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DRIVER EYE FIXATIONS AND THE OPTIMAL LOCATIONS FOR AUTOMOBILE BRAKE LIGHTS

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16. Abstract

This study evaluated the distributions of driver eye fixations when following other vehicles. The aim was to describe the areas of the forward field of view that are most frequently fixated. Such information is important for selecting optimal locations for automobile brake lights: The brake lights that are closer to eye fixations are likely to result in shorter driver reaction times than brake lights farther away from the fixations.

A head-mounted, corneal-reflection device was used to monitor eye fixations. The data were collected during daylight hours in slow-speed urban traffic. A total of 5,172 eye fixations were analyzed for three different lead cars.

The results indicate that under the conditions of this study the eye fixations tended to concentrate on the rear-window area of the lead car. Furthermore, the frequency of the eye fixations was low in the neighborhood of the standard low-mounted brake lights.

The results provide a possible behavioral explanation for the accident reductions obtained with high-mounted brake lights in previous field studies. Furthermore, high-mounted brake lights located at the edges of the vehicle might be even closer to eye fixations than a center high-mounted brake light.

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TABLE OF CONTENTS

INTRODUCTION

Three recent accident studies have found that the frequency of certain types of rear-end collisions is reduced by about one-half by using a single, center-high-mounted brake-light repeater (Malone, Kirkpatrick, Kohl, and Baker, 1978; Reilly, Kurke, and Buckenmeier, 1980; Rausch, Wong, and Kirkpatrick, 1981). However, behavioral studies that investigated possible mechanisms responsible for the accident reductions have produced mixed results. These studies evaluated the frequency and delay of brake responses (Schmidt-Clausen, 1977; Allen Corp., 1978; Sivak, Post, Olson and Donohue, 1981a, 1981b) and of vehicle speed-change responses (Sivak, Olson, and Farmer, 1981).

The present study was designed to investigate the eye-fixation patterns of drivers in slow-speed, stop-and-go traffic, typical of urban congestion. In contrast, the above-mentioned behavioral studies were run at higher speeds and in freer-flowing traffic. An additional unique feature of this study was the absence of any high-mounted brake lights. The aim was to investigate the distribution of eye fixations when following cars without high-mounted brake lights, in order to describe the areas of the forward field of view that are most frequently fixated. The underlying assumption was that the closer brake lights are to eye fixations, the shorter reaction time a following driver will have. This effect of visual angle of stimuli on reaction time was recently documented under actual driving conditions by Cohen (1983, 1984). (Cohen has shown that reaction times of drivers to small light stimuli mounted on the windshield is a monotonically increasing function of the visual angle between the eye fixation and the stimulus.)

EXPERIMENT 1

Objective

The aim of this experiment was to investigate the relative distance (relative visual angle) of eye fixations to (1) standard low-mounted brake lights, and to (2) the hypothetical location of a supplemental, center high-mounted brake light.

Method

Design. The eye-fixation measures were obtained from relatively "naive" subjects. The subjects were not told about the true purpose of the experiment. They were told that the reason for the eye-camera on their heads was to monitor the pupil size as a function of traffic conditions.

Subjects. Two males (ages 19 and 22) and one female (age 21) were tested. The subjects were paid for their participation.

Test vehicle. Subjects were instructed to follow a dark-blue 1973 Dodge Polara (Figure 1). This car was selected because similar models constituted a significant proportion of test vehicles in the first of the accident studies (Malone et al., 1978).

Route. The data for all three subjects were collected on the same route. The route, approximately 3-km long, includes several downtown streets of Ann Arbor, a city with a population of approximately 110,000. Throughout the route there is heavy vehicle, bicycle, and pedestrian traffic. The roadway on the route is mostly one lane in each direction, with on-street parking on both sides. The speed limit on the route is 40 km/h (25 mph). The data were collected at speeds of approximately 5–40 km/h, with the majority collected at 5–20 km/h. The experiment was performed in daylight hours during days with no precipitation.

Equipment. Eye fixations were measured using a NAC Eye Mark Recorder, Model 4. This is a corneal reflection instrument with eye-spot accuracy of $\pm 2°$. Data were videotaped for later analysis.

During the experimental runs subjects drove a 1980 Ford Country Squire station wagon. The recording equipment was installed in the back seat. The experimenter also rode in the back seat. He viewed a small black and white video monitor that displayed the videotaped scene and the eye mark.

Procedure. This experiment required two separate sessions for each subject. The first session was designed to familiarize the subject with the equipment and to screen out

Figure 1. Photograph of the lead vehicle used in Experiment 1 (1973 Dodge Polara).

those who were bothered by the device or on whom the eye spot could not be found. (The device precluded having subjects with glasses but not those with contact lenses.)

The actual data were collected during the second session. The instructions indicated that the subjects should follow the lead car. After the eye-mark recorder was fitted and calibrated, the subject drove about 5 km prior to arriving at the route where the data were recorded. The subject was not told that the data were collected only on a certain portion of the driven route.

Frequent calibration checks were made throughout the route. If the equipment was found to be out of alignment, the previous portion of the route (from the previous alignment, or from a sudden change in alignment) was not analyzed.

Data analysis. The data were reduced on a frame-by-frame basis. The measures derived from the video recordings are depicted in Figure 2. V1 is the distance from a given fixation to the hypothetical location of the center high-mounted brake light. This location is defined as being at the bottom of the rear window on the lateral centerline of the vehicle. V2 is the analogous distance from a given eye fixation to the center of the nearer of the two (left or right) standard brake lights. Both V1 and V2 were measured in millimeters directly off a large video monitor. (The shaded region in Figure 2 is the area in which a fixation would be closer to the center high-mounted location than to either of the two standard low-mounted locations.)

To spread the analyzed frames over a longer route distance, only every second fixation (for the first subject) and every third fixation (for the second and third subjects) were analyzed. Eye fixations directed inside of the subjects's own car (e.g., on the dashboard) were not included in the analyses. Furthermore, the data were analyzed only if both of the following conditions were met: (1) Both the subject's car and the lead car were travelling in a straight line with no significant lateral offset. (No data were taken on curves.) (2) Both of the cars were moving. (No data were taken at traffic lights and stop signs.)

Results

Table 1 shows the percentages of trials in which the eye-fixation distance from the center high-mounted location (V1) was shorter than, longer than, or equal to the distance from the nearer of the two standard low-mounted brake lights (V2). This table also shows the results of analyses testing the hypothesis that the distance to the high-mounted location is shorter than the distance to either of the two low-mounted locations.

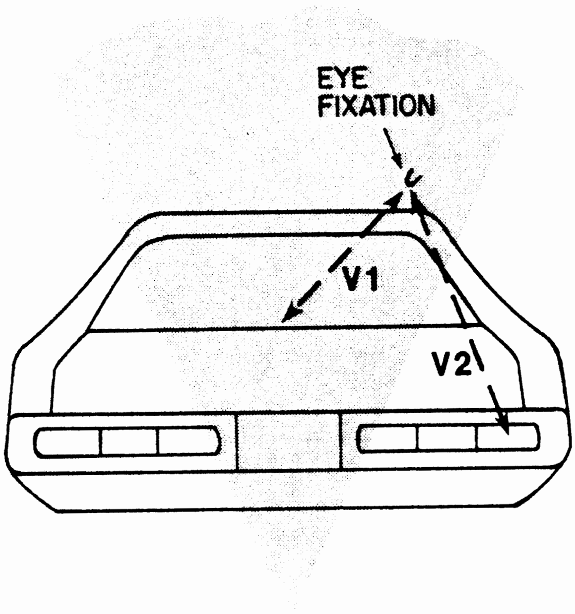

Figure 2. Basic measures derived from each analyzed video frame in Experiment 1. (The shaded region is the area in which a fixation would be closer to the center high-mounted location than to either of the two standard low-mounted locations.)

TABLE 1

EXPERIMENT 1: ORDINAL RELATION OF THE TWO FIXATION DISTANCES
(1973 Dodge Polara; entries are the proportions of cases)

	Subject		
	1 (N=307)	2 (N=145)	3 (N=300)
V1<V2	0.602	0.434	0.597
V2<V1	0.391	0.538	0.400
V1=V2	0.007	0.028	0.003
α (2-tail)*	<.001	>.05	<.001

*Tests for the equality between the first two proportions in each column.

The preceding analysis looked only at the distribution of ordinal relations of the distances from fixations to the standard and high-mounted locations. The next analysis took into account the magnitude of the ratio of these two distances as well. To accomplish this, the following transformation was performed on the raw distances:

$$V3 = (V2/V1) - 1, \quad \text{if } V2 \geq V1, \text{ and}$$
$$V3 = -(V1/V2) + 1, \quad \text{if } V1 > V2$$

This transformation created a new variable—V3, which has a positive value if V2 is greater than V1, a negative value if V2 is smaller than V1, and zero if V2 is equal to V1. Consequently, V3 is centered around zero.

Table 2 presents the minimum, maximum, mean, and standard deviation of V3 for each subject. This table also shows the z-score and the α level of the test that evaluated the hypothesis that the mean of V3 is greater than zero.

TABLE 2

EXPERIMENT 1: DESCRIPTIVE PROPERTIES OF THE TRANSFORMED RATIO OF THE TWO FIXATION DISTANCES
(1973 Dodge Polara; positive values favor center high-mounted location, while negative values favor standard low-mounted location)

	Subject		
	1 (N=307)	2 (N=145)	3 (N=300)
Minimum	−3.30	−4.38	−5.00
Maximum	7.40	11.00	11.56
Mean	0.22	0.31	0.61
Standard Deviation	1.12	1.99	1.95
z-score of the Mean	3.53	1.86	5.44
α (1-tail)	<.001	<.05	<.001

<u>Discussion</u>

The results of this experiment show that for two subjects the eye fixations were more frequently closer to the center high-mounted location than to either of the two standard low-mounted locations. The results for the third subject show no significant difference. Furthermore, a parametric evaluation, taking into account the ratio of these two distances, found significant differences in favor of the center high-mounted location for all three subjects.

In the next experiment the data analysis was refined to allow computation of fixation distance from any location on the rear of the vehicle.

EXPERIMENT 2

Objective

The aim of this experiment was to evaluate the distances of eye fixations from four possible locations for installing brake lights: (1) standard low-mounted, (2) center high-mounted, (3) dual high-mounted, and (4) center roof-mounted.

Method

The following aspects of the method of this experiment were identical to those of Experiment 1: design, test vehicle, route, equipment, and procedure.

Subjects. Three male subjects (ages 22, 33, and 34) were tested.

Following distances. The actual driver-to-rear-lamps following distances were computed from each frame by measuring the image size of the known separation between the brake lamps. The means (and standard deviations) of the following distances (in meters) for the three subjects were 11.6 (2.7), 12.7 (2.9), and 12.3 (2.9).

Data analysis. As in Experiment 1, the data were reduced on a frame-by-frame basis. The coding system is illustrated in Figure 3. For each individual frame, the horizontal axis was defined as going through the center of the standard low-mounted brake lights, and the vertical axis as being identical to the centerline of the vehicle. (More precisely, the vertical axis was defined as being equidistant from the centers of both [left and right] standard brake lights. Because of the presence of a small lateral offset between the lead and subject's vehicle on some trials, the planes running longitudinally through the centerline of the two vehicles were not always identical. Furthermore, the view of the scene was taken from the driver's point of view, which is laterally offset in relation to the centerline of the subject's vehicle. Consequently, small non-systematic horizontal errors were built into the coding system.)

The measures taken from each frame (see Figure 3) were as follows: (1) the horizontal coordinate of the fixation—x_F, (2) the vertical coordinate of the fixation—y_F, (3) the distance from the origin to the center of the standard low-mounted brake lamp—x_L, and (4) the distance from the origin to the hypothetical center high-mounted brake lamp—y_C. These four measures were obtained by using a transparent millimeter-grid overlay. (The x_L and y_C measures were recorded in order to standardize the coordinates of the fixations, and to compute the actual following distance.)

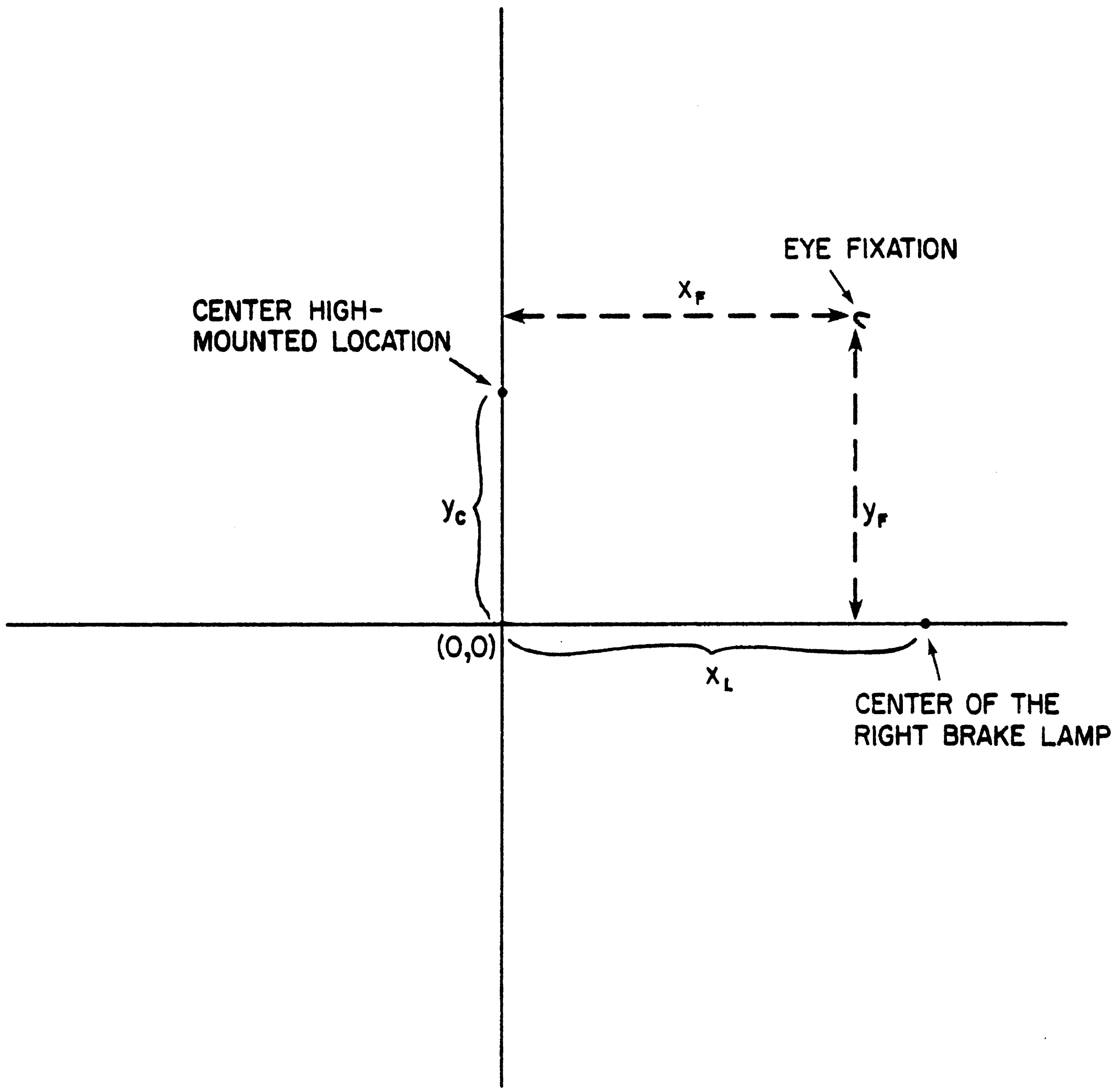

Figure 3. Basic measures derived from each analyzed video frame in Experiment 2.

For each analyzed frame the following four angular distances were computed from the fixation (see Figure 4): (1) the distance to the nearer of the two standard low-mounted brake lights (LOW), (2) the distance to the hypothetical location of the center high-mounted brake light (CENTER), (3) the distance to the nearer of the two hypothetical dual high-mounted brake lights (DUAL), and (4) the distance to the hypothetical location of the center roof-mounted brake light (ROOF). The coordinates for the locations of interest were as follows: (1) Low-mounted: $x = \pm 40$, $y = 0$, (2) center high-mounted: $x = 0$, $y = 20$ (at the centerline and at the bottom of the window), (3) dual high-mounted: $x = \pm 30$, $y = 20$ (as outboard as possible and at the bottom of the window), and (4) center roof-mounted: $x = 0$, $y = 40$ (at the centerline and on the top of the roof). The coordinates for these locations were determined by examining both the actual vehicle and the video recordings of it.

Additional analyses were performed on fixations for which (1) a location of interest was substantially distant (important because of a monotonic increase in reaction time as a function of visual angle), or (2) a location of interest fell on the fovea during a given eye fixation (important because the best photopic and mesopic vision occurs in this area of the visual field). Specifically, these analyses examined the frequencies of fixations that were more than 5° or less than 1° away from the locations of interest.

In order to plot the analyzed eye fixations on the same figure, a standardization to a common following distance was made. This standardization was performed as follows:

$$x_{standardized} = (40/x_L)x_F, \text{ and}$$
$$y_{standardized} = (20/y_C)y_F,$$

where 40 and 20 correspond to the measured values of x_L and y_C at the following distance of 9.9 m (32.5 ft.). (The selection of these two standardizing constants does not affect any of the analyses that follow.)

To spread the analyzed frames over a longer route distance, only every second fixation was analyzed.

Results

Table 3 lists the mean angular distances of the unstandardized (raw) eye fixations to the locations of interest. The results of $\underline{t}$ tests for the six pairs of fixation distances ($\underline{t}$ tests for paired samples [Dixon and Massey, 1969]) are also shown in Table 3. (Since six simultaneous $\underline{t}$ tests were considered, the critical α level was adjusted by dividing the desired composite α level of 0.05 by six [Morrison, 1976].)

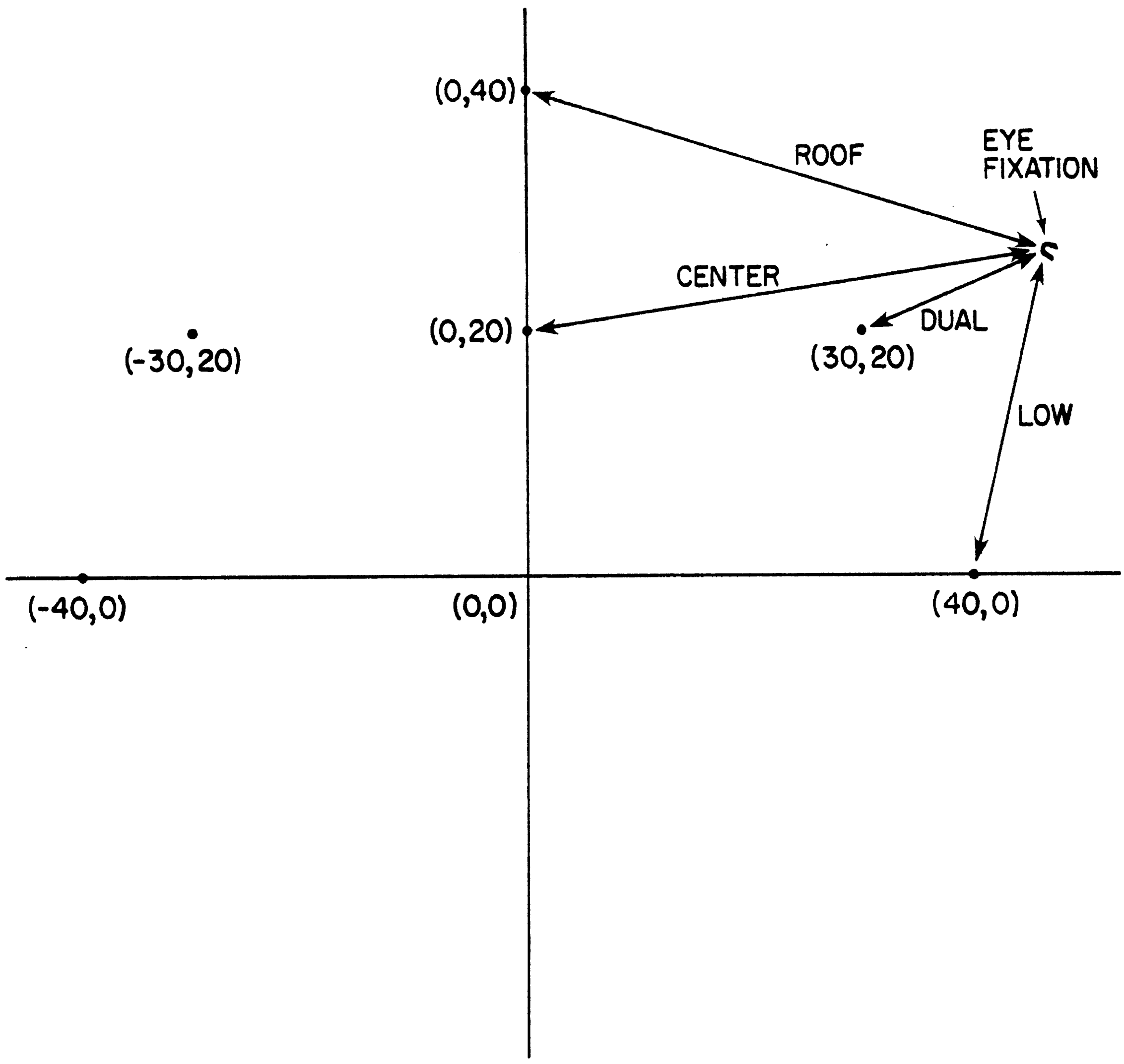

Figure 4. Schematic of the four computed distances in Experiment 2.

TABLE 3

EXPERIMENT 2: (A) MEAN ANGULAR DISTANCES (IN DEGREES) OF THE UNSTANDARDIZED FIXATIONS, (B) PAIR-WISE COMPARISONS OF THE FIXATION DISTANCES (1973 Dodge Polara; entries in (B) correspond to the significantly shorter distances)

	Subject		
	1	2	3
Measure			
LOW	4.5	3.2	3.3
CENTER	4.1	2.5	2.9
DUAL	3.2	2.1	2.2
ROOF	4.0	2.7	3.2
Comparison pair			
LOW vs. CENTER		CENTER	CENTER
LOW vs. DUAL	DUAL	DUAL	DUAL
LOW vs. ROOF	ROOF	ROOF	
CENTER vs. DUAL	DUAL	DUAL	DUAL
CENTER vs. ROOF		CENTER	CENTER
DUAL vs. ROOF	DUAL	DUAL	DUAL

Table 4 presents the numbers of fixations for each subject that were more than 5° away from the four locations of interest. Conversely, Table 5 lists the numbers of fixations that were less than 1° from these locations.

TABLE 4

EXPERIMENT 2: FREQUENCY OF FIXATIONS THAT WERE MORE THAN 5° FROM FOUR LOCATIONS OF INTEREST (1973 Dodge Polara)

Measure	Subject		
	1 (N=280)	2 (N=280)	3 (N=260)
LOW	91	25	35
CENTER	76	27	31
DUAL	38	7	17
ROOF	73	30	36

TABLE 5

EXPERIMENT 2: FREQUENCY OF FIXATIONS THAT WERE LESS THAN 1° FROM FOUR LOCATIONS OF INTEREST
(1973 Dodge Polara)

Measure	Subject		
	1 (N=280)	2 (N=280)	3 (N=260)
LOW	3	13	10
CENTER	21	53	44
DUAL	29	38	50
ROOF	36	36	18

Figures 5, 6, and 7 present the distributions of the standardized eye fixations for each subject. In these figures, an asterisk indicates a location of a single fixation, while a number indicates that more than one fixation fell on that location. The few fixations that were farther than 150 units from the origin were not included in these figures, so that the scale could be enlarged to enhance the clarity. (All fixations were included in the statistical analyses.) In addition to each individual eye fixation, these figures also depict the locations of interest on the rear of the test vehicle. The means and standard deviations of the standardized horizontal and vertical coordinates of the fixations are listed in Table 6.

TABLE 6

EXPERIMENT 2: MEAN COORDINATES FOR THE STANDARDIZED FIXATIONS AND THE CORRESPONDING STANDARD DEVIATIONS

Measure	Subject		
	1	2	3
x_{mean}	6.3	3.7	−5.8
(S.D.)	(53.0)	(33.7)	(42.0)
y_{mean}	33.8	26.1	25.0
(S.D.)	(18.4)	(15.8)	(11.8)

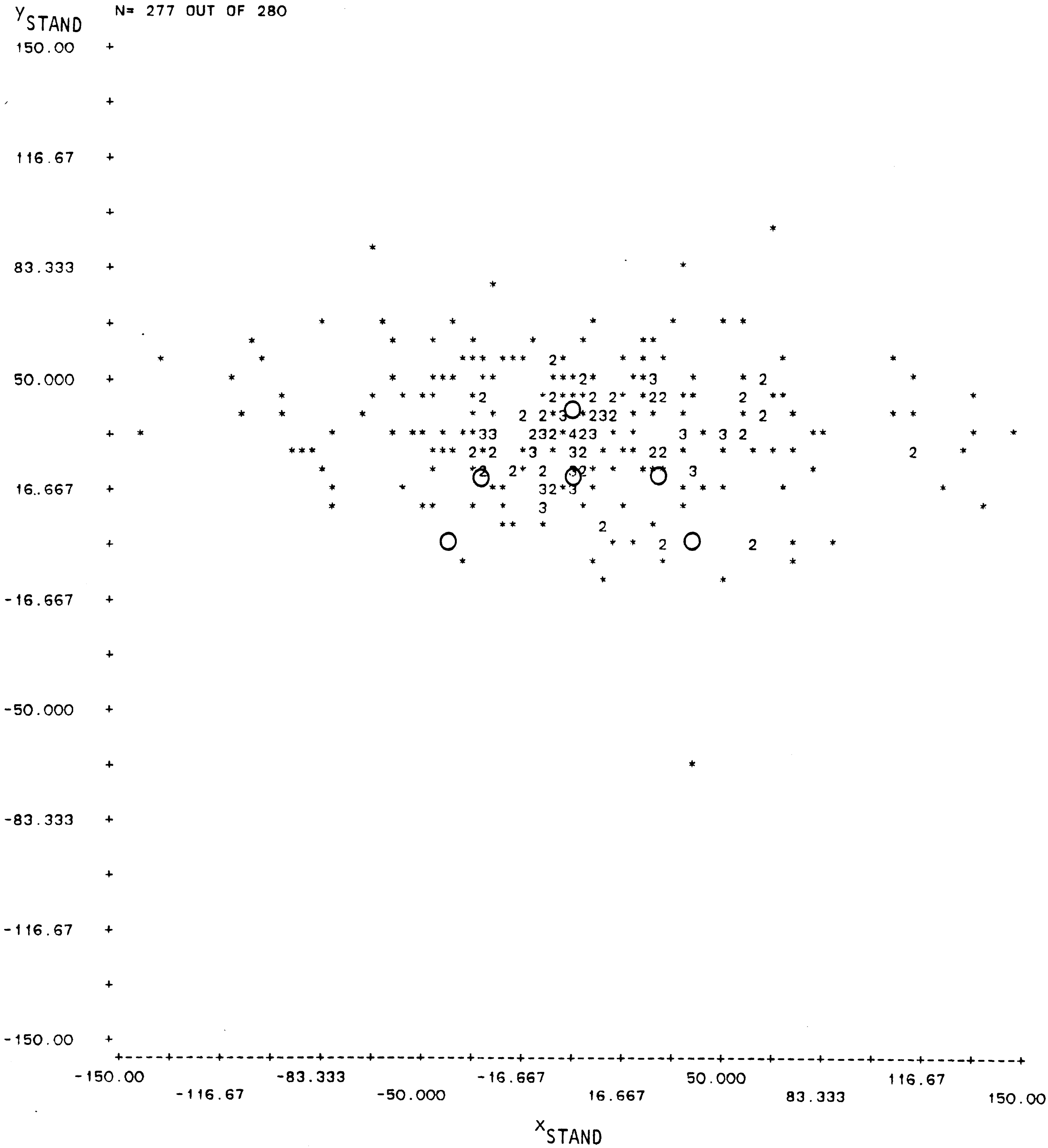

Figure 5. Distribution of the standardized eye fixations (Experiment 2: 1973 Dodge Polara, Subject 1).

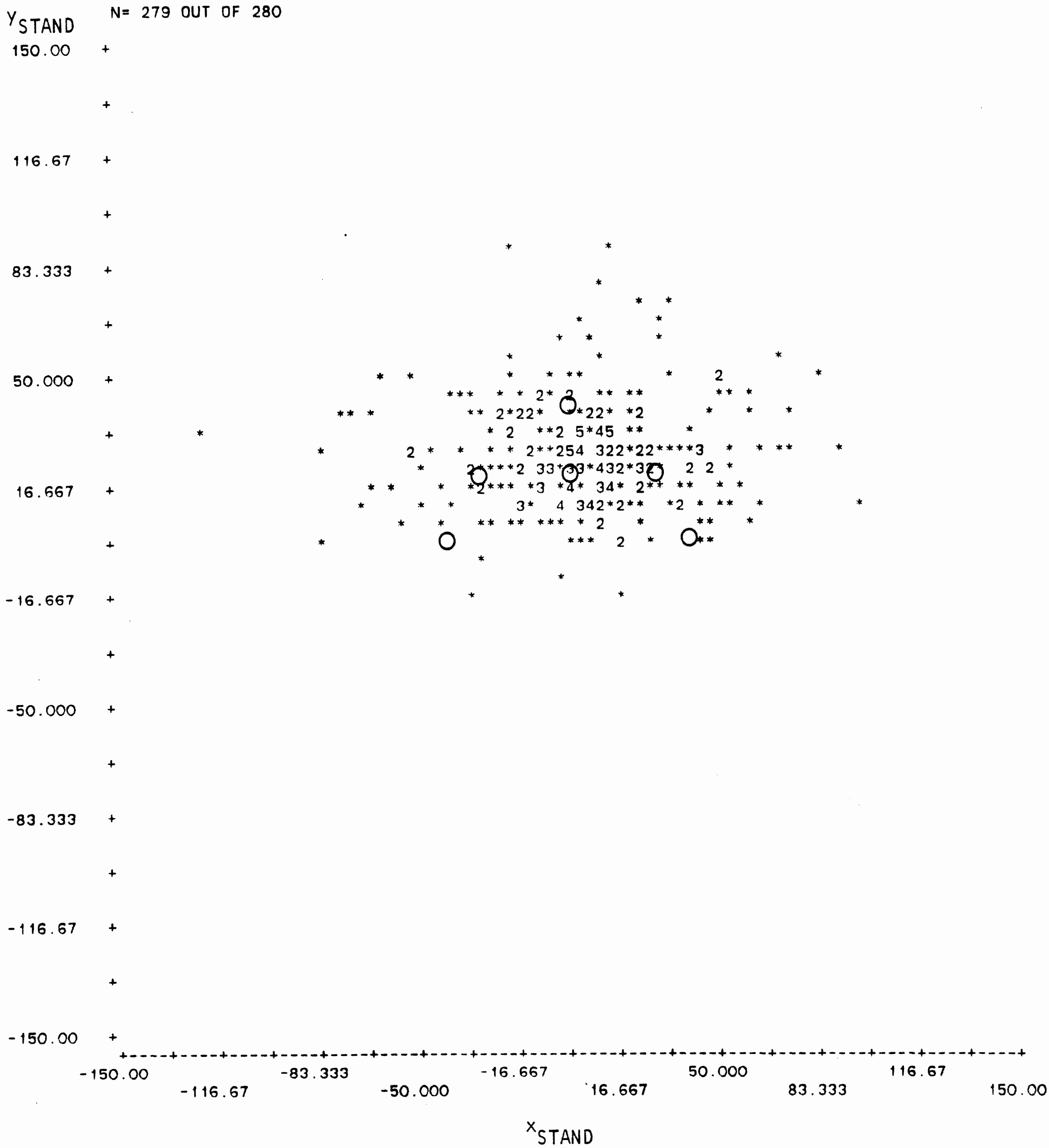

Figure 6. Distribution of the standardized eye fixations (Experiment 2: 1973 Dodge Polara, Subject 2).

Figure 7. Distribution of the standardized eye fixations (Experiment 2: 1973 Dodge Polara, Subject 3).

Discussion

The obtained distributions of the eye fixations (Figures 5, 6, and 7) reveal that the eye fixations tended to concentrate in the area of the rear window of the lead vehicle. Conversely, very few eye fixations (at least for two out of the three subjects) were in the neighborhood of the standard low-mounted brake lights.

Parametric analyses of the locations of the eye fixations revealed the following:

The eye fixations were closer to the center high-mounted location than to the standard low-mounted locations for two out of the three subjects. (There was no significant difference for the third subject.) Furthermore, for all three subjects the fixations within one degree of visual angle were more numerous when measured from the center high-mounted location as opposed to either of the two standard low-mounted locations. The analysis of the fixations that were more than five degrees distant did not indicate an advantage for either the standard low-mounted or the center high-mounted location.

Analogous comparisons tended to favor dual high-mounted locations over both the standard low-mounted and center high-mounted locations. As far as the roof-mounted location is concerned, there was a tendency for the fixations to favor this location over the standard low-mounted location, but not over the two locations at intermediate height (i.e., center high-mounted and dual high-mounted).

EXPERIMENT 3

Objective

The aim of this experiment was to evaluate the locations of eye fixations as a function of the vehicle type immediately ahead.

Method

The following aspects of this experiment were identical to those of Experiment 2: design, route, and equipment.

Subjects. Four males (ages 18, 19, 20, and 20) and two females (ages 24 and 26) were tested.

Test vehicles. Three test vehicles were used (see Figure 8): (1) the dark-blue 1973 Dodge Polara that was used in Experiments 1 and 2, (2) a dark-brown 1983 Chevrolet Caprice Classic Station Wagon, and (3) a dark-red 1984 Chrysler Laser.

Procedure. The procedure was identical to that of Experiments 1 and 2, with the exception that each subject drove the test portion of the route three times, following the three test vehicles one at a time. The order of the test vehicles was counterbalanced among the six subjects.

Following distances. The means and standard deviations of the actual following distances for each lead car and each subject are listed in Appendix A.

Data analysis. Data analysis was analogous to the analysis in Experiment 2. The following equations were used to standardize the coordinates of the eye fixations:

1973 Dodge Polara:

$$x_{\text{standardized}} = (40/x_L)x_F, \text{ and}$$
$$y_{\text{standardized}} = (20/y_C)y_F$$

1983 Chevrolet Caprice Classic Station Wagon:

$$x_{\text{standardized}} = (50/x_L)x_F, \text{ and}$$
$$y_{\text{standardized}} = (20/y_C)y_F$$

1984 Chrysler Laser:

$$x_{\text{standardized}} = (30/x_L)x_F, \text{ and}$$
$$y_{\text{standardized}} = (13/y_C)y_F$$

Figure 8. Photographs of the lead vehicles used in Experiment 3 (from top to bottom: 1973 Dodge Polara, 1983 Chevrolet Caprice Classic Station Wagon, and 1984 Chrysler Laser).

All of the above standardizing constants correspond to the measured values of x_L and y_C, respectively, at the following distance of 9.9 m. (This is the same following distance that was used for standardizing the eye fixations in Experiment 2.)

The coordinates for the locations of interest are listed in Table 7. These coordinates were determined by examining both the actual vehicles and their video recordings.

TABLE 7

EXPERIMENT 3: COORDINATES FOR THE LOCATIONS OF INTEREST

Location	1973 Dodge Polara		1983 Chevrolet Caprice Classic Station Wagon		1984 Chrysler Laser	
	x	y	x	y	x	y
LOW	±40	0	±50	0	±30	0
CENTER	0	20	0	20	0	13
DUAL	±30	20	±32	20	±30	13
ROOF	0	40	0	40	0	30

Results

Table 8 lists for the 1983 Dodge Polara the mean angular distances of the unstandardized (raw) eye fixations to the locations of interest. The results of t tests for the six pairs of fixation distances (t tests for paired samples [Dixon and Massey, 1969]) are also shown in Table 8. (Since six simultaneous t tests were considered, the critical α level was adjusted by dividing the desired composite α level of 0.05 by six [Morrison, 1976].) The analogous results for the 1983 Chevrolet Caprice Classic Station Wagon are shown in Table 9, and for the 1984 Chrysler Laser in Table 10.

TABLE 8

EXPERIMENT 3: (A) MEAN ANGULAR DISTANCES (IN DEGREES) OF THE UNSTANDARDIZED FIXATIONS, (B) PAIR-WISE COMPARISONS OF THE FIXATION DISTANCES (1973 Dodge Polara; entries in (B) correspond to the significantly shorter distances)

	Subject					
	1	2	3	4	5	6
Measure						
LOW	4.2	4.4	3.6	4.0	4.7	3.8
CENTER	2.9	3.1	3.8	3.3	4.7	3.7
DUAL	2.7	2.8	2.6	2.8	3.4	3.0
ROOF	3.3	3.3	3.7	3.4	4.6	3.9
Comparison pair						
LOW vs. CENTER	CENTER	CENTER		CENTER		
LOW vs. DUAL	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL
LOW vs. ROOF	ROOF	ROOF		ROOF		
CENTER vs. DUAL			DUAL	DUAL	DUAL	DUAL
CENTER vs. ROOF	CENTER					CENTER
DUAL vs. ROOF	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL

TABLE 9

EXPERIMENT 3: (A) MEAN ANGULAR DISTANCES (IN DEGREES) OF THE UNSTANDARDIZED FIXATIONS, (B) PAIR-WISE COMPARISONS OF THE FIXATION DISTANCES
(1983 Chevrolet Caprice Classic Station Wagon; entries in (B) correspond to the significantly shorter distances)

	Subject					
	1	2	3	4	5	6
Measure						
LOW	4.8	3.7	3.5	3.8	4.3	3.7
CENTER	3.2	2.7	3.8	3.7	4.9	3.8
DUAL	3.2	2.5	2.9	3.0	3.5	2.9
ROOF	3.1	2.9	4.1	3.6	5.2	4.0
Comparison pair						
LOW vs. CENTER	CENTER	CENTER			LOW	
LOW vs. DUAL	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL
LOW vs. ROOF	ROOF	ROOF	LOW		LOW	
CENTER vs. DUAL			DUAL	DUAL	DUAL	DUAL
CENTER vs. ROOF		CENTER	CENTER		CENTER	
DUAL vs. ROOF		DUAL	DUAL	DUAL	DUAL	DUAL

TABLE 10

EXPERIMENT 3: (A) MEAN ANGULAR DISTANCES (IN DEGREES) OF THE UNSTANDARDIZED FIXATIONS, (B) PAIR-WISE COMPARISONS OF THE FIXATION DISTANCES

(1984 Chrysler Laser; entries in (B) correspond to the significantly shorter distances)

	Subject					
	1	2	3	4	5	6
Measure						
LOW	3.2	4.0	4.1	4.1	3.8	4.0
CENTER	3.2	3.3	3.8	4.0	4.2	4.2
DUAL	2.4	3.1	3.3	3.4	3.2	3.3
ROOF	3.0	2.8	3.6	3.8	4.2	4.0
Comparison pair						
LOW vs. CENTER		CENTER			LOW	
LOW vs. DUAL	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL
LOW vs. ROOF		ROOF	ROOF		LOW	
CENTER vs. DUAL	DUAL		DUAL	DUAL	DUAL	DUAL
CENTER vs. ROOF	ROOF	ROOF	ROOF			ROOF
DUAL vs. ROOF	DUAL			DUAL	DUAL	DUAL

Table 11 presents for the 1973 Dodge Polara the number of fixations that were more than 5° from the four locations of interest; Table 12 presents the number of fixations that were less than 1° from the locations of interest. The analogous results for the 1983 Chevrolet Station Wagon are shown in Tables 13 and 14, and for the 1984 Chrysler Laser in Tables 15 and 16.

TABLE 11

EXPERIMENT 3: FREQUENCY OF FIXATIONS THAT WERE MORE THAN 5° FROM FOUR LOCATIONS OF INTEREST (1973 Dodge Polara)

Measure	Subject					
	1 (N=200)	2 (N=200)	3 (N=200)	4 (N=200)	5 (N=200)	6 (N=200)
LOW	52	65	37	57	77	44
CENTER	27	33	46	42	77	43
DUAL	14	16	17	20	41	30
ROOF	29	39	45	46	66	49

TABLE 12

EXPERIMENT 3: FREQUENCY OF FIXATIONS THAT WERE LESS THAN 1° FROM FOUR LOCATIONS OF INTEREST (1973 Dodge Polara)

Measure	Subject					
	1 (N=200)	2 (N=200)	3 (N=200)	4 (N=200)	5 (N=200)	6 (N=200)
LOW	2	1	8	4	4	5
CENTER	22	27	12	18	5	18
DUAL	23	26	25	16	12	30
ROOF	15	20	14	25	7	11

TABLE 13

EXPERIMENT 3: FREQUENCY OF FIXATIONS THAT WERE MORE THAN 5° FROM FOUR LOCATIONS OF INTEREST
(1983 Chevrolet Caprice Classic Station Wagon)

Measure	Subject					
	1 (N=200)	2 (N=200)	3 (N=200)	4 (N=200)	5 (N=200)	6 (N=200)
LOW	85	38	37	42	63	40
CENTER	30	18	46	54	84	47
DUAL	22	15	25	25	36	26
ROOF	30	22	46	54	91	48

TABLE 14

EXPERIMENT 3: FREQUENCY OF FIXATIONS THAT WERE LESS THAN 1° FROM FOUR LOCATIONS OF INTEREST
(1983 Chevrolet Caprice Classic Station Wagon)

Measure	Subject					
	1 (N=200)	2 (N=200)	3 (N=200)	4 (N=200)	5 (N=200)	6 (N=200)
LOW	2	5	15	6	5	9
CENTER	14	18	13	15	5	13
DUAL	14	34	25	16	12	20
ROOF	31	21	10	25	7	11

TABLE 15

EXPERIMENT 3: FREQUENCY OF FIXATIONS THAT WERE MORE THAN 5° FROM FOUR LOCATIONS OF INTEREST
(1984 Chrysler Laser)

Measure	Subject					
	1 (N=200)	2 (N=200)	3 (N=200)	4 (N=200)	5 (N=200)	6 (N=200)
LOW	23	53	59	54	43	52
CENTER	27	27	50	53	59	61
DUAL	13	26	31	39	36	38
ROOF	28	18	38	49	58	57

TABLE 16

EXPERIMENT 3: FREQUENCY OF FIXATIONS THAT WERE LESS THAN 1° FROM FOUR LOCATIONS OF INTEREST
(1984 Chrysler Laser)

Measure	Subject					
	1 (N=200)	2 (N=200)	3 (N=200)	4 (N=200)	5 (N=200)	6 (N=200)
LOW	7	7	4	8	9	2
CENTER	11	11	13	17	15	16
DUAL	29	18	16	10	15	23
ROOF	27	22	12	16	10	17

The eighteen distributions of the standardized eye fixations (three lead vehicles times six subjects) are presented in Appendix B. In addition to each individual eye fixation, these figures also depict the locations of interest on the rear of the test vehicles. The means and standard deviations of the horizontal and vertical coordinates of the standardized fixations are listed in Tables 17, 18, and 19.

TABLE 17

EXPERIMENT 3: MEAN COORDINATES FOR STANDARDIZED FIXATIONS AND THE CORRESPONDING STANDARD DEVIATIONS (1973 Dodge Polara)

Measure	Subject					
	1	2	3	4	5	6
x_{mean}	−2.1	0.9	−11.1	−11.9	−1.0	4.1
(S.D.)	(32.1)	(34.1)	(47.3)	(35.3)	(49.6)	(57.6)
y_{mean}	25.5	28.8	30.3	27.2	38.1	25.9
(S.D.)	(16.2)	(17.8)	(21.5)	(24.5)	(23.1)	(23.9)

TABLE 18

EXPERIMENT 3: MEAN COORDINATES FOR STANDARDIZED FIXATIONS AND THE CORRESPONDING STANDARD DEVIATIONS (1983 Chevrolet Caprice Classic Station Wagon)

Measure	Subject					
	1	2	3	4	5	6
x_{mean}	4.1	−6.7	−14.8	−0.3	6.1	−15.7
(S.D.)	(37.0)	(30.9)	(53.2)	(59.8)	(57.1)	(59.1)
y_{mean}	33.0	28.1	21.5	32.7	21.6	28.0
(S.D.)	(21.3)	(22.0)	(25.2)	(31.2)	(24.8)	(25.9)

TABLE 19

EXPERIMENT 3: MEAN COORDINATES FOR STANDARDIZED FIXATIONS AND THE CORRESPONDING STANDARD DEVIATIONS (1984 Chrysler Laser)

Measure	Subject					
	1	2	3	4	5	6
x_{mean}	18.4	−1.4	−6.1	−2.0	6.8	−7.0
(S.D.)	(33.4)	(25.4)	(34.7)	(42.5)	(51.6)	(60.2)
y_{mean}	25.4	26.2	24.8	25.4	21.7	30.3
(S.D.)	(15.5)	(16.6)	(16.1)	(23.9)	(21.1)	(19.6)

Discussion

Although there was considerable variation between subjects in the horizontal and vertical scatter of the eye fixations, two aspects were common to most of the distributions of the eye fixations. First, eye fixations tended to concentrate in the rear window area of the lead vehicle. Second, there were only a few eye fixations on or near the standard low-mounted brake lights.

Parametric evaluation of the locations of the eye fixations revealed the following:

1973 Dodge Polara. Confirming the findings of Experiments 1 and 2, the eye fixations were significantly closer to the center high-mounted location than to either of the two standard low-mounted locations for three out of the six subjects. (For the other three subjects there was no significant difference.) Furthermore, for all six subjects the fixations within one degree of visual angle were more numerous when measured from the center high-mounted location, as opposed to the two standard low-mounted locations. The analysis of the fixations that were more than five degrees distant did not indicate a clear advantage for either the standard low-mounted or the center high-mounted location.

Analogous comparisons all favored dual high-mounted locations over both the standard low-mounted and center high-mounted locations. The roof-mounted location was favored over the standard low-mounted location, but not over the two locations at intermediate height (i.e., center high-mounted and dual high-mounted).

1983 Chevrolet Caprice Classic Station Wagon and 1984 Chrysler Laser. The results of the pair-wise comparisons, and of fixations more than 5° away, indicate no overall advantage of the center high-mounted location over the standard low-mounted locations. However, as with the 1973 Dodge Polara, there were more eye fixations within 1° of the center high-mounted location than within 1° of the two standard low-mounted locations.

The obtained eye fixations favored (in general) dual high-mounted locations over both the standard low-mounted and center high-mounted locations, and (in terms of fixations within 1° of the locations) the roof-mounted location over the standard low-mounted location (but not over the center and dual-high-mounted locations).

CONCLUSIONS

This study was designed to investigate the angular distance from potential locations of brake lights to eye fixations of the following drivers. The effectiveness of a location was operationally defined as inversely related to its distance from eye fixations. Obviously, the distance was measured in 2-D, since the depth of the focus for each fixation was not known.

It is fully acknowledged that factors such as size, luminance, color, and uniqueness of the function are significant determiners of the effectiveness of a brake light. However, holding such factors equal, it is likely that the distribution of angular separations between the location and driver eye fixations is a significant factor as well. The present study has shown that the eye fixations under low-speed, stop-and-go traffic conditions were concentrated primarily in the area of the rear window. This finding suggests that drivers tended to look through the lead vehicle in an attempt to gain information from farther ahead. Consequently, angular separations of eye fixations from the locations on the rear window were generally shorter than from a standard location of brake lights. These findings may account for the reduction in rear-end collisions associated with a single, center-mounted brake light in field studies. (An improvement in the congruence between eye fixation patterns and locations of brake lights for some drivers might be sufficient for accident reduction.) However, in the present study the superiority of high-mounted locations was more consistent (across subjects and vehicles) for two outboard locations as opposed to a central single location.

From among the between-vehicle trends, the most important was that the advantage of the center high-mounted over standard low-mounted locations was more pronounced for the 1973 Dodge Polara than for the other two test vehicles (1983 Chevrolet Caprice Classic Station Wagon and 1984 Chrysler Laser). Consequently, care has to be exercised when extrapolating results of accident (and behavioral) studies using given types of vehicles (of certain size, glass area, and location of standard brake lights) to the general population of vehicles.

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APPENDIX A

Table A-1 presents the means and standard deviations of the actual following distances for each lead car and each subject in Experiment 3.

TABLE A-1

FOLLOWING DISTANCES (IN METERS) IN EXPERIMENT 3

Lead Car	Subject	Driver-to-Rear-Lights Following Distance	
		Mean	S.D.
1973 Dodge Polara	1	10.1	2.1
	2	10.3	3.2
	3	12.5	2.5
	4	11.7	3.3
	5	10.6	3.0
	6	13.0	2.8
1983 Chevrolet Caprice Classic Station Wagon	1	11.3	2.8
	2	13.7	4.6
	3	14.0	3.8
	4	15.3	4.2
	5	11.4	3.5
	6	13.9	3.6
1984 Chrysler Laser	1	11.2	2.0
	2	9.6	3.2
	3	9.2	2.7
	4	10.9	3.1
	5	11.4	3.9
	6	13.0	2.6

APPENDIX B

Figures A-1 through A-18 present the distributions of eye fixations for the three lead vehicles and six subjects in Experiment 3. In these figures, as in Figures 5 through 7, an asterisk indicates a location of a single fixation, while a number indicates that more than one fixation fell on that location. Although 200 eye fixations were analyzed for each subject/vehicle combination, the few fixations that were farther than 150 units from the origin were not included in these figures, so that the scale could be enlarged to enhance the clarity. (All fixations were included in the statistical analyses, discussed on pages 18 through 29).

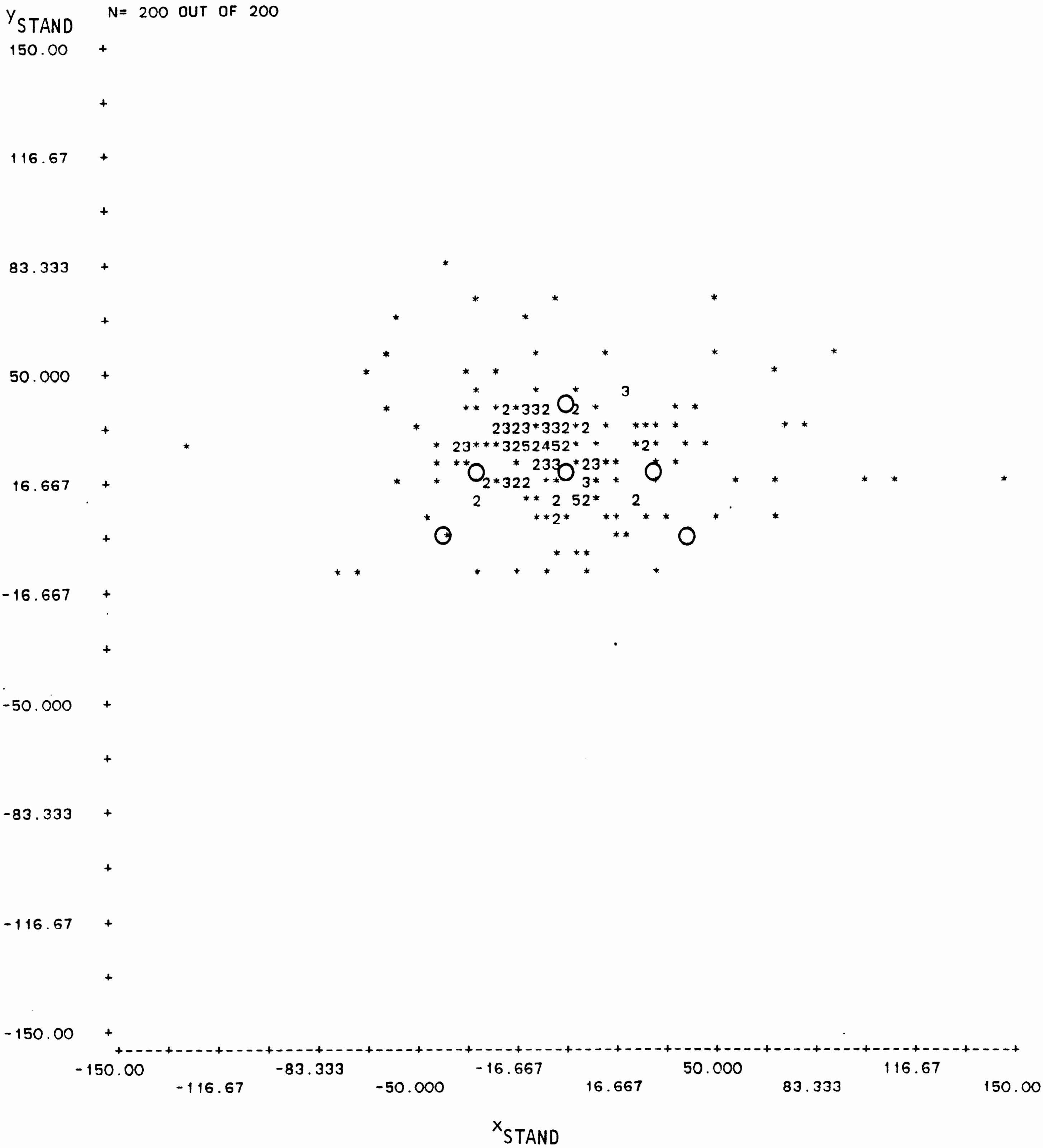

Figure A-1. Distribution of the standardized eye fixations (Experiment 3: 1973 Dodge Polara, Subject 1).

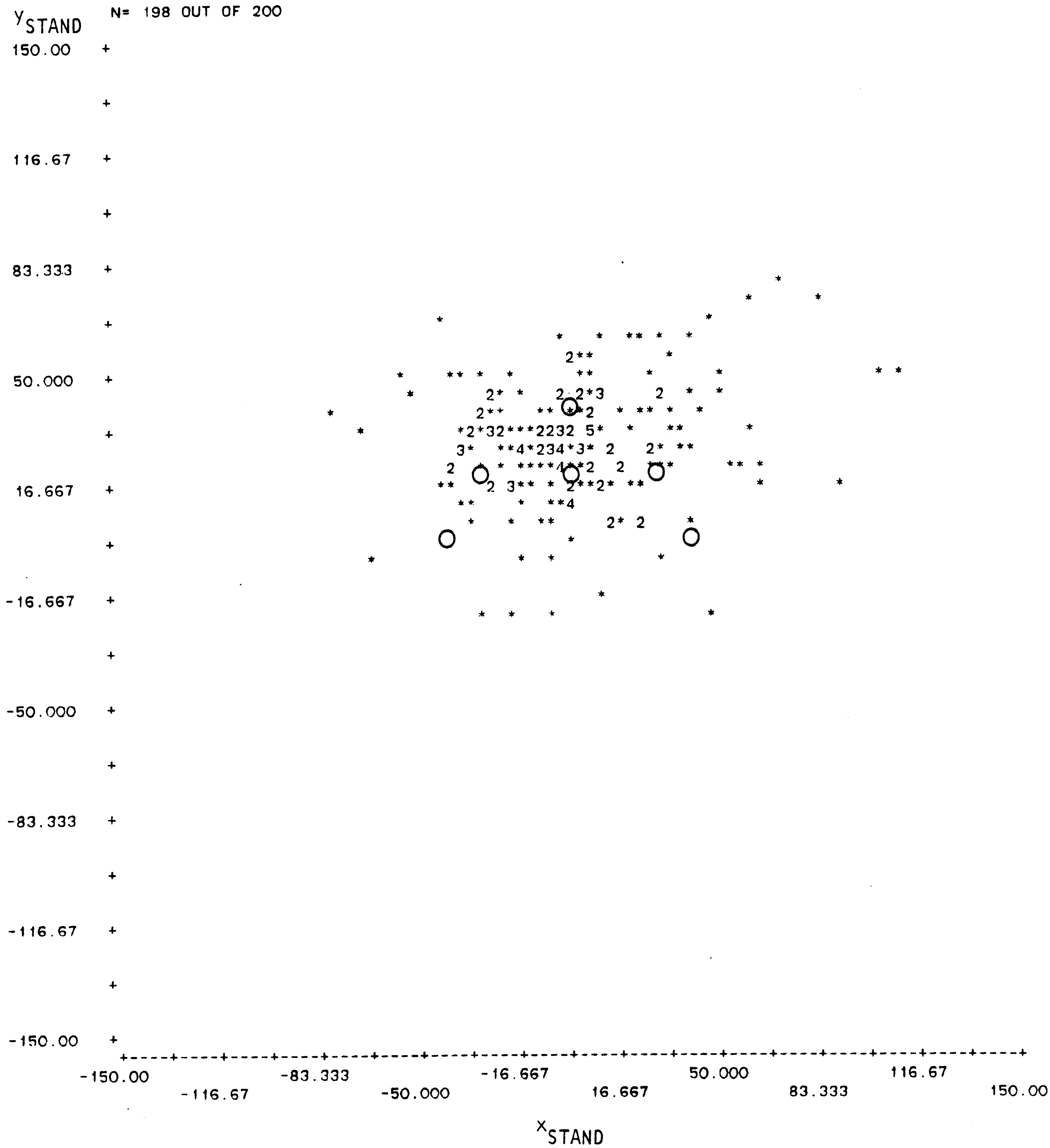

Figure A-2. Distribution of the standardized eye fixations (Experiment 3: 1973 Dodge Polara, Subject 2).

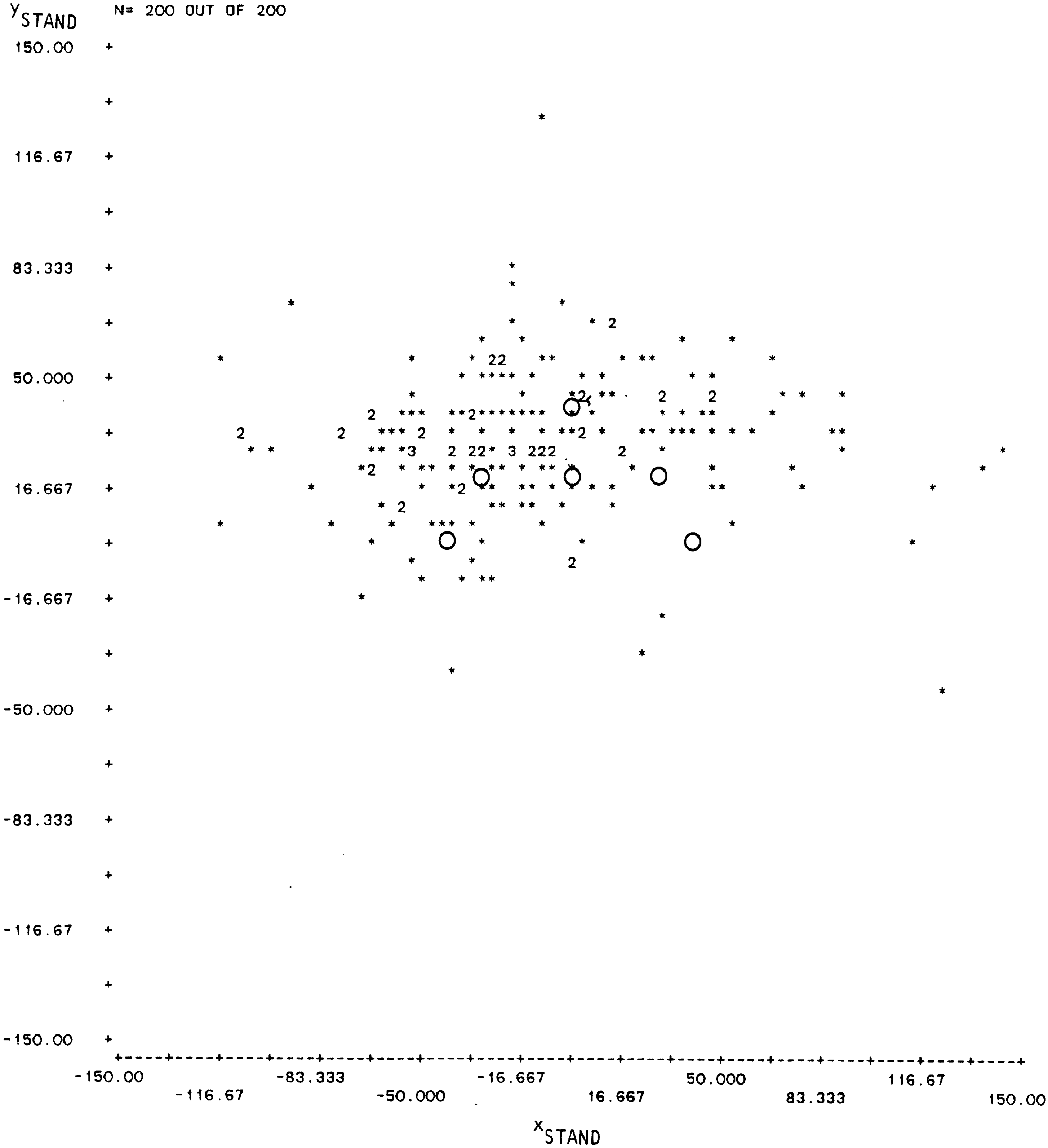

Figure A-3. Distribution of the standardized eye fixations (Experiment 3: 1973 Dodge Polara, Subject 3).

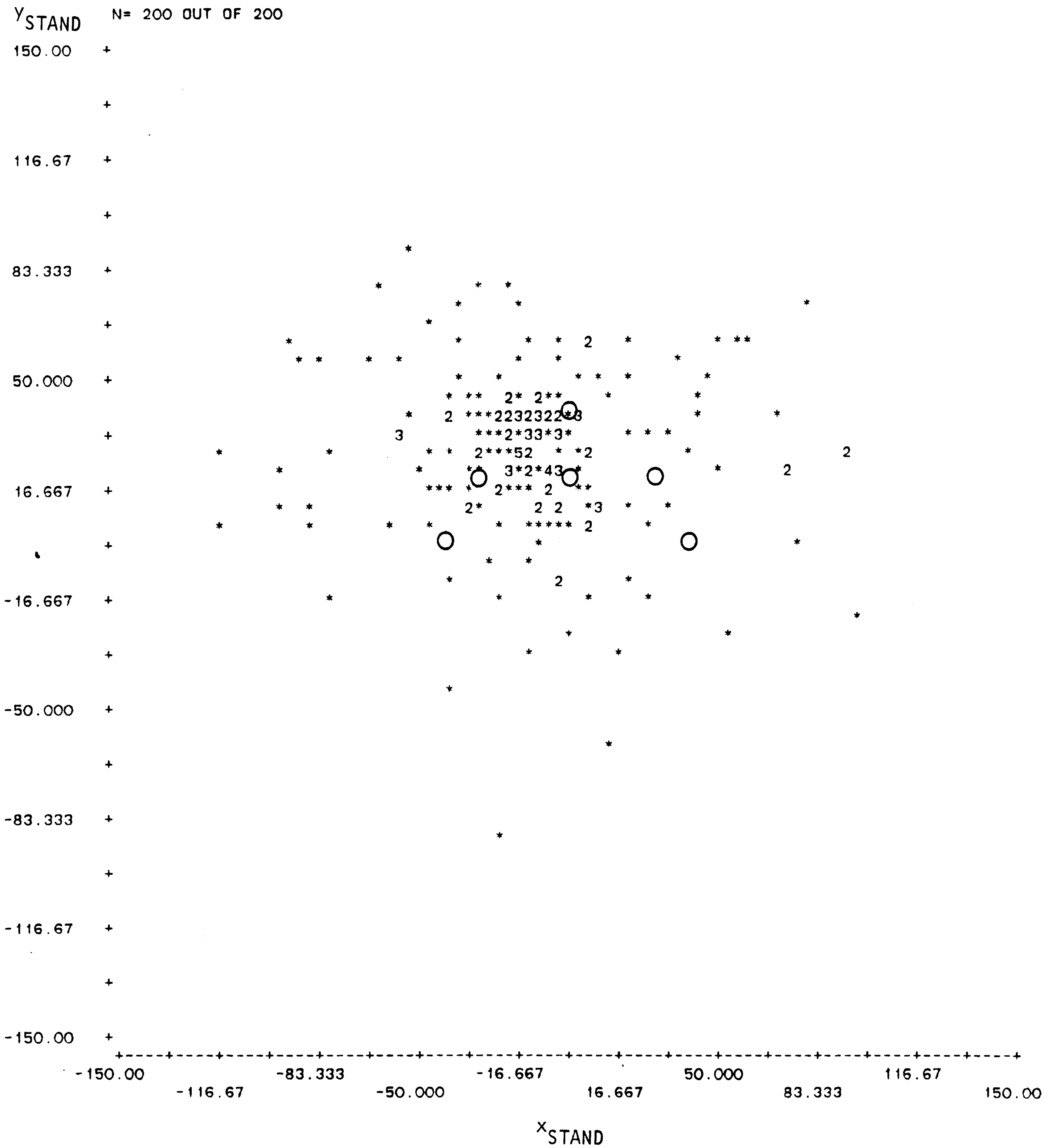

Figure A-4. Distribution of the standardized eye fixations (Experiment 3: 1973 Dodge Polara, Subject 4).

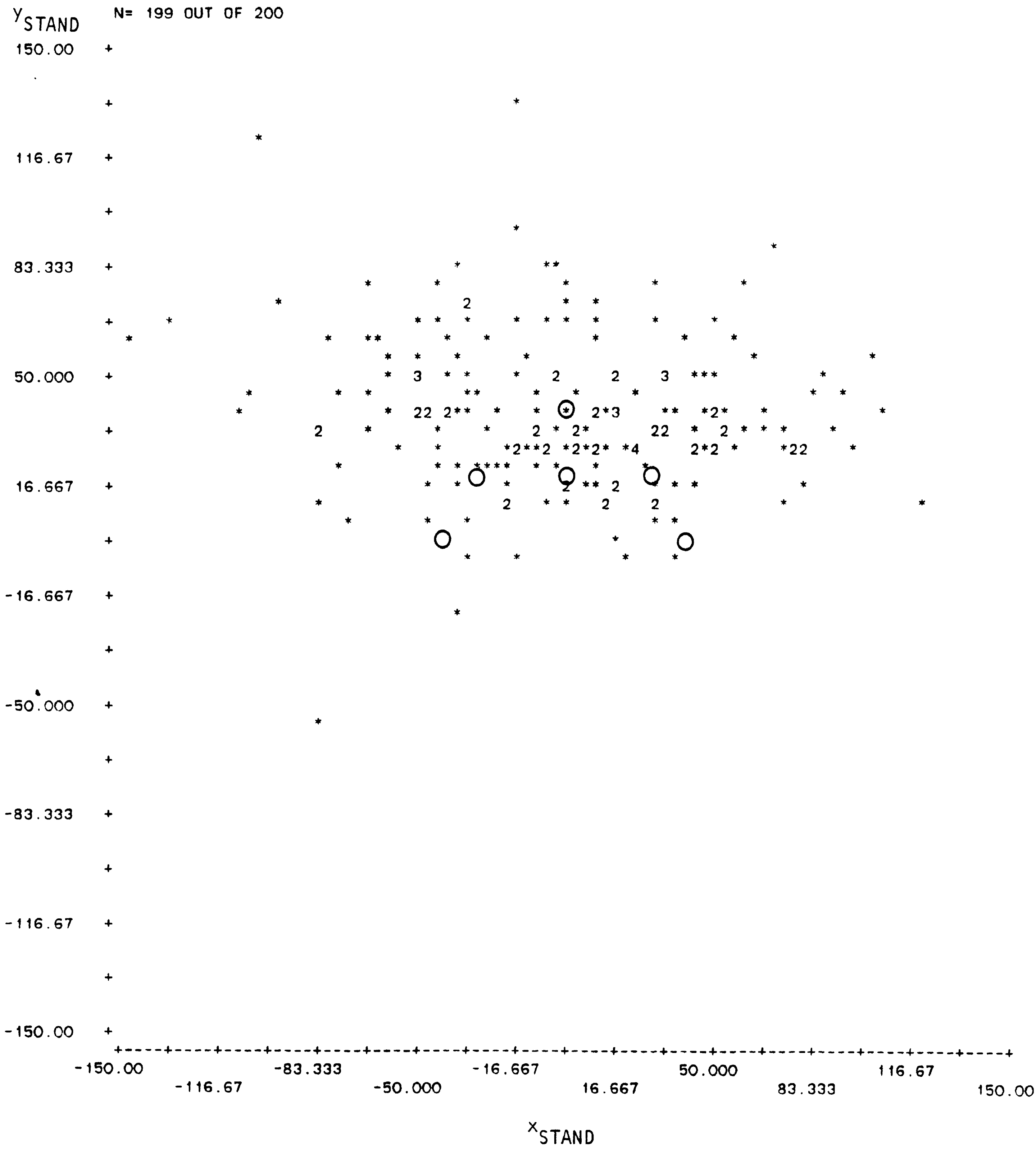

Figure A-5. Distribution of the standardized eye fixations (Experiment 3: 1973 Dodge Polara, Subject 5).

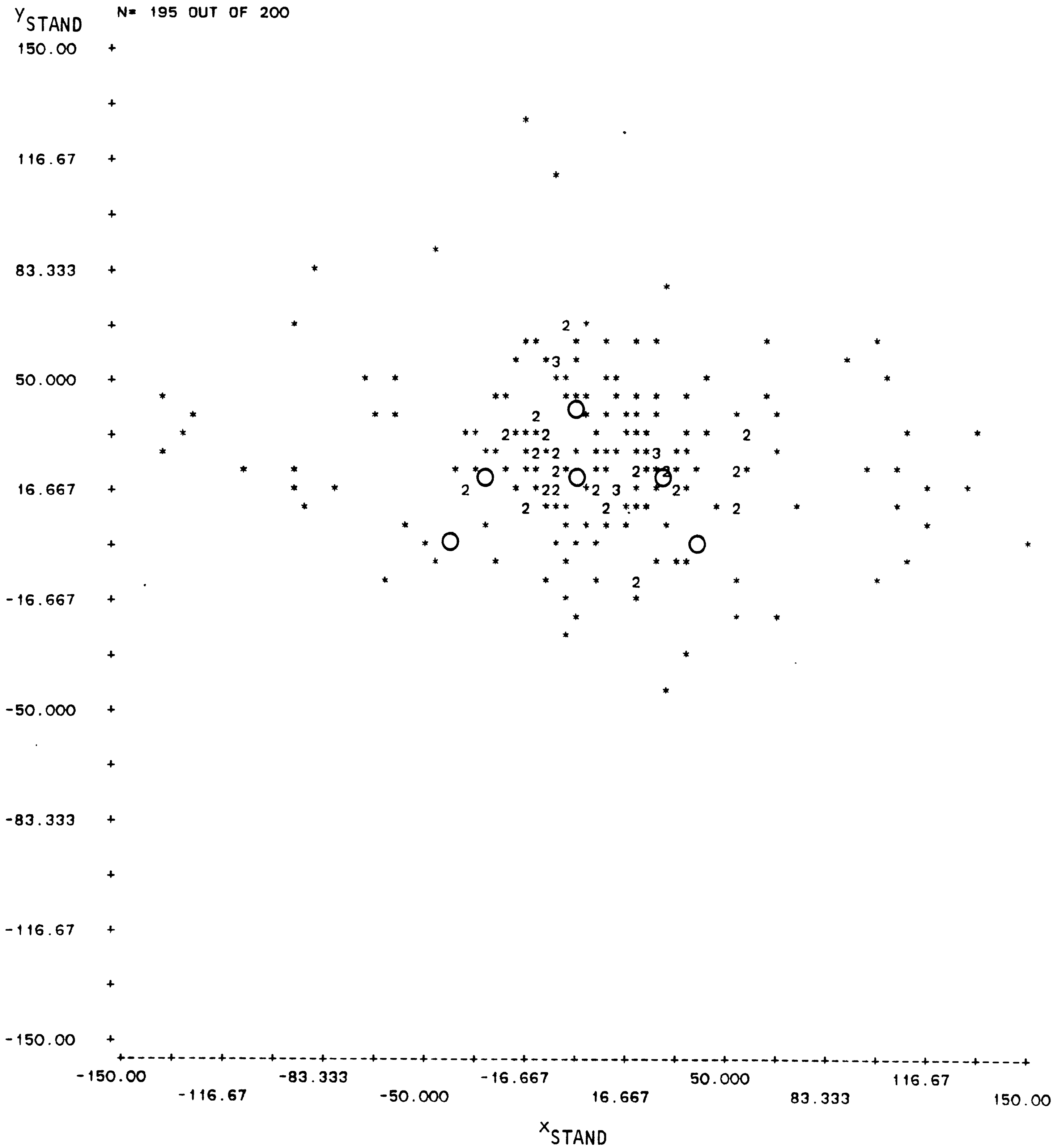

Figure A-6. Distribution of the standardized eye fixations (Experiment 3: 1973 Dodge Polara, Subject 6).

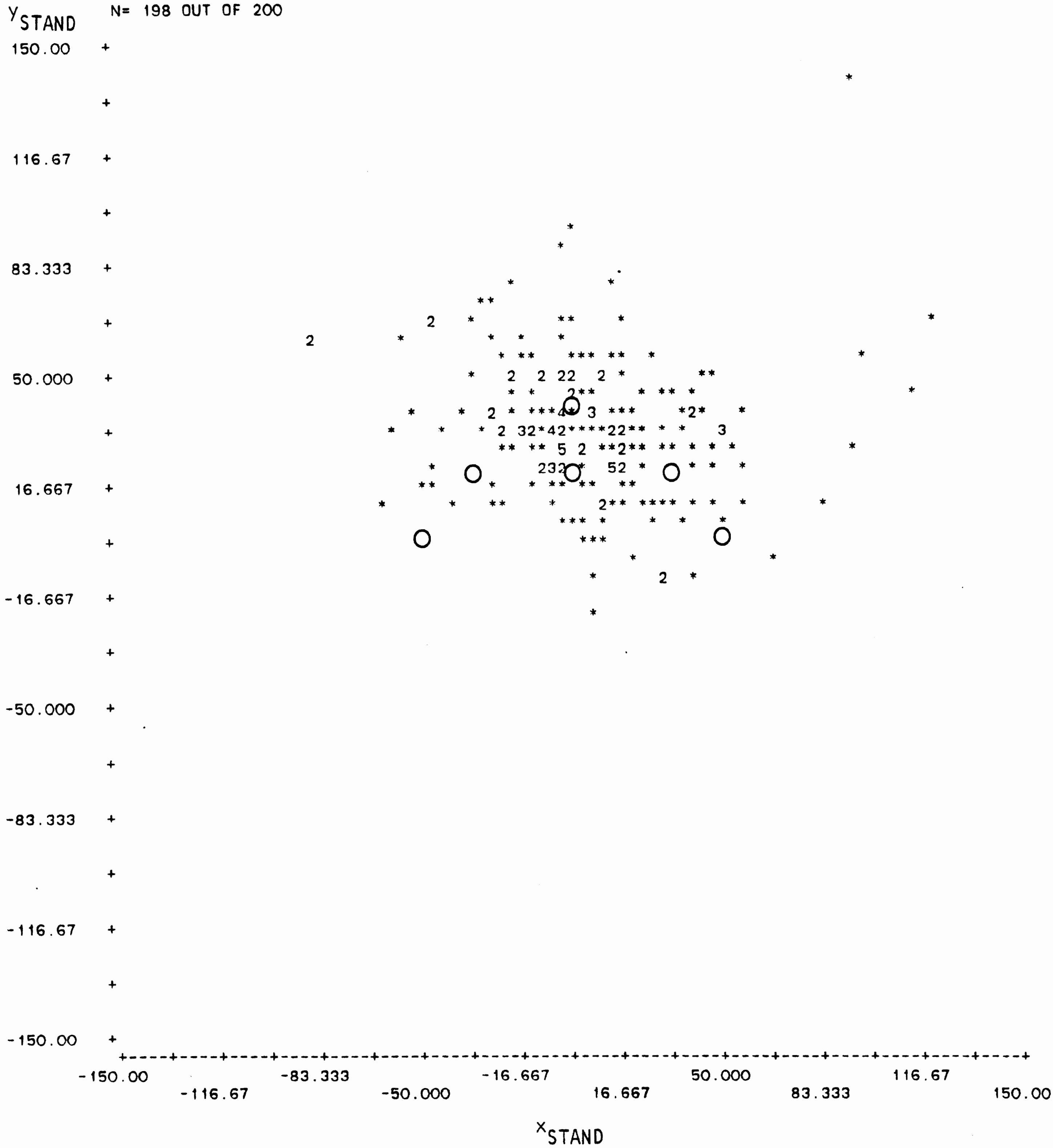

Figure A-7. Distribution of the standardized eye fixations (Experiment 3: 1983 Chevrolet Caprice Classic Station Wagon, Subject 1).

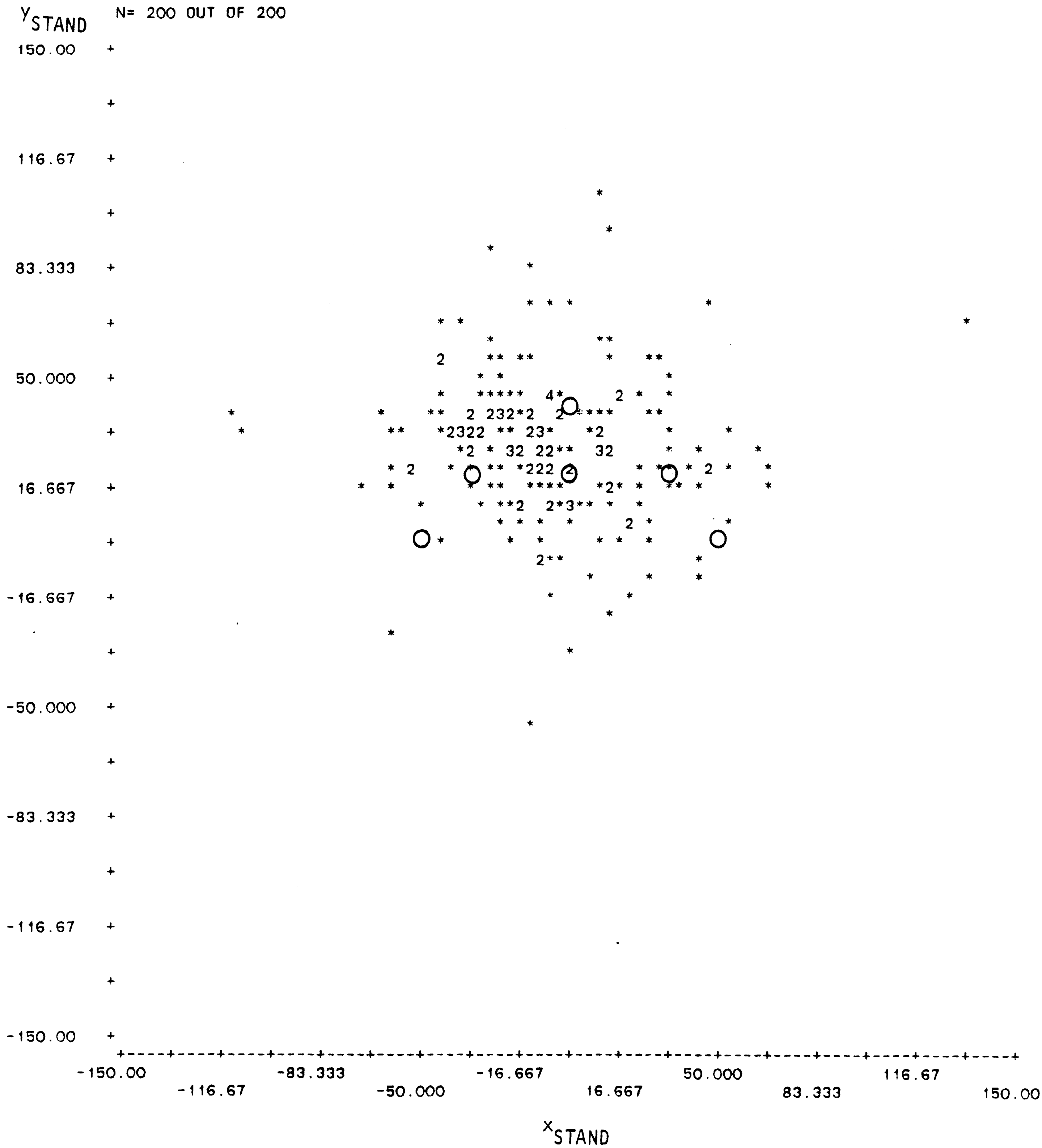

Figure A-8. Distribution of the standardized eye fixations (Experiment 3: 1983 Chevrolet Caprice Classic Station Wagon, Subject 2).

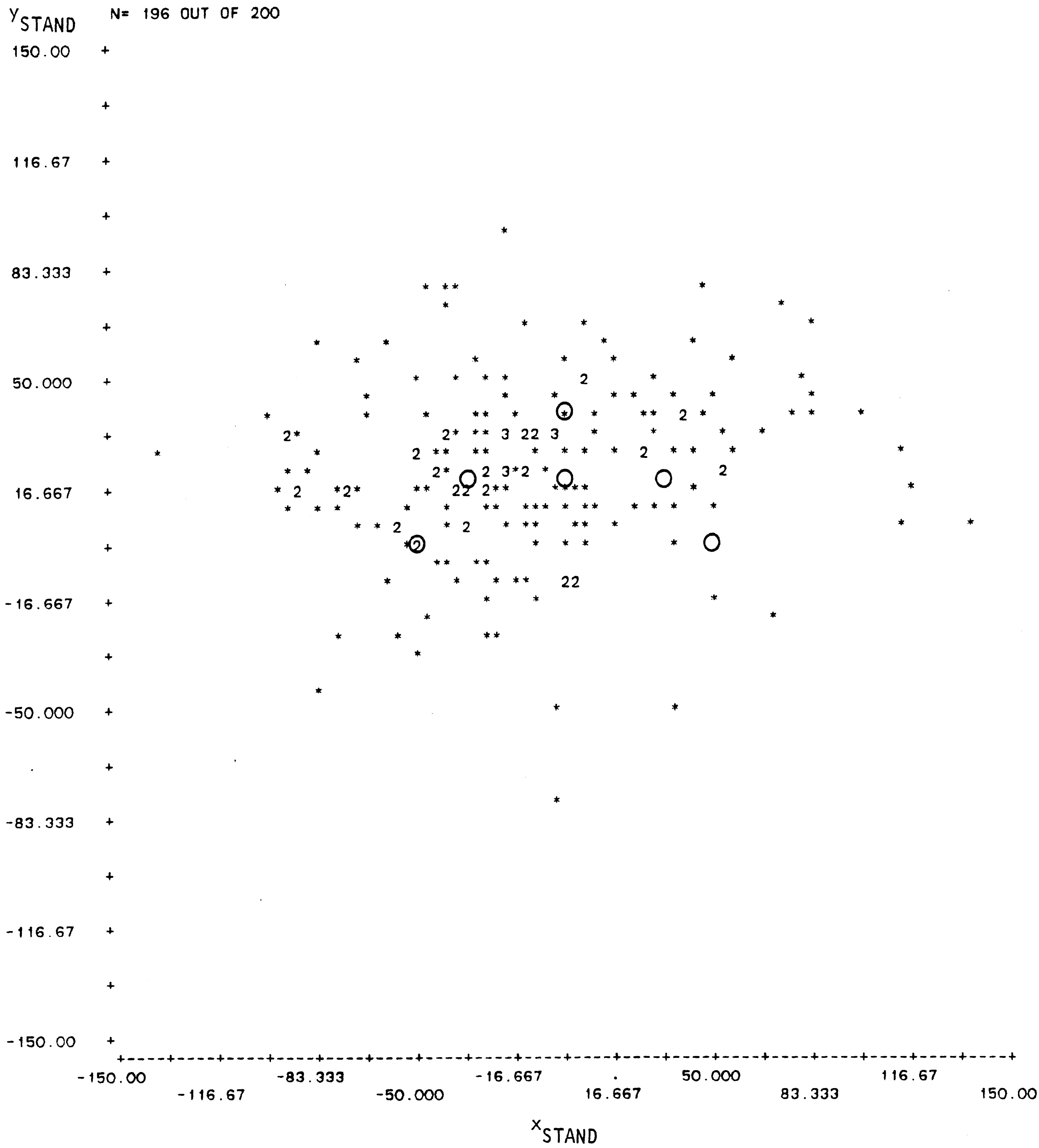

Figure A-9. Distribution of the standardized eye fixations (Experiment 3: 1983 Chevrolet Caprice Classic Station Wagon, Subject 3).

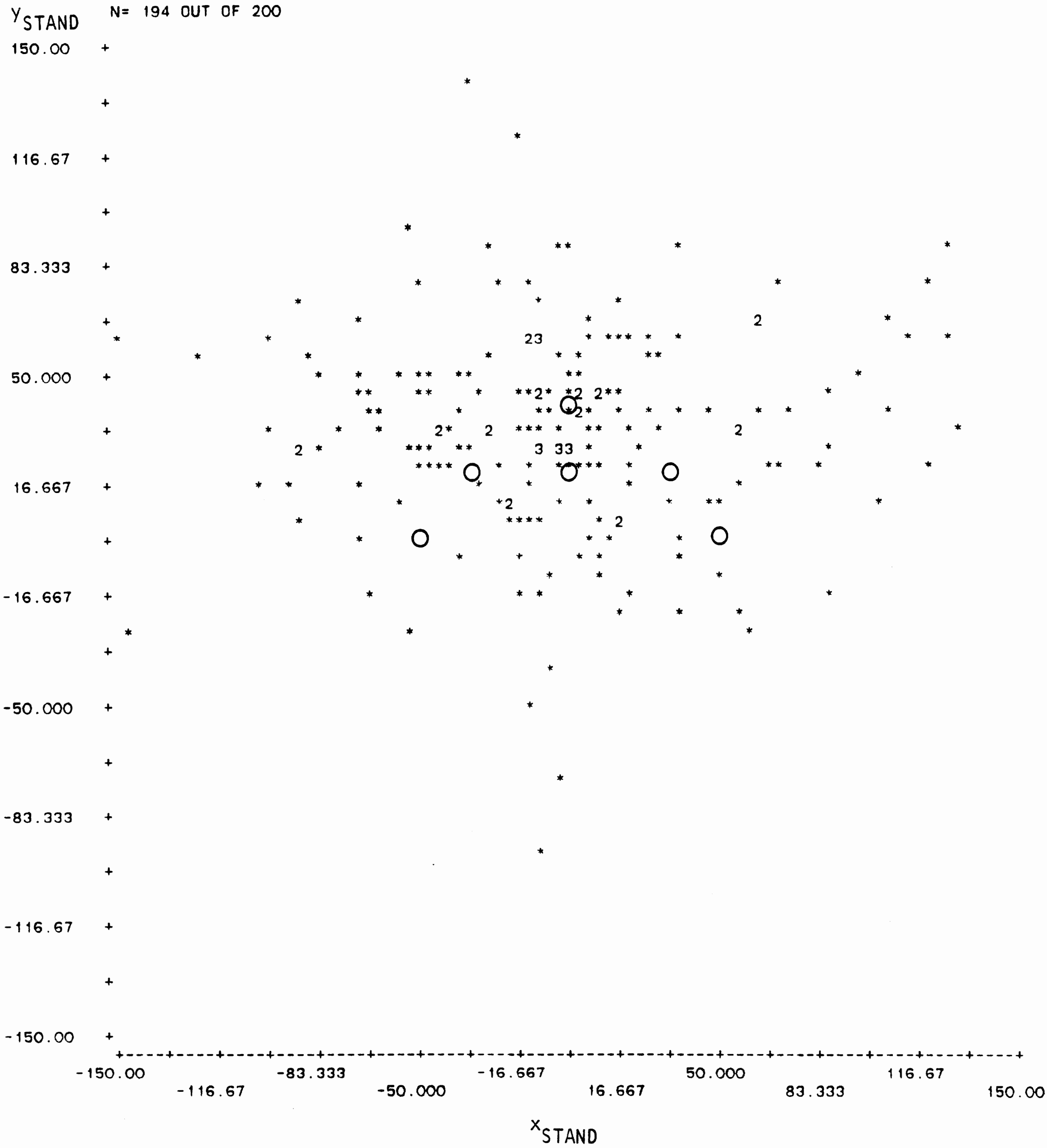

Figure A-10. Distribution of the standardized eye fixations (Experiment 3: 1983 Chevrolet Caprice Classic Station Wagon, Subject 4).

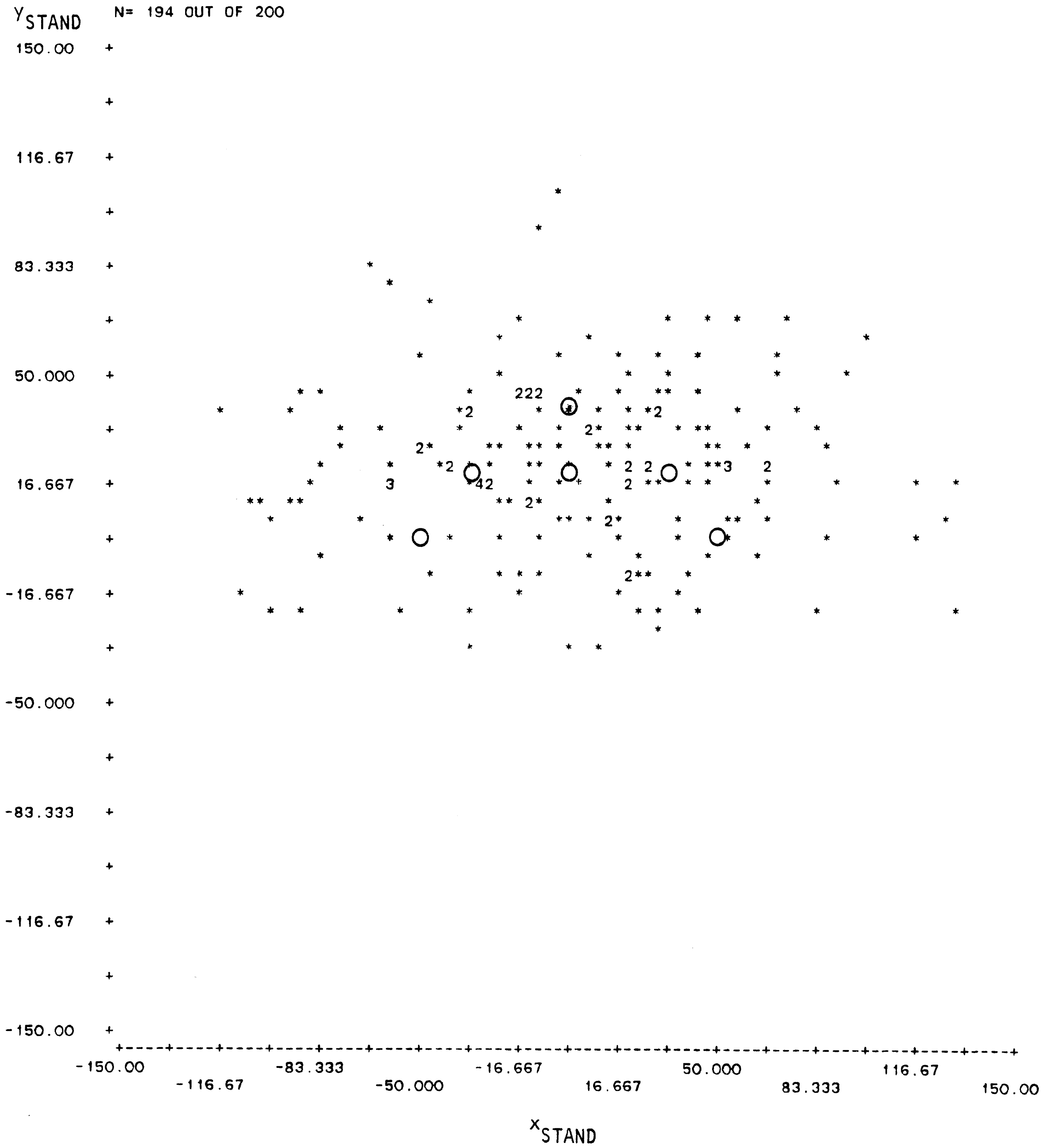

Figure A-11. Distribution of the standardized eye fixations (Experiment 3: 1983 Chevrolet Caprice Classic Station Wagon, Subject 5).

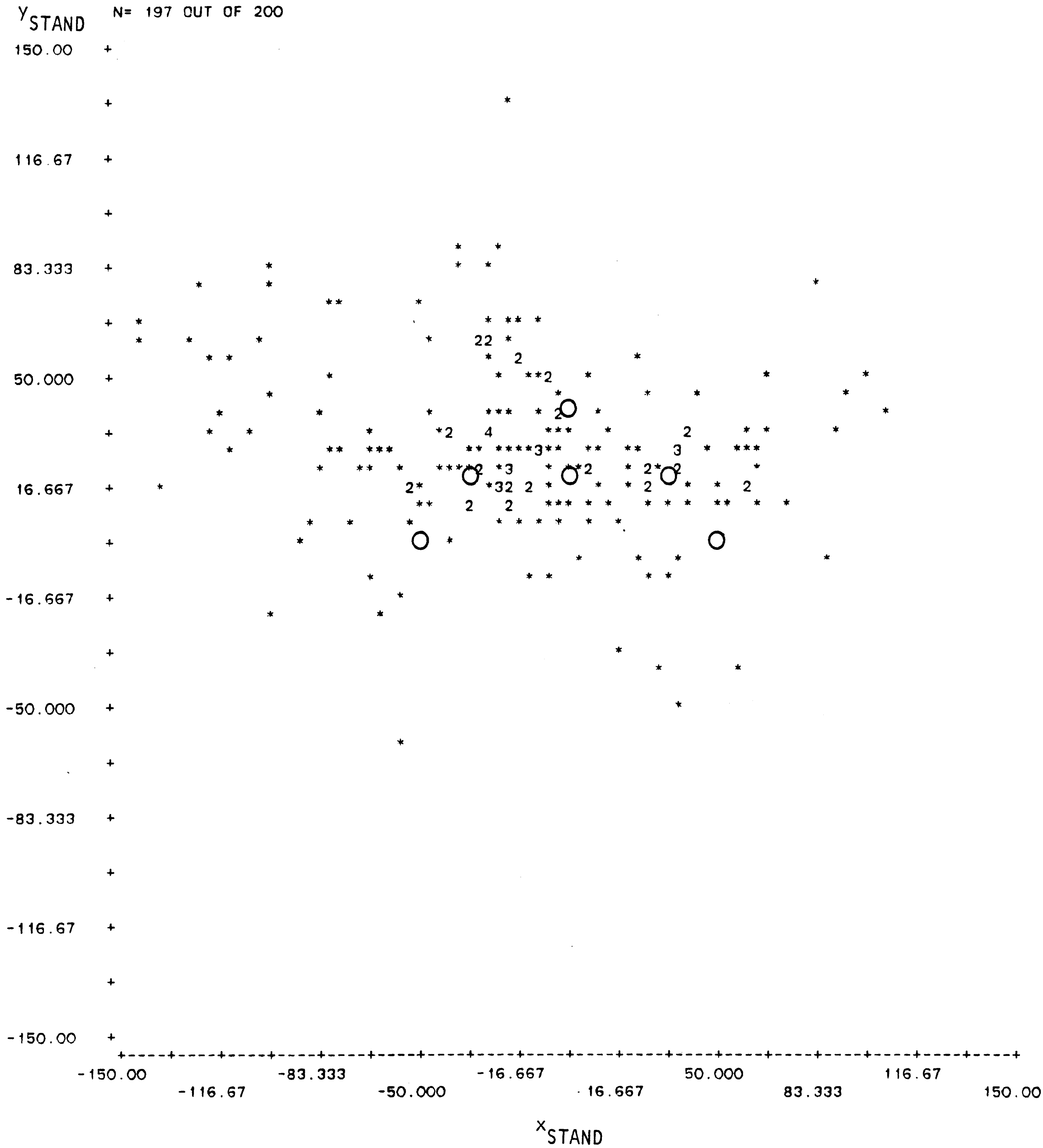

Figure A-12. Distribution of the standardized eye fixations (Experiment 3: 1983 Chevrolet Caprice Classic Station Wagon, Subject 6).

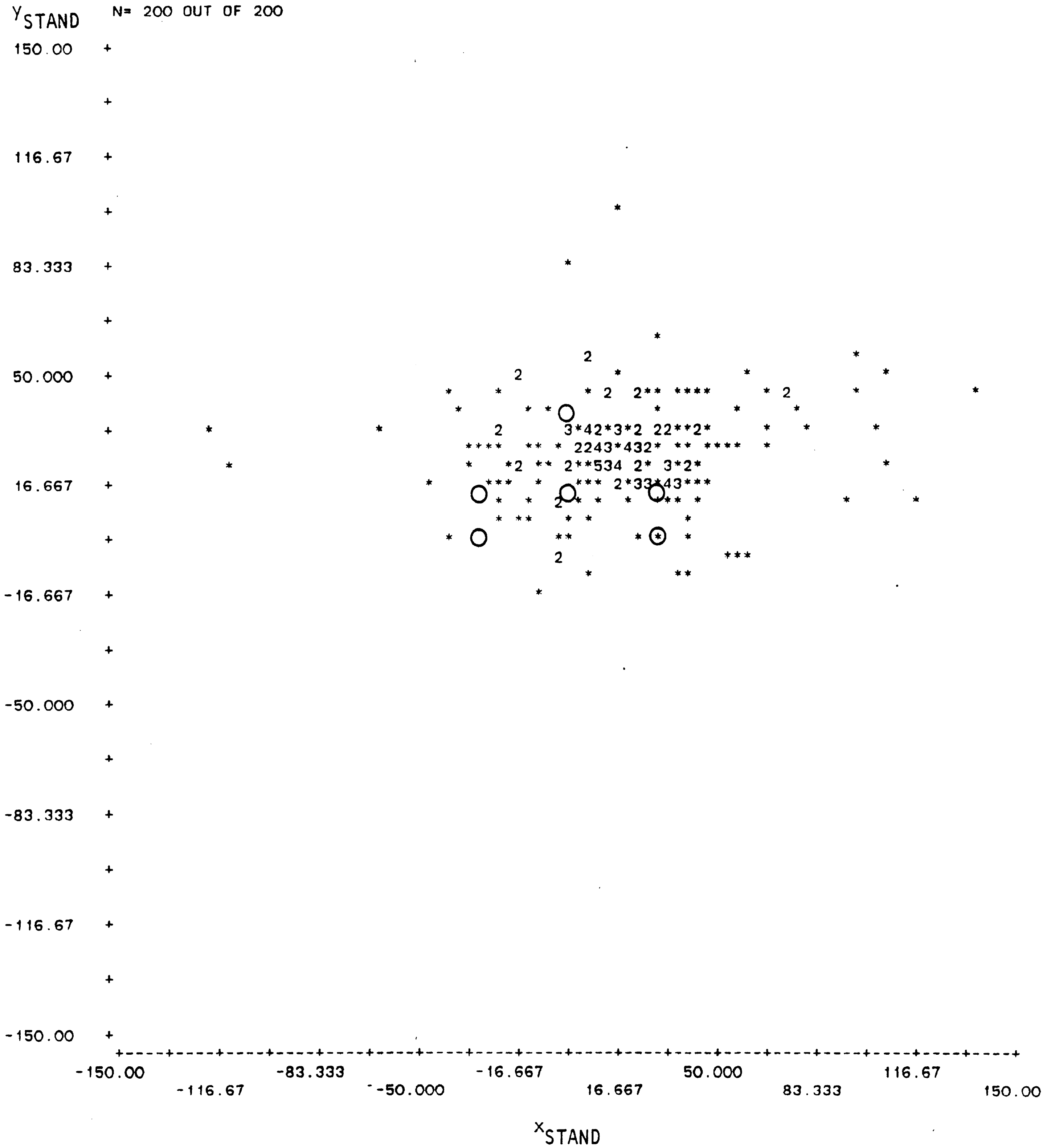

Figure A-13. Distribution of the standardized eye fixations (Experiment 3: 1984 Dodge Laser, Subject 1).

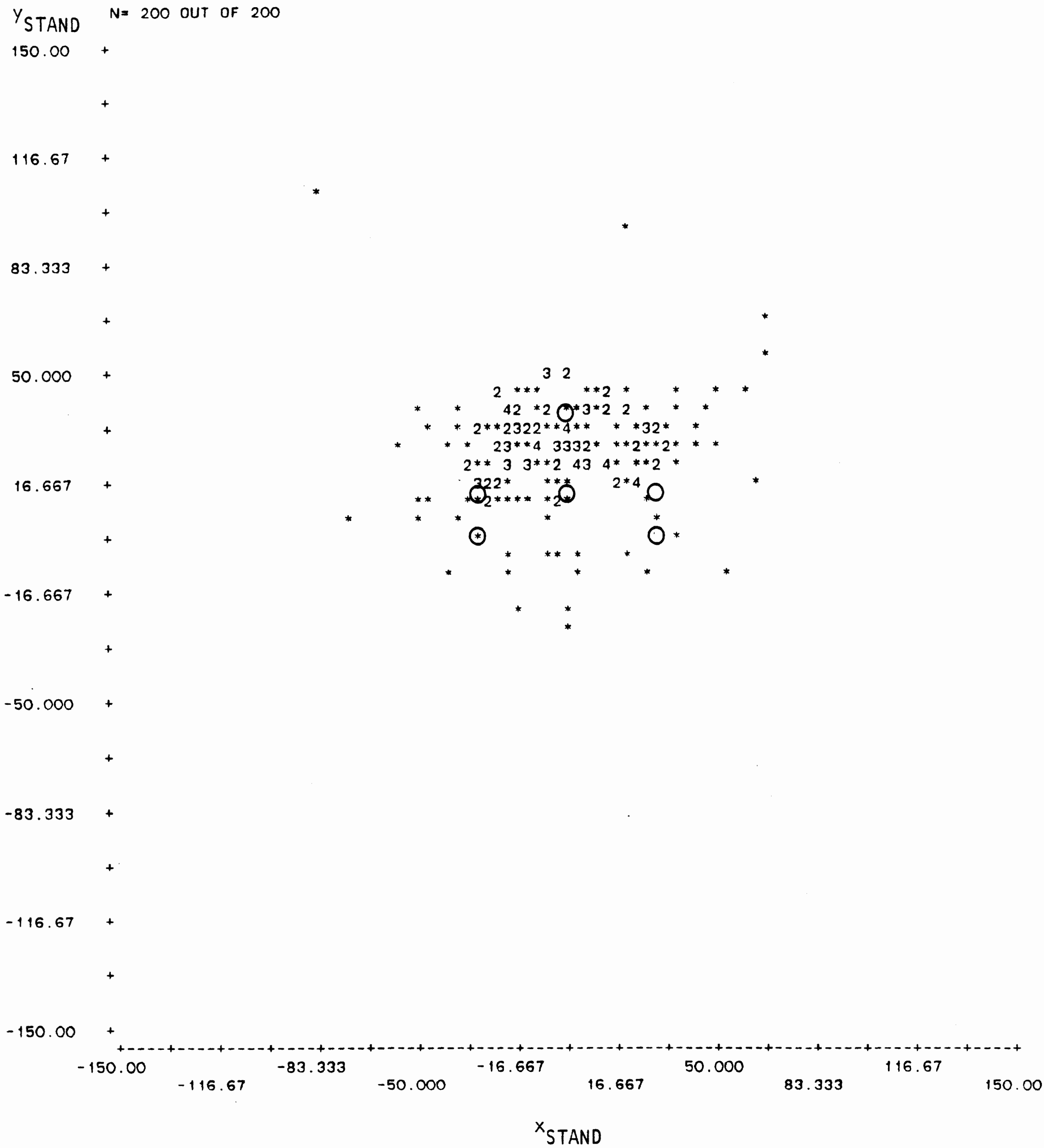

Figure A-14. Distribution of the standardized eye fixations (Experiment 3: 1984 Dodge Laser, Subject 2).

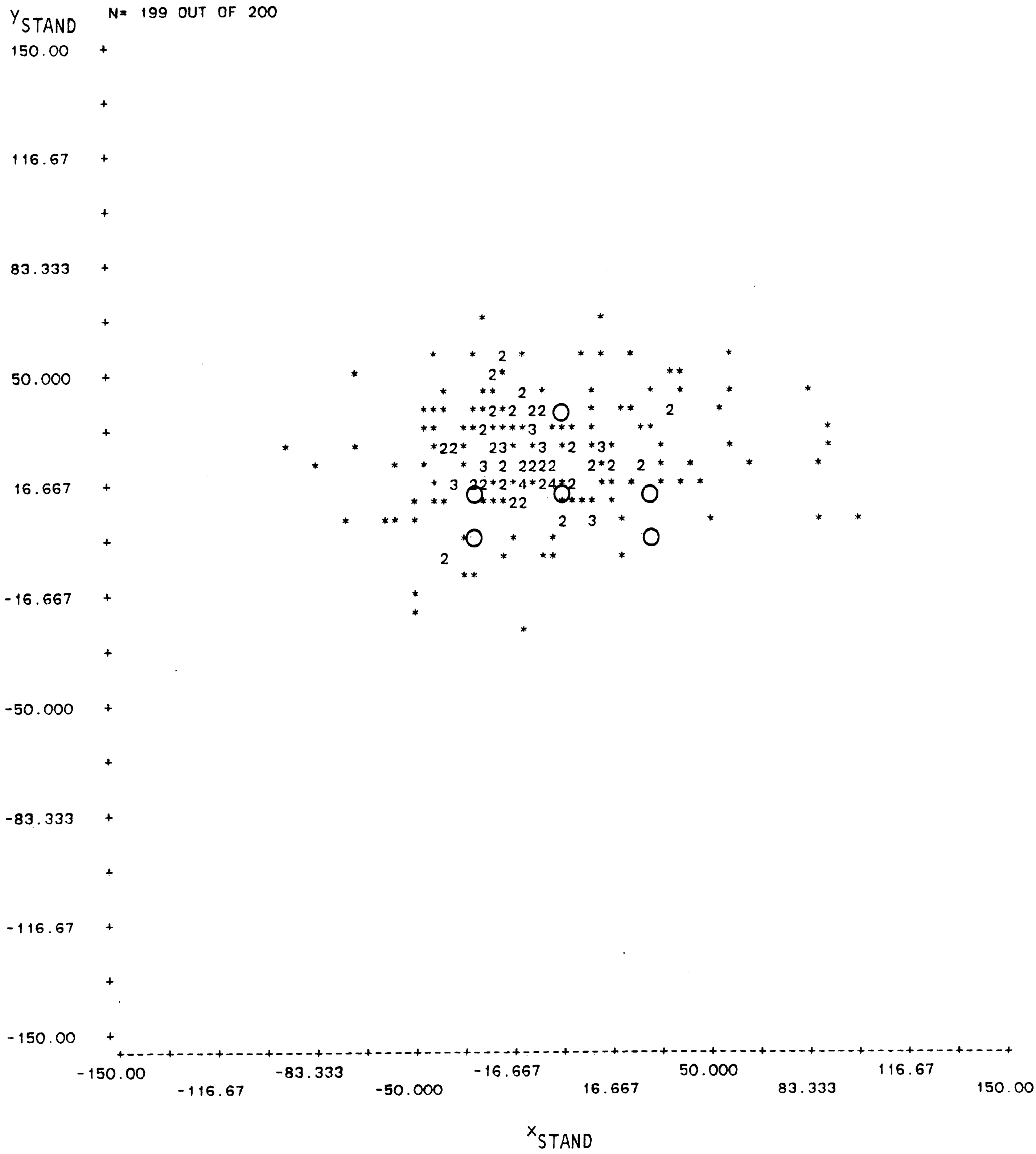

Figure A–15. Distribution of the standardized eye fixations (Experiment 3: 1984 Dodge Laser, Subject 3).

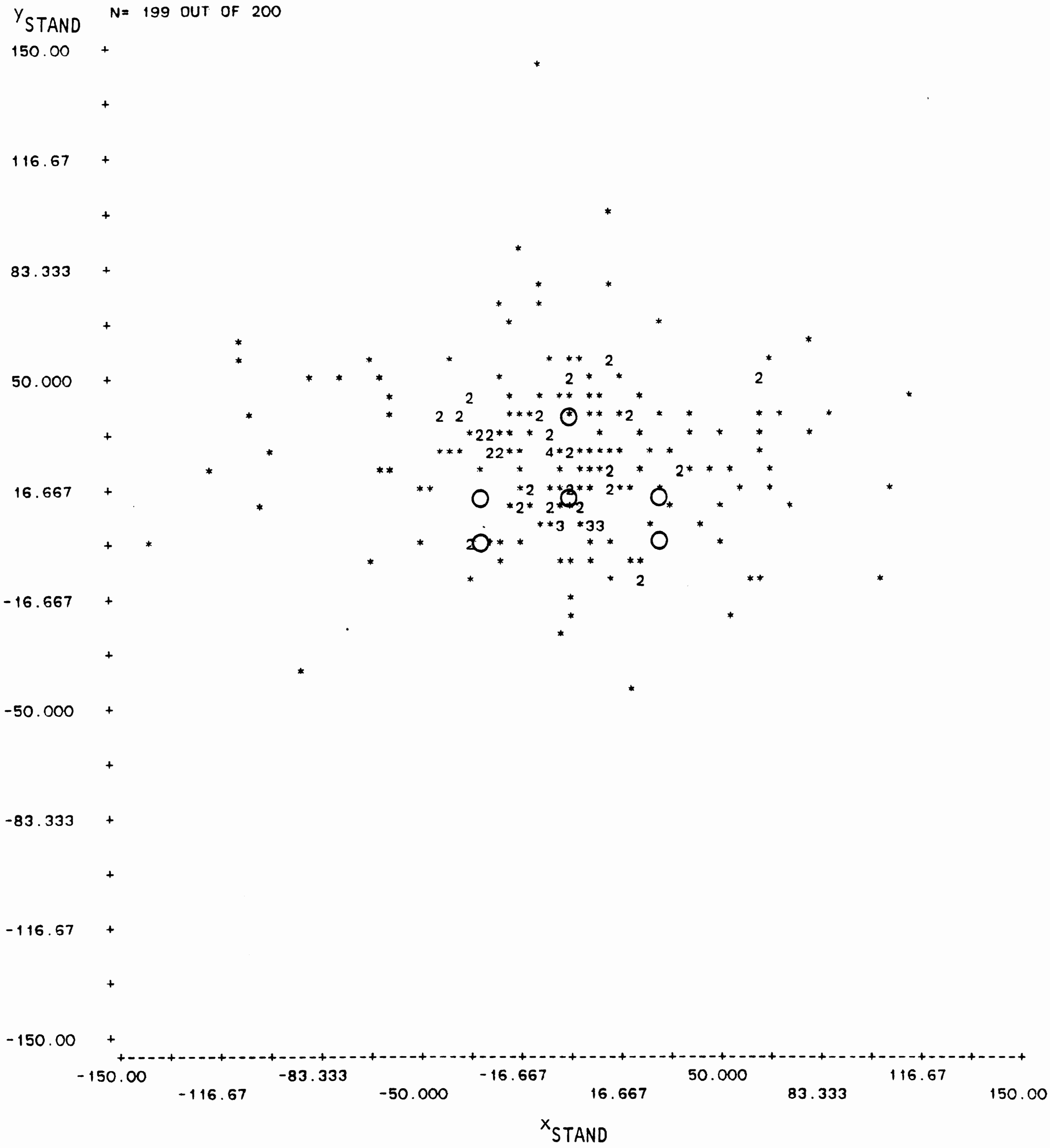

Figure A-16. Distribution of the standardized eye fixations (Experiment 3: 1984 Dodge Laser, Subject 4).

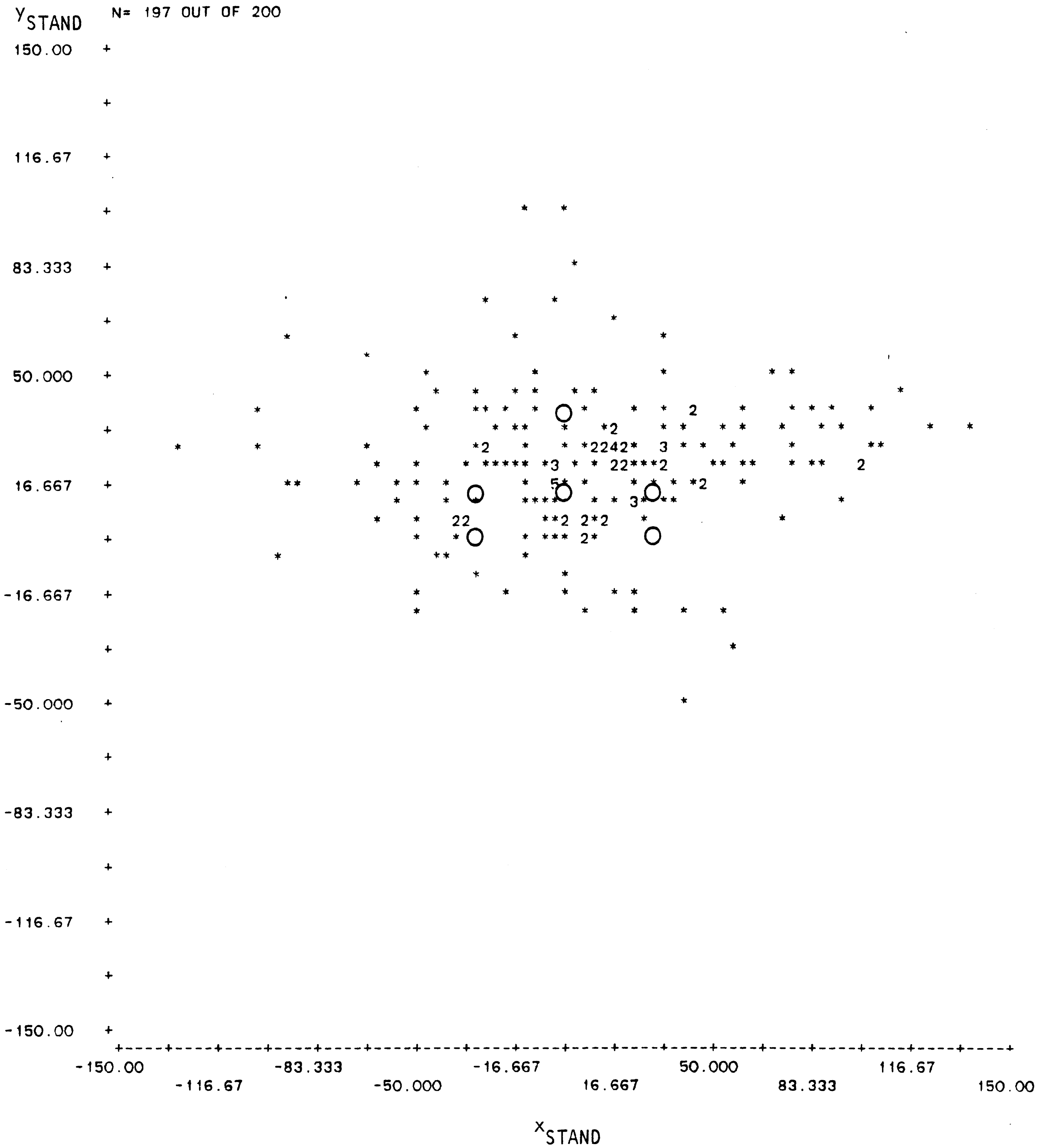

Figure A-17. Distribution of the standardized eye fixations (Experiment 3: 1984 Dodge Laser, Subject 5).

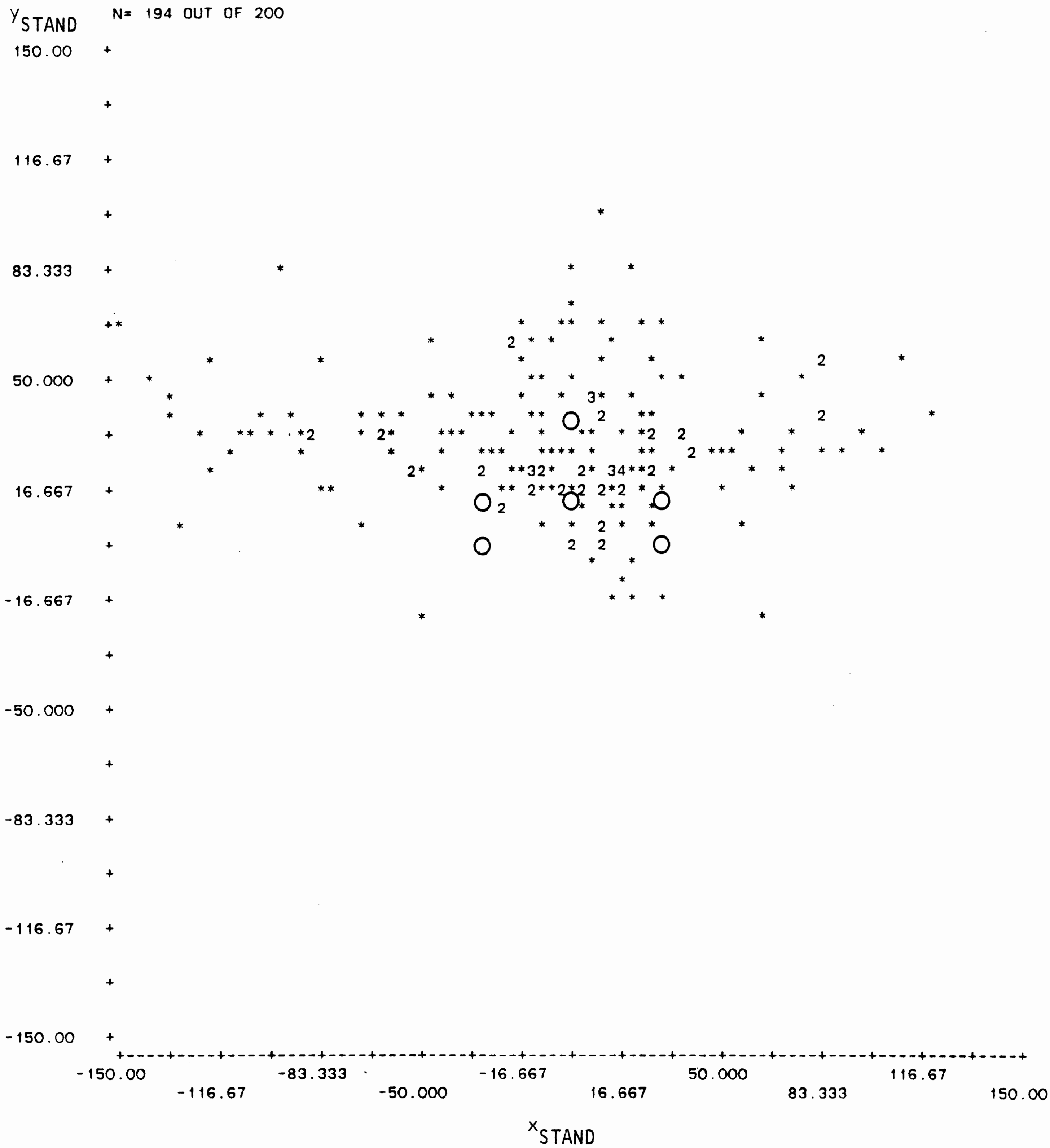

Figure A–18. Distribution of the standardized eye fixations (Experiment 3: 1984 Dodge Laser, Subject 6).