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SOME EXPERIMENTS ON EYE MOVEMENTS

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Introductory.—The experiments were devised with a view to finding the times taken, under different conditions, for a subject to move his eyes from the position in which he was fixating a point to another in which he could see a test-object, certain details of which he had to read.

The subject sat facing a large white screen in which four windows were cut. A small source of light behind a narrow slit in the screen served as the fixation point, and it was situated at the centre of the circle on which the windows lay. After the subject was comfortably seated and was looking at the fixation point, a warning signal was given and the letter C was exposed in one of the windows, that is to the right, left, above, or below the fixation point. Immediately he was aware of the light he moved his eyes towards the window in which it appeared and endeavoured to recognise the direction in which the letter was pointing.

The method used was to determine the number of mistakes made when the duration of the exposure was varied. Comparison of the number of mistakes made at the four windows with the same length of exposure was used to determine the relative times taken by the

subjects to move their eyes in different directions. We were anxious to find whether "glaring" sources of light in the field of vision had any influence on the results. At the instant at which the subject became aware of the light in one of the windows it would act as a stimulus to him to move his eyes towards that window. If at the same time another source of light was present in the field of vision, it was thought that it might act as another stimulus for fixation, the two stimuli competing for the subject's attention.* Unfortunately our evidence on this point was negative; the increase in time taken by the subject to perform the task could be accounted for in other ways.

Apparatus.—The white screen used in the experiments measured about 1 metre square and the subject sat with his eyes 46 cm. from its centre and with his chin on a fixed support. The brightness of the screen was maintained at 1.5 equivalent foot-candles by two gas-filled lamps placed so as to be out of the field of vision and to cast no shadows. Four windows, 3.8 cm. by 2.5 cm., were cut in the screen with their centres on a circle of 16.5 cm. radius, and at the centre of this circle was a horizontal slit 2.5 cm. long through which the fixation point was visible.

The test-object used was the Landolt broken circle (C) printed from a photographic negative in black on a transparent ground. The diameter of the C was 0.524 cm. and the breadth of the gap was 0.108 cm., the latter subtending an angle of 4.7 minutes to the eye. Four positions of the letter C (right, left, up and down) were printed on a slide which was bound up with ground glass and moved in runners fixed on the side of a box opposite to that on which the white screen was attached. The depth of the box was 23 cm. The subject looking through any one window in the screen could see only one position of the letter and could see it with both eyes. The slides could be illuminated from behind, at a distance of about a metre, by a 100 volt, 100 watt gas-filled projection lamp mounted behind an opening in a wooden screen. The exposure was made by a falling shutter counterpoised by means of pulleys by a weight moving in an oil dash-pot, which kept the velocity of the shutter constant. The shutter consisted of a sheet of zinc in which was a large aperture partially covered by two other pieces of zinc sliding vertically and allowing variations in the size of the aperture. The times of exposure used were 32, 30, 27, 24, 21, 19, 16, hundredths of a second. The timing of the shutter was checked from time to time by fixing a strip of blackened paper to the shutter and causing a

* Man's interest in light is well known; the advertiser, for instance, may flood-light a shop-window or exhibit arresting sky-signs; babies will look towards bright lights before other visual stimuli are effective; finally, motorists, at night, often find it difficult to avoid looking at the headlights of approaching cars. See also Loeb "Forced Movements, etc.," *Phil.*, 1918, p. 127.

FIG. 1.

tuning fork to write on it during its fall. The filament of the projection lamp was small so that the cut-off was sharp, the C being fully illuminated for practically the whole of its exposure in a window. During its fall the shutter did not accelerate, except during the first fraction of a second; the duration of an exposure was therefore the same for all windows.

When an exposure was made the subject saw a black letter on a circular ground (whose brightness was 5.15 equivalent foot-candles), the latter being framed in the rectangular aperture of the screen. Cardboard cylinders were fastened behind the four openings at the back of the box to prevent illumination of the slides from extraneous sources which might otherwise have indicated to the subject the window in which the exposure would be made. In addition, the slides were made to run quietly so that the subject could not hear them being moved.

For the investigation of the effects of glare, circular holes, 1.3 cm. in diameter, were bored in the white screen. At the back of each hole was a piece of ground glass and immediately behind this was a gas-filled lamp. When the glare was not in use the holes in the screen were plugged. The positions of the glaring sources were as follows:

Series A. Glare Inside Left (I.L.) half-way along a straight line between the fixation point and the left window.

Glare Left Top (L.T.); at the same distance from the fixation point as glare inside left and on a line bisecting the angle between the top and left windows.

Glare Outside Left (O.L.) was 20° outside the left window. It was brighter than the other glare sources and was formed by a naked 60 watt opal gas-filled lamp (diameter exposed = 5.5 cm.).

Series B. Glare Inside Right (I.R.) half-way along a straight line between the fixation point and the right window.

Glare Down Right (D.R.) immediately below glare right.

Glare Outside Right (O.R.); on the same horizontal line as "glare inside right" but on the opposite side of and at the same distance from the window.

With the exception of Glare O.L., any one of these glaring sources produced an illumination at the subject's eye of 0.6 foot-candles (measured by a lumeter). Glare O.L. produced an illumination at the subject's eye of 15 foot-candles.

Method.—Before taking readings, the subject was adapted to the brightness of the screen for from 5 to 10 minutes. During this time he sat facing the screen and adjusted the position of the chin-rest, so that by moving his eyes, and with the windows open, he could see any of the letters C or the fixation point with both eyes. The windows were then closed and the subject focussed the fixation point.

The experimenter set the aperture in the shutter and pulled out a slide to put one of the C's into position. The signal "ready" was then given and immediately the shutter was released and the exposure made.

The subject moved his eyes as quickly as possible from the fixation point to the window where the exposure was made and endeavoured to read the position of the letter. He then announced what he saw and the result was recorded by the experimenter. This operation was repeated until the four positions of the letter had been shown in each window. The order in which the exposures were to be made was determined by writing each of the 16 positions (4 windows and 4 positions of the letter) on a separate card and the cards were shuffled before each set of readings. The set was repeated for each glare source in turn, a two minutes' rest pause being allowed so as not to tire the subject unduly and to allow the eye to recover from after-images. At least three exposure times were investigated in this way on each day, starting with the largest on one day and the smallest on the next.

In series B, which was taken after the subjects were practised, a table of twelve permutations of the four conditions, no glare, glares I.R., O.R., and D.R. was drawn up and followed from day to day.

Results.—The collected results for each one of the six subjects are given in Tables I A—B and Fig. 2. The number of correct answers is given as a percentage, although in most cases less than 100 readings were taken for each window and for each set of conditions. They are arranged to show: (1) the effect of the length of exposure of the letter on the ease with which it could be read, (2), the relative ease with which eye movements in different directions could be made, and (3) the effect of different positions of the "glare" source on the subject's ability to read the letter in any one window. These three sets of data will be considered separately.

1. The effect of the duration of the exposure on the performance of the task is very marked in the case of the subjects D.C., M.K., R.L., and F.W. This is well seen in R.L.'s results for the readings in the right window (Series B, no glare) where shortening the time of exposure from 0.30 to 0.24 secs. (20 per cent.) lowers the number of correct answers from 91.5 per cent. to 40 per cent. (a fall of 55 per cent.).* The remaining two subjects, P.H. and S.M.,

* It is probable that this drop is really more marked than appears at first sight, since if the subject were to guess the direction in which the "C" pointed, making no effort at all to read it, he would, in the long run, guess 25 per cent. of the exposures correctly there being only four possible positions of the letter in one window. If during the experiment he got 60 per cent. wrong answers in a series, 20 per cent. of the correct answers would have been made by guesswork and this figure should be deducted from the 40 per cent. which he appeared to read correctly. On this basis R.L.'s apparent fall in performance from 91.5 to 40 per cent. would be more correctly represented by a fall from 88.7 to 20 per cent.

TABLE IA

Showing the effect of (1) Duration of exposure; (2) Position of the "glare" source on the percentage number of correct answers in the reading of the test-object at each window. (Series A.)

The number of readings from which the percentage is calculated is given at the beginning of each line (No. of exposures.)

Subject.	Number of exposures.	Duration of exposure in secs.	WINDOW.							
			Right.		Left.		Top.		Bottom.	
			No glare.	Glare inside left.	No glare.	Glare inside left.	No glare.	Glare inside left.	No glare.	Glare inside left.
D.C. ...	44	0.27	87	93	93	57	59	66	91	84
	44	0.24	80	80	73	25	30	34	80	70
	44	0.21	56	30	56	13	17	14	64	42
	44	0.19	21	18	40	32	5	9	14	19
P.H. ...	84	0.27	83	83	74	61	76	75	88	89
	84	0.24	74	82	68	57	70	70	89	74
	80	0.21	66	56	60	45	64	59	65	69
	80	0.19	69	68	61	48	59	63	60	53
	76	0.16	61	61	59	57	58	58	69	59
M.K. ...	60	0.27	95	99	99	99	89	80	89	91
	100	0.24	93	94	94	86	58	65	78	79
	124	0.21	86	88	90	61	33	32	61	56
	128	0.19	74	63	72	48	24	27	54	46
	76	0.16	44	45	55	54	16	15	23	23
S.M. ...	52	0.24	86	77	83	79	71	77	69	62
	56	0.21	79	72	73	72	64	73	66	45
	68	0.19	68	77	47	69	75	74	47	62
	60	0.16	69	62	42	64	80	77	45	49
F.W. ...	20	0.27	100	97	95	42	90	50	100	94
	32	0.24	75	93	72	43	44	36	81	86
	32	0.21	88	78	69	28	19	22	84	69
			No glare.	Glare left top.	No glare.	Glare left top.	No glare.	Glare left top.	No glare.	Glare left top.
D.C. ...	44	0.27	93	91	95	93	73	91	89	93
	68	0.24	82	88	85	82	44	33	85	85
	52	0.21	63	68	62	66	12	18	50	59
	48	0.19	46	33	44	44	24	19	40	30
P.H. ...	48	0.27	85	77	58	69	67	67	83	69
	60	0.24	83	83	72	53	62	53	53	62
	56	0.19	61	80	45	48	57	52	55	47
	62	0.16	88	73	56	62	52	48	56	50

TABLE 1A--*continued.*

Subject.	Number of exposures.	Duration of exposures in secs.	WINDOW.							
			Right.		Left.		Top.		Bottom.	
			No glare.	Glare left top.	No glare.	Glare left top.	No glare.	Glare left top.	No glare.	Glare left top.
M.K. ...	84	0.24	95	99	96	99	66	61	88	84
	116	0.21	93	88	89	83	38	34	61	62
	84	0.19	67	69	52	66	26	31	60	32
	52	0.16	40	57	60	43	38	16	27	27
F.W. ...	40	0.27	98	100	98	100	85	66	98	91
	64	0.24	91	79	78	77	42	43	85	86
	48	0.21	63	69	63	57	6	4	54	68
	48	0.19	33	22	23	28	2	6	28	22
D.C. ...			No glare.	Glare outside left.	No glare.	Glare outside left.	No glare.	Glare outside left.	No glare.	Glare outside left.
	80	0.27	88	93	93	84	50	40	80	66
	80	0.24	73	66	69	58	28	23	56	45
	80	0.21	43	34	43	39	15	15	28	20
S.M. ...	80	0.19	19	26	41	24	8	8	21	15
	116	0.27	77	82	88	87	80	80	77	72
	140	0.24	82	81	79	77	77	77	69	66
	136	0.21	75	68	81	71	79	79	54	51
P.H. ...	144	0.19	73	69	66	63	75	71	51	54
	128	0.16	65	60	72	58	66	76	54	52
			No glare.	Glare right.	No glare.	Glare right.	No glare.	Glare right.	No glare.	Glare right.
	64	0.27	80	56	69	58	72	66	64	69
M.K. ...	64	0.24	66	59	66	56	67	55	58	64
	64	0.21	70	50	66	66	56	66	48	49
	64	0.19	56	52	66	58	64	52	52	50
	60	0.16	58	48	62	56	55	52	43	45
S.M. ...	48	0.27	90	67	100	94	73	79	86	86
	52	0.24	87	52	92	87	65	39	71	62
	56	0.21	66	36	81	81	38	39	50	50
	64	0.19	58	39	83	67	26	30	52	44
S.M. ...	56	0.16	50	32	68	68	23	31	25	32
	88	0.27	80	85	82	79	72	65	74	74
	88	0.24	83	90	84	79	69	70	60	63
	88	0.21	78	75	70	70	69	69	60	53
S.M. ...	88	0.19	73	81	68	74	66	59	49	40
	88	0.16	64	68	62	69	81	77	41	52

did not show such a marked falling off of performance when the exposure was shortened and in the experiments a greater range of exposures was given to them. This lack of sensitivity of some subjects to change of conditions is well known in this type of experiment.

2. The relative ease with which eye movements in different directions can be made is interesting. For an equal number of correct answers the exposure must be made longest in the top window and shortest in the right and left windows, the bottom window occupying an intermediate position. The effect is not so well marked for the subjects P.H. and S.M. The result can be expressed in another way by saying that the eye can look towards and recognise objects to the right and left more easily than objects below, and those below more easily than those above.

Several elements go to make up the time taken to recognise the test-object in our experiments. These, in order, are, (1) the latent period of vision, (2) the latent period of movement, (3) the time occupied in moving the eyes, and (4) the time taken to read the test-object. When using the shortest exposure of which our apparatus was capable it was possible both to name the window in which the letter was exhibited and also when looking straight at a window to recognise the direction in which the "C" pointed. The time taken in the experiments must have been almost entirely occupied by the time taken for the impulse originated by the flash to reach consciousness, and by the time taken to move the eyes. It does not seem likely that the latent period of vision should vary with the direction from which the flash came. We conclude, therefore, that the eye can be moved horizontally more easily than vertically, the difference being due in all probability to the more complicated muscular activity necessary for vertical movements.*

3. The investigation of the effects of glaring sources of light was the main object of the experiments. The results quoted in Table I A are of the preliminary investigation (Series A). The positions and intensities of the glaring sources used have been described already. With the exception of the greater number of mistakes made at the left window with glare inside left, the results must be considered negative. There is perhaps a slight tendency for the performance at all the windows to be worse, but not enough to warrant any definite statement. Glare outside left, which on account of its size and intensity might have been expected to influence the readings, is without any significant effect.

* In reading European languages the eyes move from left to right and this might account for the greater difficulty in moving the eyes vertically. A Chinese subject, however, accustomed to reading Chinese script, showed no greater facility in the vertical movements in the few readings which he had time to give us.

TABLE IB

Subject	No. of Exposures	Duration of Exposure in Seconds.	WINDOW																			
			RIGHT						LEFT						TOP				BOTTOM			
			No glare	Glare inside right	Glare right down	Glare outside right	No glare	Glare inside right	Glare right down	Glare outside right	No glare	Glare inside right	Glare right down	Glare outside right	No glare	Glare inside right	Glare right down	Glare outside right	No glare	Glare inside right	Glare right down	Glare outside right
D.C.	60	0.30	96.5	36.5	90	88	96.5	91.5	91.5	73	71.5	93	71.5	66.5	70	80	91.5	83	85	93	84.5	
	60	0.24	80	16.5	58	55.5	75	68	73	41.5	15	71.5	15	18	13	13	40	38	40	35	35	
	60	0.21	43	21.5	45	30	48	55.5	35	41.5	15	71.5	15	10	20	11.5	33	18	23	28	28	
P.H.	60	0.32	95	93	93	93	95	93	98	95	88	95	88	90	83	95	95	91.5	91.5	98	98	
	60	0.27	90	80	73	85	75	80	70	68.5	71.5	78	71.5	78	81.5	80	90	76.5	81.5	78	78	
	60	0.21	61	61.5	65	68.5	40	40	51.5	50	45	50	45	51.5	50	60	45	60	43	53	53	
M.K.	52	0.30	96	86.5	98	100	96	94	100	96	96	96	96	88	77	92	90.5	82.5	90.5	84.5	84.5	
	56	0.24	85.5	66	80	78.5	91	92.5	82	94.5	46.5	46.5	39	48	42.5	42.5	75	55	69.5	62.5	62.5	
	48	0.19	70.5	43.5	75	70.5	70.5	70.5	64.5	68.5	29.5	33	29.5	34	18.5	20.5	39.5	37.5	29.5	33	33	
R.L.	60	0.30	91.5	30	95	93	93	98	93	96.5	36.5	96.5	36.5	33	43	36.5	86.5	90	91.5	93	93	
	60	0.27	81.5	25	78	80	88	90	91.5	83	33	83	33	23	23	23	73	63	73	68	68	
	60	0.24	40	30	35	40	55.5	55.5	53	40	31.5	40	31.5	20	25	15	90	41.5	40	35	35	
S.M.	100	0.32	93	92	88	88	95	88	91	95	85	85	85	85	85	85	91	92	86	84	84	
	100	0.27	82	88	86	83	84	78	83	83	64	64	65	72	72	67	65	72	68	70	70	
	100	0.21	77	71	72	85	63	65	70	58	63	58	63	73	68	62	48	42	47	38	38	
Mean of all sub-jects		Long Middle Short	94 84 58	67.5 55 45	92.5 75 58	92 80 58.5	95 82.5 55	93 81 57	94.5 78 55	95 80 51	76 46 37	72 44.5 37.5	76 47 36	77.5 45 34	91 68.5 39	88 61 44	89 66 36	90 62.5 37

FIG. 2.

In the second series of experiments (Table I B and Fig. 2) the glare sources grouped round the right window were used. The grouping was chosen in this way so as to give some indication of the nature of disability produced. First, the visual acuity for the test-object in the right window, and therefore the speed with which it could be recognised, might have been less when glaring sources were near it. If this were the case, then all positions of the glare source should have been equally effective since they were at equal distances from the test-object. Secondly, the retina (macula) might have been "fatigued" when the image of the glare source fell on it. This would occur when the eyes were being moved towards the right window with "glare inside right" in operation. Thirdly, the glaring sources might be "distracting" stimuli during the movements of the eye, in which case both "glare inside right" and its near neighbour "glare down right" might be expected to participate equally whilst "glare outside right," lying as it did, outside the field of operations would have been less effective. The readings were taken in a sequence (explained earlier) which should have demonstrated any differential effect of the glare sources.

TABLE II.

The readings taken immediately after an exposure made in the right window with a "glaring" source of light, are compared with those not so preceded.

The number of correct readings is shown as a percentage.

		Glare source.	WINDOW.					
			Left.		Top.		Bottom.	
			Normal.	After reading at right window.	Normal.	After reading at right window.	Normal.	After reading at right window.
P.H. ...	...	Outside right.	71	91	73	95	70	84
M.K. ...	...		89	90	51	55	51	44
R.L. ...	...		78	76	24	23	69	60
S.M. ...	...		79	74	79	81	60	51
P.H. ...	...	Down right.	71	72	73	84	66	88
M.K. ...	...		83	100	52	60	61	81
R.L. ...	...		77	85	33	37	66	74
S.M. ...	...		83	88	70	86	65	61
P.H. ...	...	Right.	79	81	75	81	72	81
M.K. ...	...		79	95	45	59	60	50
R.L. ...	...		85	75	30	32	68	63
S.M. ...	...		76	86	81	85	68	53

It will be seen from the results in Table I B that none of the readings with glare are significantly different from those without, except the readings for the right window with "glare inside right." As has been pointed out, the line of sight passes across this glare source in moving from the fixation point to the right window and we conclude that an after-image is formed on the retina or the latter becomes "fatigued" so preventing recognition of the test-object. Subjectively this phenomenon is well marked, a black splotch being seen in the place where the test-object should have been seen. The deleterious effect of a glare source situated on a line between the fixation point and the window is well marked for the subjects D.C., M.K., R.L., and F.W.: for the subjects P.H. and S.M. it is doubtful if it is present. These two subjects appear to be peculiarly insensitive to any of the changes of conditions investigated by us, whether by varying the length of exposure, using the top window, or by the introduction of a glaring source of light.

When readings were taken, the experimenter made a note of those exposures which followed immediately on the right window with "glare" readings. It was thought that the macula might take a few seconds to recover from the after-image in the case of "glare inside right" but no such effect was noticed, the readings being, if anything, slightly better. (Table II.) Apparently the eye recovers in less than 3 seconds, the average time between readings.

Summary

1. We have measured the time taken for a subject to move his eyes away from a fixation point and recognise a test-object momentarily exhibited at an angle of 20° with the fixation point.
2. Six subjects did the experiments, two of whom were rather insensitive to changed conditions, whilst the other four reacted as follows:
3. Small variations in the length of exposure of the test-object have a marked effect on the number of mistakes made.
4. The ease with which eye movements in different directions can be made is in this order: right and left: down: up.
5. A glaring source of light in the field of vision has no appreciable effect on the number of mistakes except when it lies on a straight line between the fixation point and the test-object. This effect is attributed to after-images.

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