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시각작업시 등반응시간영역의 생성†

Generation of Isoresponse Time Regions in Visual Tasks†

정의승* · 정민근* · 기도형**

Eui S.Jung* and Min K. Chung* · Dohyung Kee**

Abstract

Successful completion of a visual task in a predetermined time is very crucial to many operations such as piloting an aircraft. Although existing ergonomic interface models often provide a function of vision tests, it determines only the visibility at any given location. To complement this problem in existing models, the isoresponse time region considering the factors related to visual tasks is presented. Using a multiple regression model, equal response time regions were obtained within which mean response time is expected to be the same and is asymmetrical in shape. Among the factors considered, expectancy significantly decreased response time, and when cued, the effects of field heterogeneity, target uncertainty, density, size contrast and peripheral position on search time were less significant than those in unexpected cases. Response time and error rate, gender and visual acuity were not significantly correlated, and response time and age was positively correlated. These results are expected to be directly applicable to designing various visual tasks in real-life situations.

1. Introduction

Operators in industry often face the situation where they must be able to detect and respond to peripheral visual stimuli in a variety of real-life situations such as piloting an aircraft, ground-to-air aircraft detection, industrial inspection, and monitoring various kinds of display/control panels. To properly estimate the visibility in real-life situations, several man-modeling interface systems(e.g., SAMMIE, CAR, PLAID/TEMPUS) which provide a function of vision tests have been developed and are presently in use. For example, SAMMIE provides a two-dimensional visibility plot and a three-dimensional visibil-

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* Department of Industrial Engineering, Pohang Institute of Science and Technology

** Department of Industrial Engineering, Dongeui University

ity chart. In many cases, it is very crucial to successfully complete visual search tasks in a predetermined time, however, there has been no time concept embedded in any of existing ergonomic interface models. These models check only whether or not an object in front of workers or operators can be seen [17,22]. To complement this restriction of existing ergonomic interface models, the concept of an isoresponse time region is introduced in this study.

In such visual tasks, there are various determinants having an effect on response time to detect a target. Variables considered so far are differences between targets and nontar-gets, the number of nontargets, nontarget density, the distribution of nontargets, the number of nontargets, nontarget density, the distribution of nontarget stimuli, the size of search area, axis inclination (meridian), peripheral stimulus location, visual acuity, age, the orientation of a target, blur interpretation, cuing (cued or no cued) and physical stressors (high luminance, hypoxia, etc.) [2, 4, 11, 12, 15, 29]. When we fixate an eye to a point, our photopic visual sensitivity reaches its maximum along the line of sight, and it decreases approximately linearly into the periphery [6]. Although numerous research on visual search have been reported, only a few studies were found which investigated detection time as a function of the peripheral position of a target in the field of view [11, 14, 23, 24].

The most comprehensive study among these was Haines' stydy [11], in which response time in the full visual field was investigated for 72 locations on 9 peripheral positions and 8 meridians. Two linear least squares fits per meridian were obtained and the grand mean data were replotted from these curves as isoresponse time regions within the visual field, each boundary of which indicates the region within which mean response time is expected to be the same. These data, however, should be applied to actual design situations with caution, since these response times were obtained under almost ideal viewing conditions. In addition to peripheral position and meridian, increasing nontarget density with search area being constant produces increase in search time [9], and increasing the size of disply with density constant (by increasing the number of nontargets) has a highly significant effect [13, 7]. Congested target surrounds also linearly increases geometric mean search time [5, 19]. When stimuli of varying color, shape, size and contrast are used as nontarget stimuli, search time increases as the heterogeneity of other stimuli increases [9, 13]. Search times are exponentially distributed and response times are found to be inversely proportional both to the difference between the log of target and nontarget disc diameters, and the difference between the diameters [4]. Directed attention as a result of foreknowledge of the test disc location, generally increased the visual field [8]. In applied visual search, telling the subject whether or not a target was present had little effect on search performance [26]. Target uncertainty is found to produce 9.5% increase in search time and do not interact with either target difficulty or target position [18].

It is apparent from this review that the studies have been reported on the effect of various variables separately on search times, with no proper control of other variables. It is necessary to study the effect of such variables together, since various engineering designers require estimation of response time for more real situations. The purposes of this research are, therefore, to (1) investigate the effects of various factors on search time-field heterogeneity, target uncertainty, non-target density, size contrast, directed attention, peripheral position, and meridian, (2) obtain the isoresponse time region taking into account the effects of meaningful variables related to visual search tasks together. While there are various types of targets and non-targets, alphanumeric characters which appear most frequently in real-life situations were used in this study.

2. Method

2.1 Subject

Fourteen subjects, 9 males and 5 females, participated in this study with ages ranging from 20 to 34 with an average of 23.1. None of the subjects had pervious experience in search tasks of the type used here, and had color defects or other visual dysfunctions. All had binocular corrected far visual acuity ranging from 20/40 to 20/13 in snellen acuity.

2.2 Apparatus and Stimuli

A two-field tachistoscope with 75-125㎜ zoom projection lens was used. It had an active viewing area of 155㎝ horizontally × 122㎝ vertically projected on a rear-view projection screen located about 420㎝ in front of the display screen, subtending 51° and 43°, respectively. The tachistoscope was connected to a personal computer in such a way that Field B (fixation field, a crosshairs on the center of the screen) was presented continuously until any button on the keyboard was pressed to expose the stimulus (Field A) and then turn off Field B. The stimuli of the background were alphanumeric characters, subtending 0.75° horizontally and 0.67° vertically on a blue background surface, the size of which is similar to the characters used in the display of cars or cockpits, and an alphabetic target appeared at any one of 64 locations on 8 meridians passing through the fixation point in the center of the screen as in Figure 1. The luminance of the background was 0.81fL, and 6.40fL for the characters. A head-rest was used to position the subject at the correct distance from the screen.

Since the size of the full factorial design considering the seven factors is practically too large, L512 orthogonal arrays were used in the present study[25]. The seven independent variables and its interactions (except the interaction of meridian and peripheral) were arranged in 512 columns on L512 orthogonal arrays as in Table 1. The targets used in this stydy were found by the pre-experiment to be of equal difficulty. Two blocks were defined depending on whether the subject was informed of the target location: expected block and unexpected block. Each subject attended ten consecutive sessions on separate days, which were consisted of four training sessions and six experimental sessions. To help control circadian effects, subjects were tested at approximately the same time of a day. Each session comprised 38 practice trials and 256 experimental trials, and lasted about 30 minutes.

The subject was seated in front of the display in an isolated room in a chair with a head-rest, with his or her arms resting on the keyboard, with his or her eye staring at the fixation point. When the information of target types and locations is shown on the PC terminal, the subject initiated by pressing any key. Then Field A of the tachistoscope was opened, showing a display on the screen. The subject was instructed to use free search for the target, press any key as soon as the target was found. The subject was also cautioned against making errors. Then Field A of the tachistoscope was closed, and Field B opened, and a fixation point of crosshairs appeared on the screen. One minute rest was taken after every 64 trials. Search performance was measured as the time between the subject's initiation and termination of the experiment, and was recorded automatically. The whole experiment was self-paced.

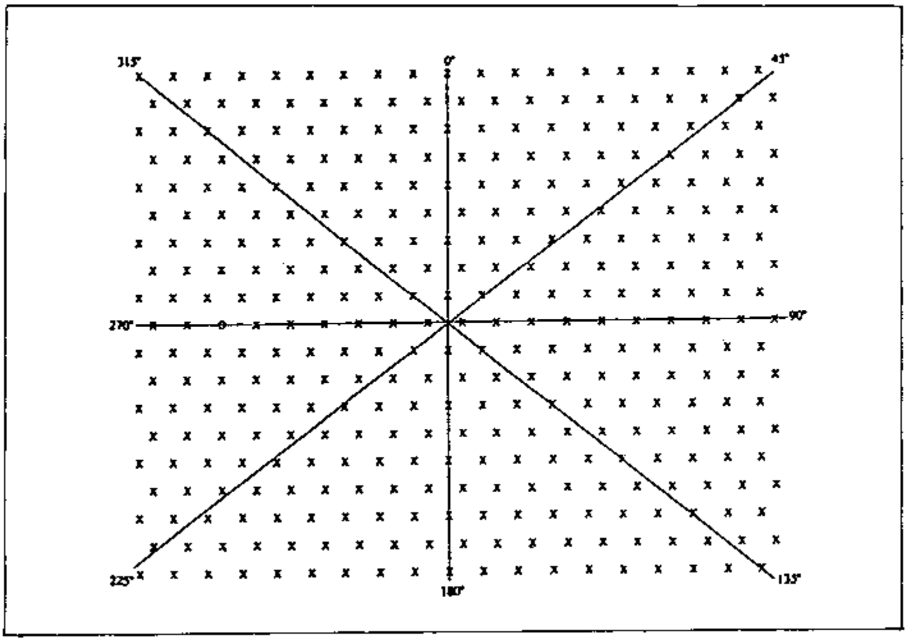


Figure 1. Stimulus with an O Target and the Meridians Used

Table 1. Definitions of Seven Independent Factors

Factor	Definition
Field heterogeneity (H)	$\frac{\text{No. of nontarget types}}{\text{No. of nontargets}} \times$ density
Target uncertainty (U)	$\log_2 n$, n = number of targets
Density (D)	N/A, N = No. of nontargets, A = area of display screen
Size contrst (S)	Height difference between targets and nontargets $\frac{H-H_0}{H_0}$, H = height of targets, H_0 = height of nontargets
Peripheralposition (P)	Angular separation from the fixation point
Meridian (M)	Angle of the axis
Expectancy (E)	Cued or not cued on target location

3. Results

Not much learning in response time was observed after the second session, although learning apparently took place during the first two sessions. Total error rate was 0.6% and those trials were excluded from all further analyses. In general, the frequency distributions of search times were found to be positively skewed. To minimize the effect of such skewness, each datum on search time was transformed logarithmically prior to analysis, and the geometric mean search time(GMST) was used as a measure of average search time [4, 18, 19].

3.1. Analysis of Variance

The results of analysis of variance are illustrated in Table 2. The seven main effects -expectancy, field heterogeneity, target uncertainty, denisty, size contrast, peripheral position, and meridian-were found to be significant at $p<0.05$. The largest effect appeared in size contrast, and the second in expectancy, and the third in peripheral position. All interactions except E × M and H × U were found to be significant, while the largest effect of interactions appeared in E × S, and the second in E × P, which implies that when cued, the effects of size contrast and peripheral position were not significant on search time. In other words, when size contrast gets large, and/or peripheral position is near the line of retina, size contrast and peripheral position did not play an important role in the expected block, as shown in Figure 2.

Table 2. Results of the Analysis of Variance

Source	d.f	Mean squares	F
E	1	25.9215	152.8468
H	3	3.1114	18.3467
U	3	2.1481	12.6667
D	3	4.4720	26.3694
S	3	29.6861	175.0447
P	7	9.7597	57.5479
M	7	0.9884	5.8271
E×H	3	0.8742	5.1549
E×U	3	0.5571	3.2848
E×D	3	0.9306	5.4872
E×S	3	7.4713	44.0545
E×P	7	2.6941	15.8857
E×M	7	0.2139	1.2610*
H×U	9	0.1525	0.8990*
H×D	9	0.4362	2.5722
H×S	9	0.6852	4.0401
U×D	9	2.1415	12.6274
U×S	9	0.7097	4.1849
D×S	9	1.1428	6.7383

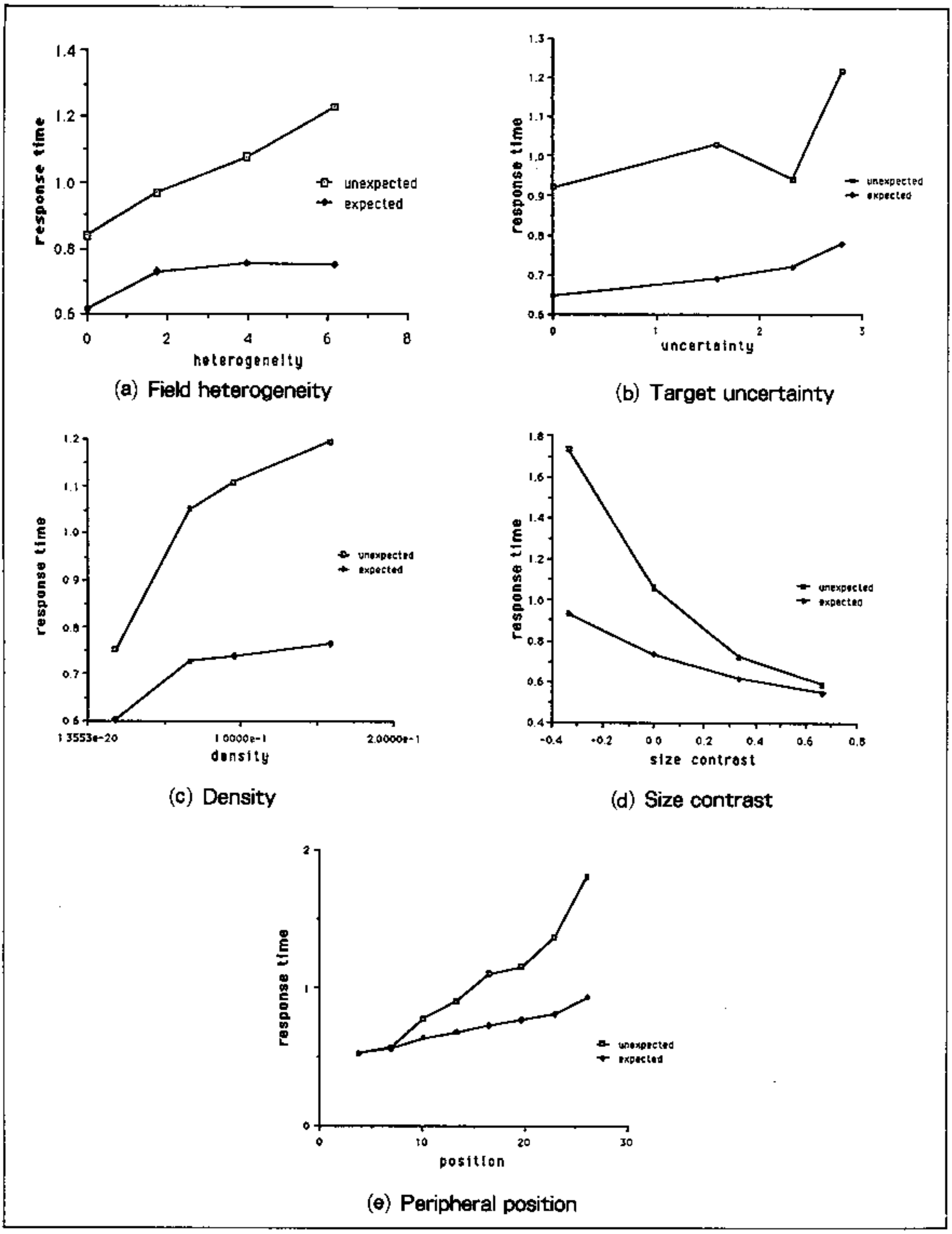
* : not significant

3.2 Effect of Expectancy on Other Factors

The results of T-test showed that the difference between the expected and the unexpected block was significant($p<0.001$), as shown in Table 3.

Table 3. Results of T-test of Expectancy on Response Time

Block	N	Mean	Std. Dev.	T-value	P-value
Unexpected	256	1.027	0.799	6.07	0.0000
Expected	256	0.709	0.257		



(a) Field heterogeneity

(b) Target uncertainty

(c) Density

(d) Size contrast

(e) Peripheral position

Figure 2. Trends of Heterogeneity, Uncertainty, Density, Size contrast and Peripheral Position on Response Time at Each Block

In each experimental block, the effects of each factor mentioned above were illustrated in Figure 2. In the expected block, the degree of effects of each factor was smaller than that in the unexpected block. In the unexpected block, response time increased linearly as field heterogeneity and peripheral position increased, and increased logarithmically as density increased, and decreased linearly as size contrast increased. The difference of response time between the expected and the unexpected block increased as field heterogeneity, density and peripheral position increased and size contrast decreased, but in case of target uncertainty, the difference was not manifest as other factors showed. Especially when size contrast gets larger and peripheral position smaller, response time was nearly the same as that in both experimental blocks. These results can be proved by the fact that interactions of size contrast and expectancy, peripheral position and expectancy were large and that of target uncertainty and expectancy was smaller compared with that of other factors and expectancy from the results of ANOVA in Table 2. These imply that each factor does not play an important role when cued.

3.3 Effect of Meridian

The effect of meridian on response time were illustrated in Figure 3, where the shortest response time was obtained on right meridian in horizontal axis($\phi=90°$), the second on upper meridian in vertical axis($\phi=0°$), the third on left meridian in horizontal axis ($\phi=270°$). In the expected block, the results of T-test showed that response time on meridians in the horizontal and vertical axis was shorter than other meridians, and comparing right meridian with left meridian in horizontal axis and upper meridian with bottom meridian in vertical axis, response times on right and upper meridian were shorter

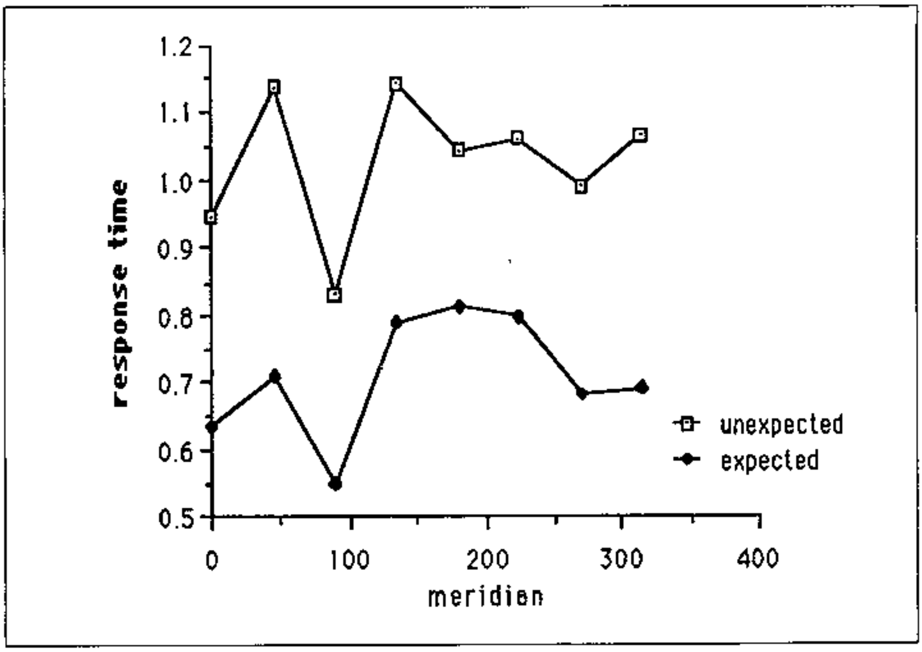


Figure 3. Effect of Meridian on Response Time in Each Block

than those on left and bottom meridians. In the unexpected block, however, there was no significant difference in response time among meridians as shown in Table 4.

Table 4. Results of T-test on Response Time among Meridians

(a) Unexpected block

Meridian	N	Mean	S.D	T-value	P-value
0°	32	0.946	0.544	-0.63	0.53
180°	32	1.043	0.688		
45°	32	1.140	1.060	0.35	0.72
225°	32	1.060	0.697		
90°	32	0.831	0.700	-0.88	0.38
270°	32	0.990	0.749		
135°	32	1.140	1.060	0.32	0.75
315°	32	1.067	0.789		
45°	32	1.140	1.060	0.31	0.76
315°	32	1.067	0.789		
135°	32	1.140	1.060	0.36	0.72
225°	32	1.060	0.697		
45°	32	1.140	1.060	-0.01	1.00
135°	32	1.140	1.060		
225°	32	1.060	0.697	-0.03	0.97
315°	32	1.067	0.789		

(b) expected block

Meridian	N	Mean	S	T-value	P-value
0°	32	0.636	0.169	-3.11	0.00
180°	32	0.813	0.274		
45°	32	0.711	0.262	-1.30	0.20
225°	32	0.800	0.288		
90°	32	0.549	0.149	-2.78	0.00
270°	32	0.682	0.225		
135°	32	0.790	0.330	1.44	0.16
315°	32	0.690	0.216		
45°	32	0.711	0.262	0.34	0.73
315°	32	0.690	0.216		
135°	32	0.790	0.330	-0.12	0.90
225°	32	0.800	0.288		
45°	32	0.711	0.262	-1.07	0.29
135°	32	0.790	0.330		
225°	32	0.800	0.288	1.73	0.09
315°	32	0.690	0.216		

3.4 Error rate, gender, visual acuity and age

The correlations between response time and error rate, gender, visual acuity and age were presented in Table 5, where the correlations between response time and error rate, gender and visual acuity were found not to be significant, while response time and age were positively correlated ($p<0.05$).

Table 5. Correlations between Response Time and Error Rate, Gender, Visual Acuity and Age

	Error Rate	Gender	Visual Acuity	Age
Response Time	0.116	0.121	0.077	0.541*

* significant at $p=0.05$

3.5 Generation of isoresponse time regions

The linear regression model for the geometric mean search time was obtained by the linear least squares fits. Three indicator variables were used as shown in Table 6. GMST and density were transformed in natural logarithms and size contrast into a reciprocal of S+1. The results are as follows :

$$LOG(GMST) = -1.630 + 0.443*M1 - 0.104*M2 + 0.0851*M3 + 0.0398*H + 0.0524*U + 0.0455*P + 0.138*LOG(D) + 0.943/(S+1) \quad (R^2=81.4\%)$$

———— unexpected block

$$LOG(GMST) = -1.220 + 0.0978*M1 - 0.0939*M2 + 0.0866*M3 + 0.0233*H$$

+0.0564 * U + 0.0845LOG (D)+0.513/(S+1)(R^2=81.9%) ——— expected block

Table 6. Indicator Variables Representing Meridians

Meridian(ϕ)	m1	m2	m3
0°	0	0	0
45°	0	0	1
90°	0	1	0
135°	0	1	1
180°	1	0	0
225°	1	0	1
270°	1	1	0
315°	1	1	1

From the above linear regression equations, GMST was replotted as isores-ponse time regions within the visual field(θ<40°) at each experimental block, with 100ms increments ranging form 500ms to 1000ms. Figure 4 shows the representative of isoresponse time regions under the number of nontarget types being 5 (H=1.767), the number of targets 3(U=1.585), the density 0.096, and the size contrast 0.333, each boundary indicating the region within which GMST is expected to be equal.

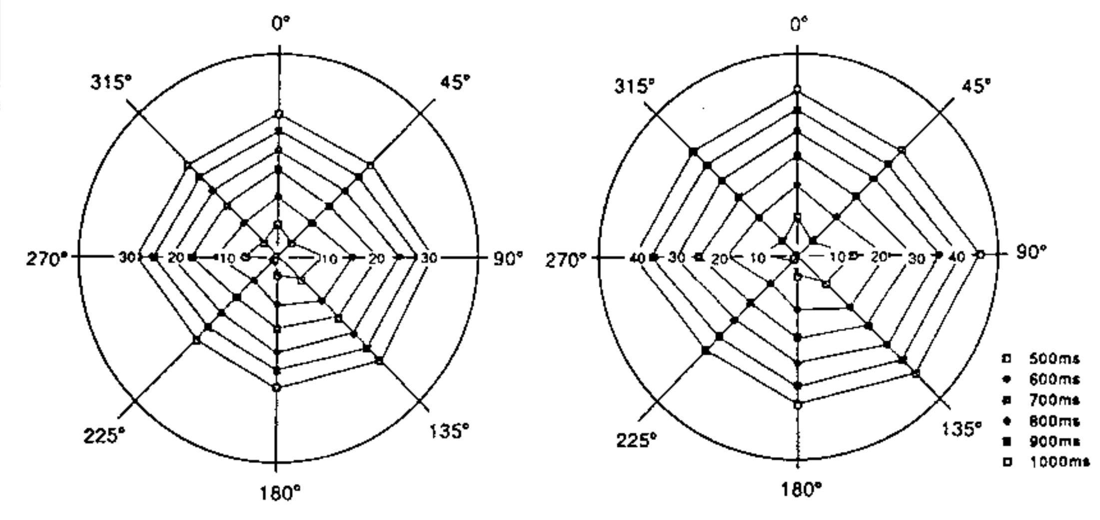
From a T-test on GMST in horizontal and vertical axis, neither significant diffference between the top and bottom, nor between the left and right meridians was shown in the unexpected block($p>0.1$), but the differences both between the top and bottom, and between the left and right meridians were significant in the expected block ($p<0.01$), as shown in Table 4. In the expected block, GMST on the vertical and right meridians was the shortest, indicating the largest isoresponse time region.

4. Discussion

The results in Table 5 showed that the correlations between response time and gender were not significant. Only the correlation between response time and age was positively correlated, which are consistent with the previous results [6, 13]. The fact that error rate and response time were not correlated disagrees with the previous finding[1], which indicated that reponse time and error rate were positively correlated. This may be due to the fact that subjects were cautioned against making errors and they perceived making errors as more severe than responding slowly, which made few errors.

Comparing the isoresponse time regions from Haines' study with those of the present study, it is seen that present isoresponse time regions are smaller and more symmetric. It is believed that the visual task used in the present study was more difficult to perform, when compared to Haines' study where only meridians and peripheral positions were considered, since the various factors were concurrently considered in the present experiment.

The isoresponse time regions in Figure 4 became symmetric when the peripheral position increased, i.e., the visual tasks became more difficult, and especially when not cued. These findings are in agreement with the previous research [3]. Engel[8] found that the influence of expectancy, also called as directed attention, as a result of foreknowledge of the target location, was not very pronounced for low values of luminance, e.g. when the difficulty of a visual task was very high. The results of this study, however, revealed that various factors showed highly significant effects on visual tasks when the difficulty of visual tasks increased in the unexpected block, but did not show significant effects in the expected block, which was the opposite to Engel's results. This fact implies that the influence of expectancy was not significant for low values of difficulty. This is proved by the fact that interactions of expectancy and all other factors except for meridian was significant in Table 3 and the signs of the coefficient of variables except for expectancy and meridian in the regression model was positive. This means that when a visual task gets difficult, it becomes necessary to supply operators or workers with expectancy by means of training or cue, but when easy, it would not be necessary.



(a) Unexpected block (b) Expected block

Figure 4. Isorespone Time Regions of Each Experimental Block

The present results can be used as a means of optimizing the location of emergency controls and displays anywhere within the subject's binocular field of view with regard to response time. It is especially true in the case when seeing a target in a predeter-mined time is more important than only seeing a target in a visibility chart (for example, for the process control in a nuclear power plant), because there are no barriers which obsure a target. The height of the targets used is similar to that of the characters in real-life situations such as those in the display of cars and cockpits. Thus we believe that the present results can be applied in real life and will complement visibility function to enhance ergonomic evaluation capability.

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