PERCEIVED ANGULAR VELOCITY
AS A FUNCTION OF THE
ANGULAR POSITION OF A ROTATING POINTER

by

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INTRODUCTION

This experiment was designed to investigate the effect of the position of a sector in the frontal plane swept by a rotating pointer on the perceived speed of the pointer. Less technically, an analogous question is whether or not a pointer moving with fixed angular velocity, such as the second hand on a clock, appears to be moving at the same rate of speed from, for example, twelve to one as between one and two, or four and five. Like the second hand on a clock, the _real_ angular velocity of the pointer in this experiment remained constant. It was speculated that if _perceived_ differences in velocity did exist, they might be interpreted in terms of a vertical-horizontal illusion, a "gravitational" influence, and habitual left-to-right movement of the eyes.

The vertical-horizontal effect refers here to the classical phenomenon, i.e., where a vertical line is perceived as longer than a physically equal horizontal line. In this study the illusion could have two effects, one on the subjective length of the pointer, the other on the length of arc described by the pointer tip. These effects would result in the perception of a shorter horizontally oriented pointer sweeping a longer vertically oriented arc. Hence, speed would be judged faster around the horizontal axes.

Shipley, _et al_ (8) indicate that variations in subjective length of lines occur as a function of inclination which they interpret in terms of the vertical-horizontal illusion. Using partial diameters of a circular field as is illustrated in Figure 1, they varied inclination from horizontal at 3:00 o'clock to vertical at 6:00 o'clock. The subjectively longest lines were found at the 5:00 o'clock position, although there were no significant differences from 4:30 to 6:00 o'clock.

Figure 1. Examples of the presentations used by Shipley, et al (8).

In a study investigating the effects of distance on perceived relative movement of two needles oriented perpendicular to their linear oscillation, Graham, et al (5) used equipment in which motion of two needles would be parallel, at equal speeds, and in planes perpendicular to the line of sight. Additionally, the needles were so oriented that one pointed at the other and vice versa. Observers manipulated the distance of the one adjustable needle using monocular vision, until it appeared to be moving in the same plane as the other oscillating needle. Failure to meet this equi-distance criterion would cause observers to perceive differential speeds, i.e., the nearest needle would appear faster, catching up with and passing the other.

Thresholds were obtained for each of twelve inclinations in steps of 30 degrees from zero through 360 degrees in a plane perpendicular to the line of sight. The threshold for perception of a different speed was higher when oscillation was vertically oriented than when it was horizontally oriented. The highest threshold appeared around 30 degrees from the vertical, with the lowest threshold for horizontal oscillation.

Coincidentally, the highest threshold for the oscillating needles corresponded in position to the "longest" line of Shipley, et al (8). On this basis it was hypothesized that a similar effect might appear in the present study. Should subjective differences in perceived angular velocity occur one would predict that less apparent difference in judged speed would be found as pointer motion is vertically oriented, since the "short" pointer would sweep a "longer" arc in an equivalent time.

The gravitational influence refers to the expectancy that an object will fall "with" gravity. Attneave (1), in studying the perception of a point in a circular field, found a consistent downward error when the observer positioned a point of light on a blank circular field to coincide with one previously established momentarily by the experimenter. He suggested that the effect is related to some influence from gravity on perception.

If gravity does have an influence on perceptual location of subjects, it could also have an influence on perception of speed when motion is "with" or "against" gravity. Since an object is expected to fall at a certain rate of speed, it would be predicted that motion downward at a slower rate of speed would be perceived simply as slow in comparison with an object moving up at the same speed but overcoming gravity.

The notion of expected motion is also involved in a "movement-to-the-left" vs. "movement-to-the-right" effect. Generally, movement of the eyes in reading is made up of a left-to-right movement as one follows the printed symbols followed by a sweep back across the page to start a new line. The first type of movement is slower than the second. Thus, it is possible that control or restriction of the second motion, i.e., the return of the eyes to start a new line, to the same, slower, speed as the first would result in perceptually slower motion.

Overall, then: the "vertical-horizontal" illusion suggests phenomenally faster speed of rotation when the pointer is horizontally oriented; the gravitational influence suggests faster speed as the pointer moves up; and the left-to-right effect suggests faster speed as the pointer moves from left to right. Considering all three factors operating together, it would be expected that with constant clockwise motion of the pointer fastest speeds would be perceived from the left horizontal to the upper vertical.

METHOD

The experimental method was a modified pair comparisons technique, the response being a report of which presentation of a sequence of two had the fastest moving pointer. Each member of a pair was equally often first and last to minimize the effects of time order error.

The Presentation for Comparison. One important factor was the time for a single presentation to the subject (S). Too short an exposure would result in insufficient time for valid judgments. Too long an exposure would make comparisons too remote in that too much time would elapse between the onset of the first presentation and the end of the second when two full sectors of motion were to be compared. It was somewhat arbitrarily considered that less than five seconds for a presentation would be too short, while more than ten seconds would be too long. With a speed of approximately one revolution per minute, the number of independent sectors swept by the pointer was thus limited to the range of from six to twelve.

Since it was speculated that perceived differences would exist relative to up and down motion and to left and right motion, an additional restriction was added affecting the positions of four of the angles. The left to right effect could be examined best if the vertical plane bisected two equal and opposing angles subtended by the pointer, since the vertical-horizontal illusion and gravitational effects could be assumed equal, or balanced, for the upper and lower vertical axes. Similarly, the gravitational effect could be examined best if the horizontal plane bisected two equal and opposite angles so that the vertical-horizontal illusion and left to right effects would be equal or balanced. Thus, the position of four sectors was such that study of opposite sectors would permit up-down and left-right analysis. As one effect is examined, the other would be in the expected direction for half the angle, and in opposition for the other. To obtain four diametrically opposed sectors for this analysis a number divisible by four was necessary.

The last restriction on angle of presented motion referred to analysis of interactions. Either eight or twelve sectors would allow such analysis, with eight indicating the most direct relation between left to right and up-down motion since only one intermediate sector would exist. Hence, the unit of analysis was set at eight, i.e., a pointer sweep of 45°. These octants, in their proper orientation, are shown in Figure 2.

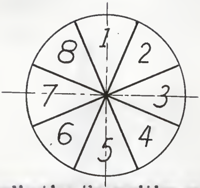

Figure 2. Diagram indicating the position and numbering of the octants.

It was assumed that the vertical-horizontal illusion would contribute equally to diametrically opposed octants, so that analysis could be in terms of the other effects for such octants. However, the other suggested factors made a specific plan of analysis for vertical-horizontal influence too tenuous should differences attributable to the others be found. If no gravitational or left to right influence were present, opposing octants would be of the same phenomenal speed from the effect of the vertical-horizontal illusion so comparison of opposing octants with their neighbors could be made.

Apparatus

The semi-pictorial diagram in Figure 3 indicates the relative positions of the components of the apparatus.

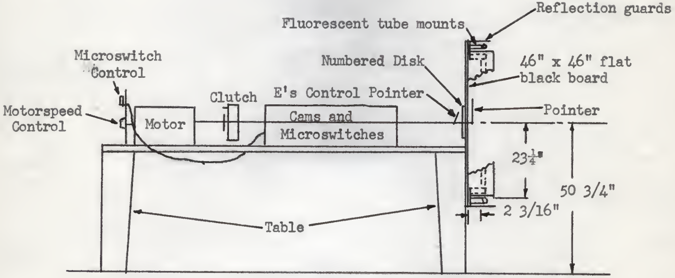

Figure 3. Diagram of apparatus and pertinent dimensions.

The pointer was flat gray, 10 inches in length and 1/4 inch in width and was attached to the clutch-driven shaft in such a way that one extreme coincided with the center of rotation for the shaft. The opposite end swept a circle twenty inches in diameter as the pointer rotated in a plane one half inch from the flat black background.

For easy identification of the center of rotation, a piece of bright green paper was attached to the central end of the rotating pointer. Green was found to contrast better with both the gray pointer and the black background than other hues.

Presentation time was controlled by cam-operated microswitches, which functioned as timing devices in operating a solenoid-activated shutter controlling the time and octant for a presentation. The cams were set at 1/8 of a revolution per cam so that each would activate the shutter for a particular octant. A seventeen position rotary switch attached to the motor speed vernier control board was used by the experimenter (E) to close the circuit to the proper microswitch for each presentation.

The motor was a 1/400 horsepower Bodine with 3.5 rpm output at 5 inch pounds, modified by an Electro-Devices Electronics Speed Control Kit which provided regulation from 0.0 to 3.5 rpm. Power was supplied through a Sola constant voltage transformer. The motor was run for at least one hour prior to each period of data collection. It operated at 61.04 seconds per revolution (with minor fluctuations) throughout the experiment.

The clutch was a multi-toothed gear on a direct drive to the motor which rotated concentrically to a circular wooden plate attached through the cams to the pointer. The clutch release was a movable hook attached to the plate which was inserted or removed from between the gear teeth as the pointer was positioned for the next presentation.

The arrangement of the cam-operated microswitches was made by removing the motor and end plates from an Industrial Timer Corporation Model MC-4 Timer with an E-12 gear rack and eight switches. The cams were mounted to a new axle that projected through substituted end plates made for this purpose and which connected directly to the clutch and pointer.

A numbered disk was mounted between the gang of switches and the board serving as the surround. A second pointer indicated to E the corresponding position of the pointer as seen by S (see Figure 3).

Illumination was obtained by masking four 30 watt 115 volt white light fluorescent tubes. Two $4\frac{1}{4}$ inch sections of the tube, starting one inch from each end, were unshielded for light emission.

EXPLANATION OF PLATE I

Figure 4: The control apparatus for the experiment, consisting of, from left to right: vernier knob for the motor and microswitch control on the panel, variable speed motor, clutch with control knob, and cam-operated microswitches. The shaft extending from the microswitches extends to the pointer visible in Figures 5 and 7.

Figure 5: Orientation of S to the rotating pointer and field.

Figure 6: The eyepiece.

Figure 7: The pointer and visible surround. The circle indicates the limits of the field as imposed by the eyepiece. No clearly defined circle was inscribed on the field, as is evident from Figure 5.

PLATE I

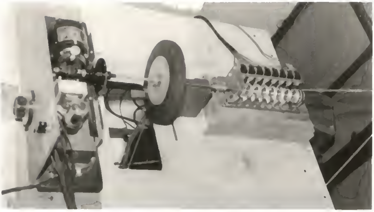

Figure 4

Figure 5

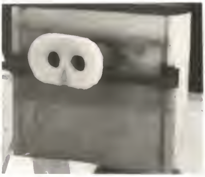

Figure 6

Figure 7

S binocularly viewed the pointer on a flat black unstructured background from a distance of fifteen feet. S's line of sight was perpendicular to the plane of pointer rotation.

Vision was through two flat black tubes with an internal diameter of 1 1/2 inches. These tubes were 9 3/16 inches long nasally and 9 7/16 inches long temporally.

The shutter, a small rectangular metal plate, was frontal to the binocular tubes which limited the field of vision to the pointer and its background. It was mounted on a 1 5/8 inch stroke solenoid plunger and was operated at a speed sufficiently fast for no shutter motion to be perceived. A pair of coiled springs closed the shutter fast enough to meet the same requirements. The side nearest S was painted the same flat gray as the pointer to allow S to anticipate the location of the visual field prior to the opening of the shutter.

The apparent brightness of S's side of the shutter was less than .01 foot-candles. The background of the pointer reflected .23 foot-candles, with the pointer reflecting 1.2. All brightness readings were taken with a MacBeth illuminometer.

Variations in Speed of Rotation. Times for pointer movement through each octant were taken with a stopwatch as E adjusted pointer positions for one of the random orders actually used in an experimental session. The speed measurements for each of the eight octants were obtained sixteen times. Differences between octant times were very small (average variation was .06 seconds between octants and .08 seconds within octants) and could be attributed to random fluctuations of the motor or method of timing.

Variations in Time of Presentation. The shutter-open time indicated some uncontrollable variability prior to the experiment. Since precision adjustments of the cams could not be made, the shutter-open time was checked with a Standard Electric timer regularly over the course of the experiment. An analysis of variance indicated that significant variations relative to pointer position did exist, with a probability of less than .001 for such differences to exist by chance. Tukey's gap test (2) failed to reveal a significant gap, requiring his test for "stragglers." This test indicated that the time was significantly less for octants 4, 5, and 6 (the lowest 135° of rotation), dividing the octant-presentation times into two groups. Tukey's criterion for excessive variability did not result in a significant "deviant" for either group. It was concluded that two groups of presentation times were present: octants 4, 5, and 6, having the mean time of 7.57 seconds per presentation, with a mean time of 7.66 seconds per octant for the remaining five octants.[1]

The variations in time of presentation were considered to be well below the $\Delta t/t$ limen. Woodrow (9) indicates that over 1.2 seconds variation in reproduction of time would exist for a 7.5 second exposure. Translated in terms of visual angle per octant, less than 1.1 per cent variation existed.

Subjects

_S_s were 58 undergraduate male and female student volunteers enrolled in the general psychology and personnel psychology courses at Kansas State University. Equipment failures necessitated eliminating eight _S_s. The remaining 50 _S_s ranged in age from 16 to 44 with a mean of 20 years 9 months and a median of 20 years 6 months. No test of visual acuity was administered.

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[1]The Pearson product-moment correlation between individual shutter times and the obtained number of judgments faster indicated in Table 1 was -.28 which, with 6 d.f., is not significant at the 5 per cent level.

Procedure

Six orders of presentation were made up using a table of random numbers (4) so that each octant would appear first once and second once with every other octant, with each octant appearing for comparison with itself once. Hence, sixty-four pairs would be presented to each S in a manner designed to balance anticipated time order error. Each S received one of the six different random presentations in the order in which they appeared for the experiment.

A pair, such as 8 - 4 (pointer sweeps octant eight followed by octant four) was responded to as "one" or "two" depending upon which presentation appeared to have the fastest moving pointer.

Each pair consisted of 7.63 seconds mean presentation time per exposure with approximately three seconds intra-pair pointer and shutter adjustment time. Interpair time was approximately five secnnds.

S reported to E at a prearranged time and was led to the experimental room. Upon entering the room S was instructed to sit in a chair located approximately midway between and to one side of the shutter and display.

The experimental session was divided into two 15-minute periods separated by a short rest period in addition to instruction and discussion time. The total session lasted 55 minutes.

Instructions to Subjects

All Ss received the same instructions, which were as follows:

(Sit S at a position between pointer and shutter.)

This experiment is concerned with human judgment of speed, that is, how fine a difference in speed can we determine. You will judge the rotation speed for a moving pointer at different positions. Essentially, two exposures of the pointer will be presented, one following the other closely in time. Your task will be to compare the two pointer speeds and report which is faster.

To help clarify the problem, you will see the pointer rotating on the black background. (Point to pointer) You will be seated behind the shutter over here (indicate shutter and walk over to it) so that you can see the pointer and the black background. Nothing else will be visible when the shutter is open. The shutter works like this (pull down and let snap back twice).

Are there any questions so far?

Now, if you will move around and sit so that you can look through the eyepiece we'll see how this works.

(Adjust stool for comfort.)

(Hold shutter down.) You will notice a colored dot on one end of the pointer. It is at the center of rotation, so that it will help if you center it in your field of vision. You can see now what the set up will look like while you are comparing speeds (let shutter snap up). Now here is, roughly, how long you will have to make a judgment. (Hold shutter down and allow to snap up twice for approximate length of experimental exposure.)

That's about what it will be like when we get started. You will just see the pointer for part of a revolution during the experiment. The parts of a revolution in a pair will be different most of the time.

Your job will be to judge each pair as to which is faster. In other words, you will compare two successive presentations, a pair, for speed of rotation. Then you will tell me which is faster, the first, or the second. I might add that most of the presentations may appear nearly equal. As this happens, I want you to tell me which in your best judgment is <u>really</u> faster.

Are there any questions so far?

Now, if you'll sit back, I'll start up the electrical part of the shutter, so that it operates automatically. It's (indicate shutter) going to make some noise.

(Go back and set the shutter for position 1, let operate once, then call out) Put your eyes to the eyepiece and you'll get a little better idea of how it's going to be. (Let operate at position 1 once more.)

(Disengage clutch)

If you'll come back here now, I'll show you how this end works.

(Allow the subject to position himself for the best overview.)

The dial on the motor, here (indicate) makes it possible to regulate the speed. This (indicate shutter control switch) allows me to control the shutter and where it opens. (Operate once.)

(Indicate clutch) Now, this allows me to regulate the pointer position so we don't have to wait so long between times the shutter operates. (Show how). If you will step around to the front, you can see the pointer move. (Operate the pointer with the clutch disengaged from motor.)

If you'll step back to the stool now, we'll make sure you're going to be comfortable. (Return with subject to the stool. Wait until he positions himself.)

Remember, if the first of a pair appears faster, you will let me know by calling out "one". If the second appears faster, you will let me know by calling out "two".

Is everything clear now?

After reading the instructions E returned to the control board and began the series of pair comparisons.

RESULTS

The results of the experiment are summarized in Table 1. Each entry represents the number of times the octant listed at the head of each column was judged faster than the respective octant listed at the left of each row. Each entry can be interpreted as a percentage since there were 100 judgments per pair.

Table 1. Pair comparisons matrix. Each entry is the number of times the octant at the top of each column was judged faster than the octant listed at the left of each row.

Octant	1	2	3	4	5	6	7	8
1	—	45	39	33	31	40	58	49
2	55	—	53	29	49	41	72	68
3	61	47	—	37	38	33	58	51
4	67	71	63	—	52	41	60	65
5	69	51	62	48	—	58	65	56
6	60	59	67	59	42	—	66	61
7	42	28	42	40	35	34	—	51
8	51	32	49	35	44	39	49	—

Rearrangement of the table according to the total number of judgments "faster" was necessary for the pair comparisons matrix. The pair comparisons solution under the assumptions of Thurstone's Case V is given in Table 2. This table also includes the estimates of standard deviations derived for solution under the assumptions of Thurstone's Case III. Case V assumes that (a) there is no correlation between responses to any stimuli and that (b) the discriminal dispersions are equal. Case III assumes (a) only. A plot for Case V, mean of Z-deviates, is presented in Figure 8.

Table 2. Pair comparisons scale separations matrix, for Z-deviates of the obtained proportions, Case V solution.*

Octant	4	6	5	2	3	8	1	7
4	———	-.228	.050	.553	.332	.385	.440	.253
6	.228	———	-.202	.228	.440	.279	.253	.412
5	-.050	.202	———	.025	.306	.151	.496	.385
2	-.553	-.228	-.025	———	..075	.468	.126	.583
3	-.332	-.440	-.306	-.075	———	.025	.279	.202
8	-.385	-.279	-.151	-.468	-.025	———	.025	-.025
1	-.440	-.253	-.496	-.126	-.279	-.025	———	.202
7	-.253	-.412	-.385	-.583	-.202	.025	-.202	———
Z_{jk}	-1.785	-1.638	-1.515	-.446	.647	1.308	1.417	2.012
$M_{z_{jk}}$	-.223	-.205	-.189	-.056	.081	.164	.177	.252
R_j	.000	.018	.034	.167	.304	.387	.400	.475
σ	.764	1.162	1.365	.335	.778	1.428	.942	1.226

*Calculations for the pair comparisons solutions are according to Guilford (6). Each column entry indicates the scale separation between the octant at the top of the column and the octant listed to the left of each row. Mean separations and rearranged R_j scale values are indicated at the bottom of the columns. Standard deviations derived in the Case III solution for each octant according to judgments faster are given in the last row.

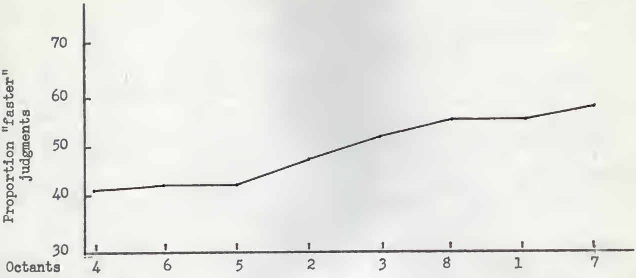

Figure 8. Plot of the mean Z deviants for each octant, transformed to proportions and plotted on a normal probability ordinate according to the Case V solution. Left to right indicates slower to faster.

The Chi-square test of internal consistency with the arc-sine transformations of probabilities and 21 degrees of freedom indicated variability with a probability of occurrence of less than .01 by chance for the Case V solution, necessitating an attempt at a Case III solution. The Chi-square obtained using Case III was statistically significant, with a probability of less than .01 for occurrence by chance using the same transformation. Thus, neither the assumptions of Case V nor Case III fit the data—a strong indication of multidimensionality.

The Chi-square analysis was used to test for differences in judgments as a function of the octant subtended by pointer motion. The analysis was for the total number of judgments of "faster" for each column of Table 1 compared to expected values of 350 if no differences existed. A statistically significant Chi-square of 71.00 ($p < .001$) with 8 degrees of freedom indicated overall reliable differences in judged speed when all octants, individually, were compared with all others. Chi-squares with one df were also computed to determine the probability of obtaining the tabulated number of faster judgments for each pair of octants presented, with an expected value of 50 judgments faster for each position. The results of these tests are presented in Table 3.

Table 3. Matrix of probabilities of obtaining per cent faster judgments as shown in Table 1 assuming equi-probable estimates of pointer speed. For example, octant 2 is judged faster than octant 1 45 times and slower than octant 1 55 times. If there were no perceptual differences in speed (i.e., a 50-50 split) the probability of obtaining a 45-55 division of judgments would be equal to .49 as shown in the cell intersected by column 4, row 7.

Octant m:	4	6	5	2	3	8	1	7
4	—							
6	.20[a]	—						
5	.78	.26[a]	—					
2	.005**	.20	.89	—				
3	.07	.02*	.08	.68	—			
8	.04*	.13	.42	.01**	.89	—		
1	.02*	.17	.009**	.49	.13	.89	—	
7	.17	.03*	.04*	.003**	.26	.89[a]	.26	—

[a]Indicates that the obtained proportion was over 50 per cent.
* $p < .05$
** $p < .01$

Time Order Error

Two tests were made to determine the existence of time order error and whether such an error would bias the results. A Chi-square analysis of time order error when each octant was compared with itself, i.e., octant 1 followed by octant 1, octant 2 followed by octant 2, etc., gave a value of .09 with one degree of freedom ($.70 < p < .80$). In other words, no particular difference in terms of time-order was present in comparing an octant with itself. A similar test applied to all other pairs as a group indicated that a marked time order error did exist. Obtaining Chi-squares for each octant as it appeared first and second with each other octant indicated that only octant 2 varied significantly in judged speed as a function of position in the sequence. The Chi-square obtained was 14.93 with 7 degrees of freedom ($p < .05$). However, an increase in the number of judgments of faster was found for most of the pairs as a function of appearing second in the sequence.

DISCUSSION

The plot of mean Z deviants in Figure 8 suggests that perception of speed did vary as a function of pointer position. Furthermore, inspection of Table 3 indicates that more significant differences existed than could be expected by chance at the .05 level of significance. Nine pairs of the 28 were perceived as of significantly different speeds when the .05 level would lead one to expect only two such occurrences.

The graph of Figure 8 also summarizes the relation of perceived speed for each octant compared to all others with three major groupings of speed being apparent. Octants 1, 7, and 8 were "slower" than no others, 4, 5, and 6 were "faster" than no others, and 2 and 3 were of an intermediate perceptual speed.

Pertinent probabilities indicated in Table 3 suggest the validity of the distinctions, with octant 7 significantly "faster" than 6 and octant 3 near a significant difference from 4 ($p = .07$). Additionally, octants 7 and 8 were identical to 1 while "faster" than 2. Comparing 1 and 2 with other octants as well indicated that the third division was not without justification although it lacked the distinct separation of the other two.

Hence, it was concluded that differences in perceived angular velocity did exist as a function of angular position for a rotating pointer. Three areas of differentially perceived speed were indicated which included from "slowest" to "fastest": octants 4, 5, and 6; octants 2 and 3; and octants 1, 7, and 8.

It had been speculated that perceptually different speeds, if found, could be interpreted in terms of the effects of the vertical-horizontal illusion, a gravitational influence, and a left to right influence related to habitual motion of the eyes, and the interactions of these effects. The design of the study was to make analysis of the influences possible.

Direct comparison of opposite octants shows that an interpretation cannot be made in terms of the vertical-horizontal illusion alone, since the illusion, by itself, would result in a prediction of similar speeds for opposing octants, which prediction was not confirmed by the data. Hence, additional factors must have been present.

It had been predicted that interactions of the vertical-horizontal illusion with the other effects would result in subjectively faster speed, through octants 7, 8, and 1, which are "slower" than no others, suggesting that the three speculated effects do contribute to the perception of angular velocity. However, comparison of opposing octants for gravitational and left to right influences, respectively, according to the design of the study indicated that significant differences from a gravitational influence did not exist, with barely a trend in the predicted direction. Significant differences ($p < .01$) did exist in the predicted direction for the left to right effect. Comparison for interactions also indicates that differences existed for intermediate octants as suspected with $8 < 2 > 4$, and 6 in the direction that would be expected on the basis of the effects, i.e., faster than 4 and slower than 2 and 8.

Thus, the only direct evidence of effects as suspected from the study is in support of the left to right influence proposed, although interactions of the three effects can explain the overall results in the predicted way.

More specific examination of the relation between octants in Tables 2 and 3 suggests that octant 2 might be "slower" than 3, which implies a failure of the left to right effect, since motion in octant 2 has only one component of left to right motion while 3 has equal components "with" and "against" the effect. However, it had been suggested on the basis of the studies of Shipley, et al (8) and of Graham, et al (5) that perceived motion could be faster as the pointer swept horizontally oriented octants which would suggest the possibility of the results for octants 2 and 3.

Also, a perceptually faster speed about the horizontal axis, from the vertical-horizontal effect, could be proposed as responsible for the lack of a significant difference between horizontal octants. One could suggest that the contributions of gravity to difference judgments were subliminal. The existance of relationships as predicted on the basis of interactions with the other effects can be cited as supporting evidence.

The study, while indicating clearly that perceptually different angular velocities do exist as a function of pointer position, serves only as preliminary research in terms of the explanatory concepts employed. While the differences appear interpretable in terms of the proposed interactions, clarification by additional research is necessary. Experimental data is required to determine the relative contribution from each of the proposed influences to overall differences found in this study before proper analysis can be made.

Additionally, it will be noted that the analyses for predictions of angular velocities were on the basis of interactions of linear motion with the results suggesting that the two are related and that additional studies of the individual factors could investigate linear motion. Also deserving investigation is the wide divergence in opinion indicated by the standard deviations in Table 2. The deviations could be a function of differing degrees if not reversals of some of the effects, or they could reflect the indistinct separations between neighboring octants as is indicated by most comparisons of octants with the nearest neighbors in Table 3. It is suggested that studies be done in which speed, octant position and size, and direction of motion, are varied with and without a structured field. Additional clarity of relative perceptual speeds might be obtained by inserting a gap between neighboring octants to avoid possible confusion from perceptual overlapping of sectors compared.

Another result of the present study was the relation between perceptually faster speed and time order error. All 8 octants, taken as a group, indicated a highly significant bias in terms of judging the second of a group as faster. The tabulations (see Appendix) indicated only two reversals, those being for 2-2 and 3-3. However, when taken individually only octant 2 was judged faster significantly more times when presented second.

Some Ss reported that occasionally the needle would appear to rotate around some point other than the center, with the phenomenal center of rotation varying in displacement from 1/2 inch to the outer end of the pointer. The phenomenon apparently resulted from temporary inability to locate the central end. This probably was attributable to inadequate brightness of the green dot used to mark the center. While certain areas of pointer motion were cited as associated with the effect by individuals, with only one S who noticed it not being able to relate the experience to a particular area, inter-individual differences negated an attempt to determine a relationship of the occurrences to a particular area.

SUMMARY

The purpose of this experiment was to study the perception of angular velocity for a rotating pointer as a function of the position of the angle subtended by pointer motion. It was speculated that, should variations be discovered as a function of the subtended angle, the differences could be interpreted in terms of the vertical-horizontal illusion, an effect from gravity, and habitual left-to-right and right-to-left motion of the eyes. It was predicted that presence of the first would result in perceptually faster motion as the pointer was horizontally oriented, the second as it rose "against" gravity, and the third as it moved from left to right, corresponding to the normally slower eye motion in such tasks as reading.

Pointer motion subtended eight angles of 45° each. The orientation of the angles was such that the vertical and horizontal axes bisected four octants. Thus, analysis of both the speculated "gravitational" and left to right effects could be made for these positions where other effects could be assumed to be balanced or neutral.

Using binocular vision S perceived 45° of clockwise pointer motion in an unstructured field as a shutter opened and closed at opposite extremes of the subtended angle. S reported which of two consecutive presentations was faster as E varied the position of pointer motion in a predetermined random order. Between-presentation time for a pair was approximately three seconds. Pointer motion remained constant as 100 comparisons were made for each pair of different octants and 50 for each pair of identical octants.

The data could not be scaled by the pair comparisons method under the assumptions of Thurstone's Case V or Case III, which was taken as indicative of more than one dimension as would be expected if the speculated dimensions

were present. Additionally, a consistent time order error was indicated resulting in perception of the second presentation of a sequence as faster in practically all cases.

Highly significant differences related to position of pointer motion were found, from which it was concluded that perception of speed does vary as a function of the position of a rotating pointer. Additionally, three major divisions of phenomenological speed were indicated. Taking the upper vertical as 0° and measuring clockwise, the "fastest" moving pointer subtended the angle from 247.5° to 22.5°, the next "fastest" from 22.5° to 112.5°, and the "slowest" speed of pointer travel ranged from 112.5° to 247.5°.

By direct comparison, significant differences were found for the left to right effect only although the "gravitational" influence was in the predicted direction. It was suggested that differences attributable to gravity could be present but subliminal. A larger difference in perceived velocity from the "gravitational" effect would have been necessary in order to establish a limen, since "faster" speeds about the horizontal axes were indicated. The hypothetical influences and anticipated interactions facilitated classification of the differences in subjective speed, with motion "against" gravity and from left to right judged as faster. Horizontal orientation of the pointer also appeared to influence the perception of velocity.

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APPENDIX

The centrally located numbers in each group indicate the octants compared, with the order corresponding to the sequence. For example, in the first group, 1 2 / 2 1 indicates that the top row consists of the sequence octant 1 followed by octant 2. The lower row represents the reverse order. The underlined number nearest each member of the group indicates the number of times it was judged faster for the particular order.

Chi-square values for each octant as it appeared first and last with each other octant are indicated in the upper-right corner of the table. Subscripts refer to the particular octant.

$\chi_1 = 5.3412$	$\chi_5 = 3.4134$
$\chi_2 = 14.9332$*	$\chi_6 = 9.6620$
$\chi_3 = 6.6930$	$\chi_7 = 8.8034$
$\chi_4 = 9.2460$	$\chi_8 = 5.1580$

24 26 1 2 2 1 19 31							
30 20 1 3 3 1 19 31	21 29 2 3 3 2 24 26						
33 17 1 4 4 1 16 34	32 18 2 4 4 2 11 39	27 23 3 4 4 3 14 36					
33 17 1 5 5 1 14 36	23 27 2 5 5 2 22 28	28 22 3 5 5 3 16 34	21 29 4 5 5 4 23 27				
28 22 1 6 6 1 18 32	23 27 2 6 6 2 14 36	28 22 3 6 6 3 11 39	25 25 4 6 6 4 16 34	20 30 5 6 6 5 28 22			
17 33 1 7 7 1 25 25	6 44 2 7 7 2 28 22	17 33 3 7 7 3 25 25	15 35 4 7 7 4 25 25	15 35 5 7 7 5 30 20	13 37 6 7 7 6 29 21		
20 30= 1 8 8 1 19 31	15 35 2 8 8 2 33 17	21 29 3 8 8 3 22 28	15 35 4 8 8 4 30 20	20 30 5 8 8 5 26 24	16 34 6 8 8 6 27 23	24 26 7 8 8 7 25 25	
25 25 1 1	30 20 2 2	30 20 3 3	22 28 4 4	21 29 5 5	25 25 6 6	23 27 7 7	21 29 8 8

PERCEIVED ANGULAR VELOCITY
AS A FUNCTION OF THE
ANGULAR POSITION OF A ROTATING POINTER

by

DONALD LEE PARKS

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The purpose of this experiment was to study the perception of angular velocity for a rotating pointer as a function of the position of the angle subtended by pointer motion. It was speculated that, should variations be discovered as a function of the subtended angle, the differences could be interpreted in terms of the vertical-horizontal illusion, an effect from gravity, and habitual left-to-right and right-to-left motion of the eyes. It was predicted that presence of the first would result in perceptually faster motion as the pointer was horizontally oriented, the second as it rose "against" gravity, and the third as it moved from left to right, corresponding to the normally slower eye motion in such tasks as reading.

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