility was that immediately after exposure, the central and the peripheral displays could be masked.

The central display was masked by a horizontal line randomly moving up and down. This was controlled by a wide band (5 Hz) zero mean noise signal. The peripheral displays were masked by making the checkerboard pattern move randomly up and down by the same noise signal.

At the start of a next interval a new value of roll rate was generated by adding a quantized sample \( i_n \) of a noise signal to the latest value of the error value \( e_{n_2} \):

\[
e_{n_1} = e_{(n-1)_2} + i_n
\]

The standard deviation of the noise signal from which the sample \( i_n \) was taken and the scaling of the display were chosen such that the number of discrete values and the practical range of \( i_n, e_{n_1}, e_{n_2} \) and \( \Delta O_n \) during the experiment corresponded to the range and the number of keys used on the keyboard device (± 10 keys).

During each run, the variables \( i_n, e_{n_1}, e_{n_2}, \Delta O_n \) and the subject’s reaction time RT were recorded.

After a run the following values were calculated by the computer:

- the number of correct keyboard responses, \( n_c \),
- the number of times that a display level \( j \) was shown, \( n s_j \),
- the sum of observation errors per display level \( j \), \( n e_j \),
- the mean value and variance of \( i_n, e_{n_1}, e_{n_2}, \Delta O_n \), the reaction time RT and a score parameter \( S_c \), defined by

\[
S_c = \frac{\sigma^2_e}{\sigma^2_{e_{n_2}}} + \frac{\sigma^2_e}{\sigma^2_{e_{n_1}}}
\]
3. EXPERIMENT

As mentioned in the introduction the present experiment is an extension of the one on roll rate perception described in Ref. 5.

As before three display configurations were used: central display only (C), peripheral display only (P) and central and peripheral displays combined (CP). The stimulus interval time was set at 2 seconds as in the earlier experiment. The range of the roll rates presented was to be representative of routine airline flight ($\phi_{\text{max}} = \pm 25 \text{ deg./sec.}$), so the standard deviation was set at $\sigma_{\phi} = 8 \text{ deg/sec.}$ The range of keys to be used on the keyboard was set again at $\pm 10$ corresponding with $\pm 25 \text{ deg./sec.}$ on the displays.

Based on previous experience the range of exposure times used in the present experiment was chosen such that the score parameter $S_c$, i.e. subject's performance, was most strongly influenced.

The minimum exposure time was imposed by the hardware of the test facility. The peripheral displays, having a repetition rate of 30 frames/sec., can only display 3 frames during an exposure time of 0.1 sec., which was, after extensive evaluation, considered as a minimum for the present tests.

In the previous experiment the minimum exposure time was varied between 0.2 and the response time RT ($\pm 0.8 \text{ sec.}$). In that exposure time range, the score parameter $S_c$ for the central display configuration (C) was influenced, but in the case of the two other configurations (P and CP) the score parameter $S_c$ did hardly change.

The pre-experimental evaluation shows that using 0.1, 0.15, 0.2, 0.3 and 0.4 sec. as exposure times, the roll rate perception process and thus the score parameter $S_c$ could be influenced over a wide range for all three displays configuration.

From the previous experiment on roll attitude perception and from Sperlings work Ref. 8 it is known that the perception of roll attitude or characters deteriorates if immediately after a short exposure, a random image is exposed.

This phenomenon called 'masking' is due to the fact that the 'noisy' picture partly destroyed the short visual storage of images (iconic memory). The question raised was whether for rate perception there would also exist a short visual storage or iconic memory. Therefore the experiment was extended with the masking feature for the exposure times mentioned above. In addition to the above mentioned experimental conditions, the exposure time was extended to the subject's response. In that case the displays could not be blanked or masked. With the above mentioned experimental conditions a total number of 33 different experimental runs were obtained. Each subject replicated all 33 experimental runs 5 times.
4. SUBJECTS AND TEST PROCEDURE

Three subjects, two University staff members and one Dutch Airworthiness Authority staff member, all three qualified jet transport pilots, volunteered in the experiment. They were instructed to respond primarily as accurate and secondly as quickly as possible to the presented stimuli. They were not required to continually fixate their eyes on the central display but were free to look at the keyboard device when giving responses. If only peripheral displays were used, subjects were instructed to fixate their eyes after responding, on the blank central display, until the next response. Apart from the immediate feedback of the error after each keyboard response, subjects were informed of the score parameter $S_c$ and the number of correct keyboard responses after each run.

For the preliminary evaluations and for the purpose of training a total number of 220 runs was made. After an adequate steady level of performance was obtained in this way, the experiment was carried out during a number of morning sessions. This number of sessions differed over the subjects due to the large number of experimental runs and depending on subjects availability. A total of $33 \times 3 \times 5 = 495$ runs were made for the experiment.
5. RESULTS

The results of the score parameter in the present experiment are shown in Figs. 5 and 6. Rate perception from the central display only with the exposure time $\Delta t_{\text{exp}}$ equal to the response time $RT$ will be referred to as the standard condition. There is a clear difference between the score parameters for roll rate perception from the central display (C) only on the one hand and the peripheral displays (P) and the combined central and peripheral display (CP) on the other. From the peripheral displays a more accurate roll rate perception is achieved, especially at short exposure times.

It is apparent that the roll rate perception needs a much longer exposure time to reach the final accuracy, in the case of a central display than in the case of the peripheral displays.

Masking (see Fig. 6) influences the roll rate perception at the small exposure times ($\Delta t_{\text{exp}}$, 0.2, 0.15 and 0.1 sec.). In the case of the combined central and peripheral displays, subjects apparently are not able to derive any additional information from the peripheral displays at $\Delta t_{\text{exp}} = 0.1$ sec. This causes the score parameter $S_c$ to increase from 0.158 to 0.475 due to masking at $\Delta t_{\text{exp}} = 0.1$ sec.

When considering the decrease of the score parameter with increasing exposure time the following analytical function can be used to model this phenomenon:

$$S_c = A + B e^{-\Delta t_{\text{exp}} / \tau} \quad (5.1)$$

Equation (5.1) is in fact a tentative model of perception and its subsequent processing based on the reasonable hypothesis that a certain time duration is needed to obtain a reasonable estimate of a noisy observation.

The simple expression enables us to express the decrease of the score parameter with exposure time by the time constant $\tau$, see Fig. 7.

The following tables gives the different values obtained with eq. (5.1).

<table>
<thead>
<tr>
<th>Display configuration</th>
<th>Blanking $\tau$ in sec.</th>
<th>Masking $\tau$ in sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>0.070</td>
<td>0.068</td>
</tr>
<tr>
<td>Peripheral</td>
<td>0.041</td>
<td>0.072</td>
</tr>
<tr>
<td>Central and Peripheral</td>
<td>0.041</td>
<td>0.061</td>
</tr>
</tbody>
</table>
In this way the shorter exposure time needed to perceive the roll rate if peripheral visual cues are available, are expressed in terms of smaller time constants in eq. (5.1).  
In table 1 the results of analysis of variance on the score parameter $S_c$ and response time RT are given.

Subjects, display configurations and exposure time are seen to have a significant influence on the score. Masking itself has no influence at all, but the interactions between masking and exposure time and masking and display configurations do have a significant influence.

In Fig. 8 the response times RT are shown as a function of exposure time. The mean values of the response times are shorter than the response time for the standard condition. The response time for rate perception from the central display is longer than for the conditions with peripheral and central and peripheral displays, see table below.

<table>
<thead>
<tr>
<th>Display configuration</th>
<th>Blanking RT in sec.</th>
<th>Masking RT in sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>0.83</td>
<td>0.85</td>
</tr>
<tr>
<td>Peripheral</td>
<td>0.77</td>
<td>0.76</td>
</tr>
<tr>
<td>Central and Peripheral</td>
<td>0.80</td>
<td>0.82</td>
</tr>
</tbody>
</table>

The results of the analysis of variance in Table 1 show a significant influence on the response time of the subjects, the display configuration and the interaction between exposure time and masking.

In Figs. 9 and 10 some examples of the mean errors of the perceived roll rate $\Delta \dot{\varphi}$, plotted as a function of displayed roll rate $\dot{\varphi}$ for the display configurations C and CP and exposure times $\Delta t_{\text{exp}} = 0.1$ and 0.4 sec. are shown. The perception error is increasing with increasing absolute magnitude of the perceived roll rate, resulting in a typical V-shaped curve. Decreasing exposure times tend to shift these curves upwards to larger values of $\Delta \dot{\varphi}$. 
6. DISCUSSION AND CONCLUSIONS

Rate perception, blanking and masking
From the results it appears that roll rate can be perceived from the central as well as from the peripheral displays. However, responses for the peripheral displays are faster than for the central display. This fact emerges from the shorter exposure time $\Delta t_{\text{exp}}$ needed for accurate roll rate perception. In more general terms this can be expressed by the shorter time constant in the expression of chapter 5. In addition the response times $RT_p$ and $RT_{\text{CP}}$ are shorter than the response time $RT_{\text{C}}$.

Based on Ref. 6 it is concluded that the change in response time result from the changes in the perception stage of the information processing due to the changes in the display configuration.

The influence of masking on the perception process seems to be rather complicated. The score parameter increases for the shortest exposure times. Thus roll rate perception becomes less accurate. The response times are hardly influenced. The time constant $\tau$ as defined in eq. (5.1) for the peripheral display- and central- and peripheral display configuration are increasing due to masking.

The relative increase of the score parameter for the peripheral displays $S_{\text{CP}}$ is larger than for the central display. The increase of the score and its standard deviation due to masking corresponds with the greater uncertainty in the perception process. Based on these results an 'iconic memory' for rate perception seems to be possible.

Due to the differences in minimum exposure time needed, the shorter response time and larger influence of masking, it can be concluded that the perception of roll rate from peripheral displays and central display are to be considered as different processes.

Do subjects combine redundant sources of information?
From the foregoing it is obvious that subjects use and combine information from both kinds of displays. It is easily derived (see Refs. 9 and 10) that if $\sigma_z^2$ is the variance of an optimal estimation of $z$ derived from different and independent observations $z_1$ and $z_2$, characterized by $\sigma_{z_1}^2$ and $\sigma_{z_2}^2$ respectively, that the following relation holds:

$$\frac{1}{\sigma_z^2} = \frac{1}{\sigma_{z_1}^2} + \frac{1}{\sigma_{z_2}^2}$$

(6.1)
Using the score parameter, the corresponding expression would become:

$$\frac{1}{(S_c)_{CP}} = \frac{1}{(S_c)_{C}} + \frac{1}{(S_c)_{P}}$$  \hspace{1cm} (6.2)

In Fig. 11 the score $S_c$ calculated according to (6.2) has been plotted as a function of the measurement score $S_{CP}$. The result of the masking condition with exposure times 0.1 and 0.15 sec. were not used, due to the fact that the score parameters $S_{CP}$ and $S_C$ were almost equal and the response times $RT_{CP}$ and $RT_C$ were almost equal. This indicates that the subjects did not use peripheral information.

It appears that:

$$\hat{S}_{CP} = 0.0061 + 0.70 S_{CP}$$

From the results now available it is apparent that subjects indeed combine the available information to a more accurate perceived roll rate.

That the experimental results do not fit the relation given by eq. (6.1) may be due to the fact that subjects either do no 'optimally' combine independent sources of information or that the information derived from the different displays is not strictly independent.
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Table 1: Results of the analyses of variance, on the score parameter $S_c$ and the response time RT.

<table>
<thead>
<tr>
<th></th>
<th>$S_c$</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects S</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>Exposure time $\Delta t$</td>
<td>****</td>
<td>*</td>
</tr>
<tr>
<td>Display configuration C</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Blanking/Masking M</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td>Interactions:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta t, S$</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>$C, S$</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>$M, S$</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>$\Delta t, C$</td>
<td>****</td>
<td>*</td>
</tr>
<tr>
<td>$\Delta t, M$</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>$C, M$</td>
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<td>$\Delta t, C, S$</td>
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</tr>
<tr>
<td>$\Delta t, C, M$</td>
<td>****</td>
<td>*</td>
</tr>
<tr>
<td>$\Delta t, C, M, S$</td>
<td>-</td>
<td>***</td>
</tr>
<tr>
<td>Replications</td>
<td>***</td>
<td>-</td>
</tr>
</tbody>
</table>

$\alpha < 0.25$  *
$\alpha < 0.10$  **
$\alpha < 0.05$  ***
$\alpha < 0.01$  ****
Fig. 1. Overview of the test facility showing central display, the peripheral displays and the digital keyboard.

Fig. 2. Digital keyboard device.
Fig. 3. Positions of displays relative to the subject's eye reference point. Central display image and dimensions.
Fig. 4: Sequence during one interval of a test run.

Fig. 5: Score parameter $S_c$ for blanking as a function of exposure time $\Delta t_{\text{exp}}$ and display configuration.
Fig. 6: Score parameter $S_c$ for masking as a function of exposure time $\Delta t_{\text{exp}}$ and display configuration.

Fig. 7: The model of eq. (5.1) fitted to the data of the display configuration with control display only and blanking after stimulus exposure.
Fig. 8a: Response time to roll rate stimuli as a function of exposure time and display configuration and blanking after stimulus exposure.

Fig. 8b: Response times to roll rate stimuli as a function of exposure time and display configuration and masking after stimulus exposure.
Fig. 9: Mean error $\Delta \dot{\phi}$ roll rate as a function of displayed roll rate $\phi$. Central display only, blanking.
Fig. 10: Mean error $\Delta \dot{\phi}$ of perceived roll rate as a function of displayed roll rate $\dot{\phi}$. Central and peripheral displays, blanking.
Fig. 11: The estimated score parameter $\hat{S}_C$ versus the actual score parameter $S_C$ for the central and peripheral displays combination.