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THE SPIRAL AFTEREFFECT:
Influence of Stimulus Size and Viewing Distance on the Duration of Illusory Motion

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I. Introduction

Visual illusions represent a significant problem area in aviation research. Although many such illusions are the result of misleading cues, others appear as an aftereffect of real motion. Included among the latter is the spiral aftereffect—the apparent reversed motion of a spiral after it ceases spinning.

Previous studies dealing with the relationship between the duration of the spiral aftereffect (SAE) and the visual angle subtended by the spiral have led to contradictory results. Holland[5] indicated no significant difference in the duration of the aftereffect with a change in visual angle reported elsewhere[6] to be from 4° to 6°. Similar findings were noted by McKenzie and Hartman[7] with visual angle variations of 2°8′, 4°14′, and 6°22′.

Contrary to the results summarized above, Pickersgill and Jeeves[8] found a nonlinear relationship between spiral size and the duration of the SAE. An increase from a 3-inch spiral (2°52′) to a 6-inch spiral (5°44′) produced a significant increase in the duration of the aftereffect; however, an increase from a 6-inch spiral to a 12-inch one (11°26′) resulted in a shorter duration. Costello[1] employed a visual angle of 6°30′ for two distance conditions (an 8¼-inch spiral at 6 feet and a 3-inch spiral at 2¼ feet) and reported significantly shorter effects for the 3-inch spiral. Freud[3] demonstrated statistically significant size effects on the SAE when the spirals subtended visual angles of 2°, 4°, and 8°. The relationship appeared to be linear; as the spiral size increased there was a corresponding increase in the duration of the aftereffect. Fozard, Fuchs, Palmer, and Smith[2] obtained SAE duration measures with 4-inch, 8-inch, and 16-inch spirals at a distance of 8 feet (2°23′, 4°46′, and 9°23′, respective visual angles). They reported a slight increase in duration of the aftereffect from the 4-inch to the 8-inch spiral, but a notable decrease when the 16-inch stimulus was used.

In a study concerning the duration of the "water-fall illusion," a related phenomenon, Granit[4] found that an increase in the size of the drum produced a significant increase in the duration of the aftereffect, with an optimum duration occurring between 2°–4° of visual angle. The increase in duration could only be produced by a larger sized drum, not by moving the drum closer to the subject.

Scott and Noland[10] have reevaluated conclusions of the Freud[3] and Granit[4] studies from the viewpoint that changes in the viewing distance produce changes in the speed of stimulation. Thus, by comparing data from Scott[9], Freud[3] and Granit[4], they report that the aftereffect increases for stimulating speeds between 30–132 minutes of arc per second (minarcs/sec) and that results reported as due to viewing distance may be accounted for by stimulus speed.

In previous studies of SAE, authors altered visual angles either by using spirals of different size or by changing the viewing distance. Pickersgill and Jeeves[8], McKenzie and Hartman[7], and Fozard et al.[2] used spirals of various sizes, while Freud[3] and Holland[5] changed the viewing distance. In the present study both spiral size and distance from the observer were systematically varied.

II. Method

Apparatus. The spirals were three-throw arithmetic spirals, produced by photographic means, with diameters of 2, 4, 8, 12, 14, and 16 inches. The spirals were attached to a shaft driven by a variable speed motor with speed of rotation set at 80 rpm. A timing system started the spiral rotating, determined the stimulus duration, and stopped the rotation.

The spiral and motor were enclosed in a box. The spiral was illuminated by two 8-watt bulbs located near the front of the box and was viewed binocularly from a seated position at one end of a 48-foot visual alley. The subject's head was positioned with a chin rest so that his line of sight to the center of the spiral was parallel to the floor. By shielding the light source and leaving the alley in darkness, few cues were available regarding the distance of the spiral from the observer. Duration of the aftereffect was measured with timing equipment activated by depression of a microswitch located at the subject's position.

Experiment A. Twelve male subjects were used in the first part of the study which involved a repeated sessions design with each subject receiving every condition in random order. The subject attended a 1-hour session on each of 4 successive days. Spirals with diameters of 4, 8, and 16 inches were each used at distances of 4, 8, and 16 feet. These nine conditions produced a total of five different visual angles: 1°12′, 2°24′, 4°46′, 9°32′, and 18°56′.

Each subject was given a demonstration of the operation of the spiral. While watching the spiral, the subject was instructed to maintain visual fixation on the center of the stimulus and immediately after cessation of the rotatory motion, as the aftereffect commenced, to depress a microswitch and to keep it depressed until the aftereffect was no longer perceived. The subject was then given a group of three practice trials. The spiral was rotated for 15 seconds during each of the trials and there was a 2-minute break between trials.

Immediately following these familiarization trials, each subject received a series of five practice trials for each of three conditions (the 4-inch spiral at 4 feet, the 8-inch one at 8 feet, and the 16-inch spiral at 16 feet). The duration of the stimulus and length of time between practice trials was the same as that allowed during the previous three familiarization trials. The subjects were also given 5-minute rests between conditions.

On each of the 3 following days (Experimental Days) the instructions were repeated and the experimental trials were conducted with the alley in darkness. No further practice was given. Five judgments were obtained for each size-distance condition. By the end of the third Experimental Day the subject had viewed the three spiral sizes at each of the three distances. The order of presentation of the various spiral size-distance combinations was counterbalanced among subjects (Table 1).

Experiment B. A reliability check and extension of the test conditions were accomplished by using two new subjects, illuminating the visual alley, and introducing an additional spiral (2-inch diameter displayed at 4, 8, and 16 feet). The order of presentation for these two subjects also appears in Table 1.

Experiment C. A different group of six subjects viewed spirals with diameters of 12, 14, and 16 inches at distances of 36, 42, and 48 feet. The visual angles produced by these combinations were 1°12′, 1°22′, 1°35′, 1°51′, and 2°7′, and were within the range of the three smallest visual angles used in the preceding experiments. The distances were selected in an attempt to obviate possible accommodation-convergence effects which might have affected the data collected in Experiments A and B. The order of presentation appears in Table 1.

III. Results

Experiment A. An average of the five duration scores was obtained for each subject for each of the nine spiral size-distance settings. These scores were then averaged to yield a mean duration score for the group for each of the nine conditions and were then plotted as a function of visual angle (Fig. 1).

Mean scores for each subject were submitted to an analysis of variance. The effect of visual angle was found to be significant (.05 level).

The angles were then tested for trends. Although linear and quadratic tests were significant, the quadratic component accounted for 50% of the variance, whereas the linear component accounted for only 25%. Thus, the relationship between visual angle and the duration of the SAE would appear to be curvilinear with the critical break occurring approximately between 2°–4° of visual angle.

Using the formula from Scott and Noland[10] for determining speed of normal rotation, motion values in minarcs/sec were calculated for each of the size-distance settings, and SAE duration was then plotted as a function of the speed of eliciting motion (Fig. 2). Contrary to the report of Scott and Noland[10], the duration of the aftereffect appears to increase only up to a point between 30–60 minarcs/sec and then declines.

Table 1. Order of stimulus presentation for all subjects. Five readings were obtained for each spiral size at each distance. The spiral sizes were presented in the order indicated for each distance.

	Experimental Day 1		*Experimental Day 2*		*Experimental Day 3*	
Subject	*Distance (Feet)*	*Spiral Size (Inches)*	*Distance (Feet)*	*Spiral Size (Inches)*	*Distance (Feet)*	*Spiral Size (Inches)*
Group A						
KW	4	4,8,16	8	8,16,4	16	16,4,8
LC	16	8,16,4	8	16,8,4	4	8,4,16
RF	4	16,8,4	16	16,8,4	8	4,8,16
JW	8	16,4,8	4	16,4,8	16	8,4,16
DW	16	4,16,8	4	4,16,8	8	4,16,8
RW	8	8,4,16	16	4,8,16	4	8,16,4
CS	4	4,8,16	8	8,16,4	16	16,4,8
BS	16	8,16,4	8	16,8,4	4	8,4,16
WF	4	16,8,4	16	16,8,4	8	4,8,16
CM	8	16,4,8	4	16,4,8	16	8,4,16
GL	16	4,16,8	4	4,16,8	8	4,16,8
WP	8	8,4,16	16	4,8,16	4	8,16,4
Group B						
JT	4	2,4,8,16	8	16,8,4,2	16	2,4,8,16
RM	16	16,8,4,2	8	2,4,8,16	4	16,8,4,2
Group C						
SG	36	16,14,12	42	12,14,16	48	16,14,12
CB	36	16,12,14	48	14,12,16	42	16,12,14
DS	42	14,12,16	48	16,12,14	36	14,12,16
MK	42	12,16,14	36	14,16,12	48	12,16,14
CN	48	14,16,12	42	12,16,14	36	14,16,12
JT	48	12,14,16	36	12,14,16	42	16,14,12

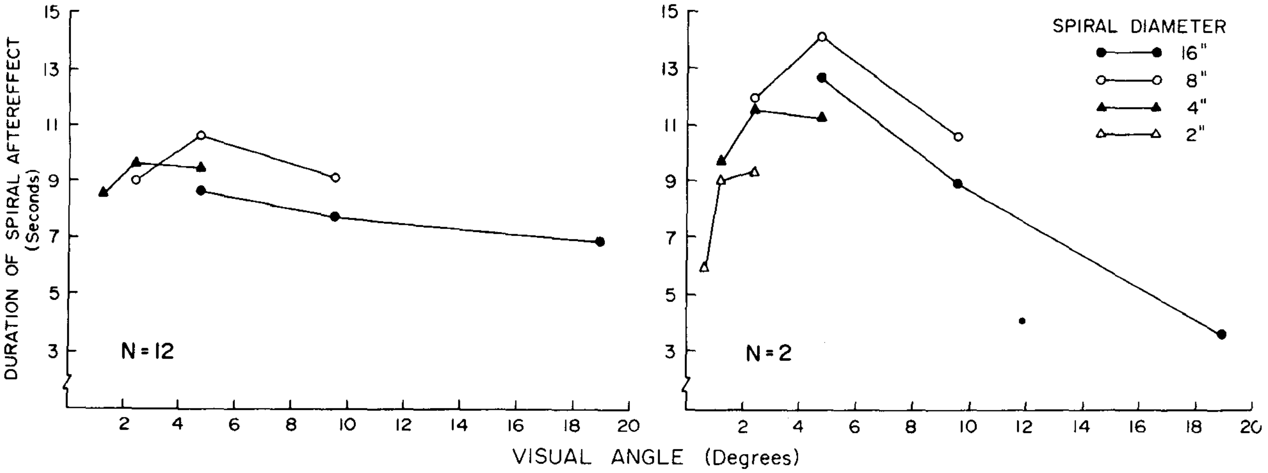

Figure 1. Mean duration of the spiral aftereffect as a function of visual angle for Group A (N=12; visual alley dark) and Group B (N=2; visual alley illuminated). Two subjects in Group A reported no aftereffect for the 16-inch spiral at 4 feet (18°56′ visual angle).

Experiment B. Another group (N=2) served as a replication and further check of the results noted above. These subjects viewed the same three spirals plus a new spiral (2-inch diameter) at each of the three distances and with the alley illuminated. The mean SAE duration values for each of the size-distance settings are plotted as a function of visual angle in Figure 1, and of min-arcs/sec in Figure 2. Confirmation of the results from the larger group of subjects was obtained.

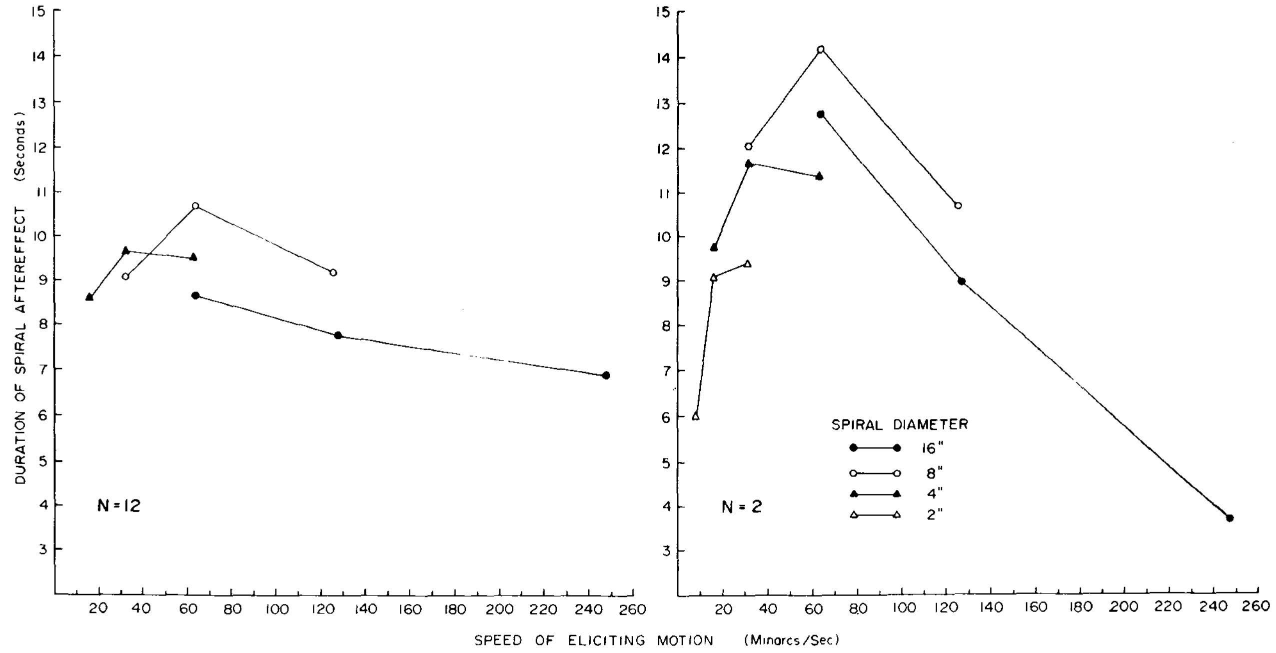

FIGURE 2. Mean duration of the spiral aftereffect as a function of the speed of eliciting motion for Group A (N=12) and Group B (N=2).

Experiment C. Mean group SAE duration values were calculated for each of the nine size-distance settings and plotted as functions of visual angle and of minarcs/sec (Fig. 3). The duration values increased in a relatively linear fashion as functions of increasing visual angle and increasing speed of eliciting motion. It is to be noted that only one of the visual angle conditions (2°7′) used in this phase of the study approached the range (between 2°24′ and 4°46′) within which a decrease in aftereffect occurred in Experiment A, and that the maximum speed of eliciting motion for these spirals was less than 30 minarcs/sec.

IV. Discussion

The results obtained here are in close agreement with the data and conclusions presented by Granit[4] in his study of the waterfall illusion, i.e., that the optimum duration of the aftereffect occurs between 2°–4° of visual angle. The present data also support the reports of Pickersgill

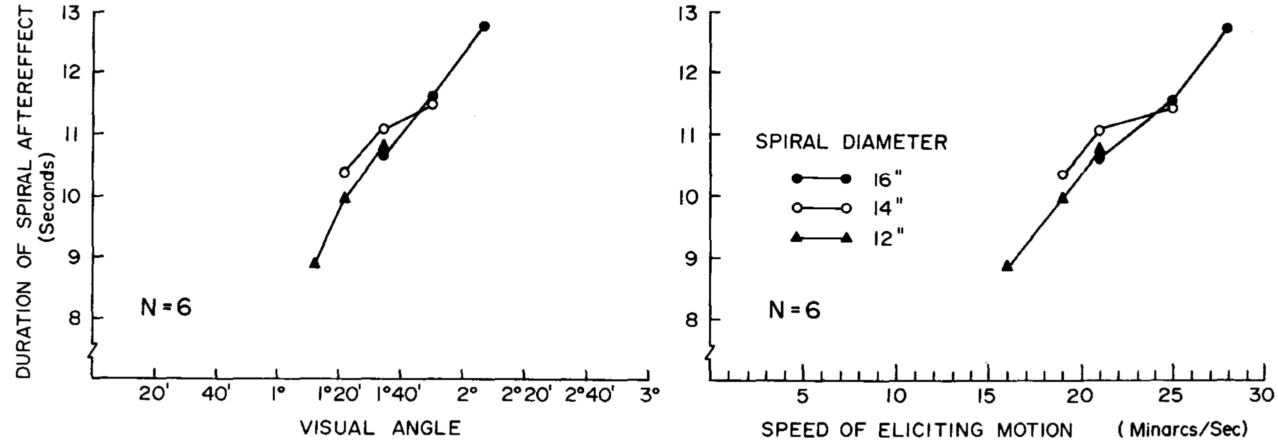

FIGURE 3. Mean duration of the spiral aftereffect as a function of the visual angle and the speed of eliciting motion for Group C.

and Jeeves[8] and of Fozard et al.[2]. That Holland[5] found no significant effects (his mean data were not reported) may be due to the fact that the two angles which he employed (4° and 6°) were too close to the optimum visual angle to show statistical significance. A similar explanation might account for the results of McKenzie and Hartman[7] who obtained a shorter SAE duration (4.91 sec) at 2°8′ of visual angle than at 4°14′ and 6°22′ (where the mean duration was 5.51 sec in both cases); in any event, the SAE duration did not increase for the largest visual angle even though the speed of eliciting motion probably averaged less than 100 minarcs/sec.

Only one study appears to show a clear divergence from the results of this investigation. Although his main interest was in retinal place and hemiretinal transfer effects, Freud[3] also reported an increase in SAE duration from 2° through 8° of visual angle regardless of whether predominantly cone or rod areas were stimulated. Since Freud had subjects view the spiral with only one eye whereas most studies involve binocular stimulation, it was thought that such a difference might account for the lack of agreement. A brief examination of this possibility (using the two subjects who participated in Experiment B) resulted in approximately identical data for uniocular and binocular conditions.

Scott and Noland[10] sought to resolve some conflicts in findings among studies in which spiral size, type of spiral, distance from the observer, and motor speed were different, by taking into account the usually neglected variable of speed of eliciting motion. The authors point out that a frequently ignored factor in SAE studies is that the speed of motion of the stimulus pattern across the retina varies with the viewing distance. Based upon calculations from data reported by Granit[4], Scott[9], and Freud[3], Scott and Noland concluded that SAE duration increased up to 132 minarcs/sec (then declined) and that the aftereffect appeared highly predictable on the basis of information about the speed of eliciting motion. Data from the present study, however, show increasing SAE durations only up to 30–60 minarcs/sec, and a further analysis (calculations of the speed of eliciting stimuli) of the work of Fozard et al.[2] shows a wide range in minarcs/sec during which peak SAE durations occur depending upon other manipulated variables (Table 2). In both of the latter studies the visual angle appears to have a critical effect on peak duration. It seems clear, then, that both the visual angle and the speed of eliciting motion are variables of significance in determining the duration of the spiral aftereffect.

V. Summary

This study examined some effects of stimulus size and distance on the persistence of one type of illusory motion, viz., the spiral aftereffect. Duration of SAE was investigated with stimuli of 2, 4, 8, 12, 14, and 16 inches in diameter. The distance between the observers and the rotating spirals was varied to produce visual angles between 1°12′ and 18°56′ of arc. Data indicate that the duration of illusory motion reaches peak values between approximately 2°–4° of visual angle.

Table 2. Speed of eliciting motion (minarcs/sec) calculated from the data of Fozard et al.[2] and the durations of the spiral aftereffect (in seconds) which they obtained under various test conditions.

			25 rpm		*100 rpm*		*250 rpm*	
Spiral Turns	*Spiral Size*	*Visual Angle*	*Minarcs Per Sec*	*SAE Duration*	*Minarcs Per Sec*	*SAE Duration*	*Minarcs Per Sec*	*SAE Duration*
1.5	4″	2°23′	19.9	18.5	79.6	15.6	198.9	16.8
	8″	4°46′	39.8	18.9	159.1	18.6	397.8	14.9
	16″	9°23′	79.6	14.3	318.2	13.7	795.6	12.0
2.5	4″	2°23′	12.0	19.7	47.9	17.8	119.7	19.8
	8″	4°46′	22.5	18.9	90.1	19.7	225.2	20.1
	16″	9°23′	45.1	16.1	180.2	13.2	450.5	24.7
3.5	4″	2°23′	8.6	20.5	34.2	19.7	85.6	19.3
	8″	4°46′	17.1	23.2	68.5	23.3	171.3	21.4
	16″	9°23′	34.3	20.4	137.1	19.7	342.7	16.3

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21066