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Temporal Pattern of Within-harborage Time and Visiting Frequency in Two Strains of the German Cockroach, *Blattella germanica*, in Semi-natural Conditions*

반자연적인 조건에서 두 계통 바퀴 (*Blattella germanica*)의 휴식처 체제 시간 및 방문빈도에 대한 시간적 유형*

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ABSTRACT A mutant, *or* (orange body), and the KNIH (Korea National Institute of Health) strain of the German cockroach, *Blattella germanica* (L.) (Orthoptera: Blattellidae), were observed continuously in semi-natural conditions through video taping and data processing by computers. Male adults were individually observed for 4~5 days in a rectangular-shaped rearing cage with four different microhabitats, allowing observations of behavior such as resting, feeding, drinking and communicating with other individuals. The frequencies of visits to and times spent within harborage were determined. Although there were relatively large variations among individuals, the average stays within harborage ranged from 47~61% of the total observation time. The duration of within-harborage time was significantly different between maternal origins, while not distinctively different between the strains. Diel differences were observed in both strains. The time spent within harborage was longer in photophase than in scotophase. Visiting frequency, which represented local activity around harborage, appeared slightly higher in the *or* strain than in the KNIH strain, and was significantly different between maternal origins and strains. Diel difference in visiting frequency was significant in the *or* strain while it was not significant in the KNIH strain. Although there were variations among individuals, similar temporal patterns in some progenies from the same maternal origins were observed in time spent within harborage and in visiting frequency.

KEY WORDS *Blattella germanica*, Behavior, Temporal pattern, Within-harborage time, Visiting frequency, Semi-natural conditions

초 록 돌연변이체인 *or* (orange body) 계통과 KNIH (Korea National Institute of Health) 계통의 바퀴 (*Blattella germanica* (L.) (Orthoptera: Blattellidae)를 반자연적인 조건하에서 비디오와 컴퓨터 자료처리를 통하여 연속적으로 관찰하였다. 휴식처에 머무르거나, 먹고, 물 마시며, 다른 개체들과 교신하는 행동을 관찰 할 수 있는 사각형의 관찰상자 내에서 수컷 성충을 개체별로 4~5일 동안 연속적으로 관찰하였는데, 본 논문에서는 휴식처에 머무르는 시간과 방문 빈도를 분석하였다. 개체들 간의 변이가 상대적으로 컸지만 시험개체들은 휴식처에 전체 관찰시간의 47~61%를 평균적으로 머무르는 것으로 나타났다. 관찰 개체가 휴식처에서 머무르는 시간은 모계에 따른 유의한 차이가 있었으나, 계통 사이에는 뚜렷하게 구분이 되지 않았다. 명암기의 차이는 두 계통 모두 관찰되었는데 휴식처에 머무르는 시간은 암기보다 명기에서 더 길었다. 휴식처 주변의 국소적 활동성을 나타내주는 방문빈도는 KNIH 계통보다 *or* 계통에서 상대적으로 높게 나타났는데, 모계와 계통간에 유의한 차이가 있었다. 방문빈도의 명암기 차이는 *or* 계통에서는 유의하게 나타났지만 KNIH 계통에서는 없었다. 개체들 간

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의 변이가 있었으나 동일한 모계 내에서 휴식처에 머무르는 시간이나 방문빈도가 유사하게 관찰되는 개체들이 있었다.

검색어 바퀴 (*Blattella germanica*), 행동, 시간적 유형, 휴식처 시간, 방문빈도, 반자연적 조건

INTRODUCTION

Continuous observations on behavior of the German cockroach have been conducted since the 1950's with various observation tools such as micro-calorimeter, radiotracer, videorecorder, etc., and reviewed by Silverman (1986) in terms of diel activity and exploratory behavior in various experimental conditions. Silverman (1986) observed feeding and drinking behavior of the German cockroach under simulated conditions through video taping, and reported that diel periodicity in feeding and drinking was more pronounced when the resource was placed farther from the harborage. Denzer *et al.* (1987, 1988a, b) observed activity at various stages of the German cockroach in rearing cages consisting of compartments of food, water, and harborage. They reported that in most stages except female carrying oothecae, cockroaches were equally or more active in the light-on period than in light-off period. Leppla *et al.* (1989) observed circadian rhythm in locomotion of the German cockroach in response to different photoperiod and wavelengths of light, and mentioned that locomotion and periodicity could be affected by different quality of light such as ultraviolet.

These studies showed that the temporal activity pattern of the German cockroach is variable depending upon the experimental conditions, and needs to be further analyzed. Most of the above-mentioned studies were observed collectively, or if observation was made individually, the data were analyzed collectively. Observation of individuals may be one approach to understanding this variability, and, although cockroaches have been generally observed in groups, we tried to observe individuals for the purpose of investigating the variability of behavior on an individual basis in different strains. This could be compared with the results from collective rearings. With the aid of a videorecorder, image processing and data analysis system, the behavior of an individual was observed continuously under semi-natural conditions, allowing observations on important behavior such as resting, feeding, drinking, and communicating with other individuals. The frequency of visits to and times spent within harborage are reported in this study.

MATERIALS AND METHODS

A mutant, orange body (*or*; Ross & Cochran, 1962), obtained from the Genetic Stock Center for the German Cockroach, Department of Entomology, Virginia Polytechnic Institute, and the KNIH strain reared in Korea National Institute of Health (Bang *et al.*, 1993), were used for the study. The insects were provided with food for laboratory animals (Shin Chon Animal Food Inc. Superserips), and were reared at temperatures of $27 \pm 1^{\circ}$ C, and at relative humidity of $60 \pm 10\%$. The light (fluorescence at 1,500 Lux in photophase and less than 10 Lux (in red light) in scotophase) was given in the regime of L12 : D12 (Light On; 20:30, Light Off; 08:30).

As a preliminary to the experiment, groups of one female and two to three males were randomly selected, and reared until oothecae were produced by females. The progenies hatched from the same oothecae were subsequently reared, and males were randomly selected as the hatched nymphs grew older. About 7 days after emergence, adult males were transferred individually to the observation cages and were observed for 4 ~ 5 days. Twenty eight individuals from six different maternal origins were used for the *or* strain while twenty individuals from four different maternal origins were observed for the KNIH strain.

The observation cage was constructed in a rectangular shape ($200 \times 200 \times 7$ (height) mm^3), made of transparent acrylic board (2 mm in thickness) (Fig. 1). A large plate ($400 \times 400\ mm^2$) was evenly divided into four portions, which made it possible to observe four insects simultaneously. Each corner of the observation cage was modi-

fied to provide microhabitats.

For the harborage, an additional rectangular container ($10 \times 10 \times 10$ mm^3) made of transparent acrylic board was attached to a corner. Inside the container, a sheet of black colored blotting paper (20×10 mm^2) was attached to provide shade for resting. One side of the harborage was cut open for ventilation and a screen (mesh size; 500 μm) was attached. Food was prepared in a rectangular shape ($5 \times 5 \times 7$ mm^3), and was attached to one corner by using an adhesive agent (DAYTON Superserips). The amount of food was sufficient to feed the test insect during the observation period. At one corner of the cage tap water was provided with a plastic tube (5 mm in diameter and 5 mm in length), which was inserted with the soaked tissue paper (Wonjin Superserips).

Since the German cockroach behave normally in groups, "neighbor" insects were placed in the cage in order to alleviate the problem of solitary rearing of the test insect. An additional cage of acrylic board ($50 \times 50 \times 10$ mm^3) was constructed at a corner of the observation cage to hold neighbor German cockroaches. After cutting the corners of the observation cage as well as the neighbor insect cage, a screen (10×10 mm^2, mesh size 500 μm) was attached to the opening and the two cages were connected with each other so that the test insect could communicate with neighbor insects with antenna and other appendages.

The test insect was observed through a black and

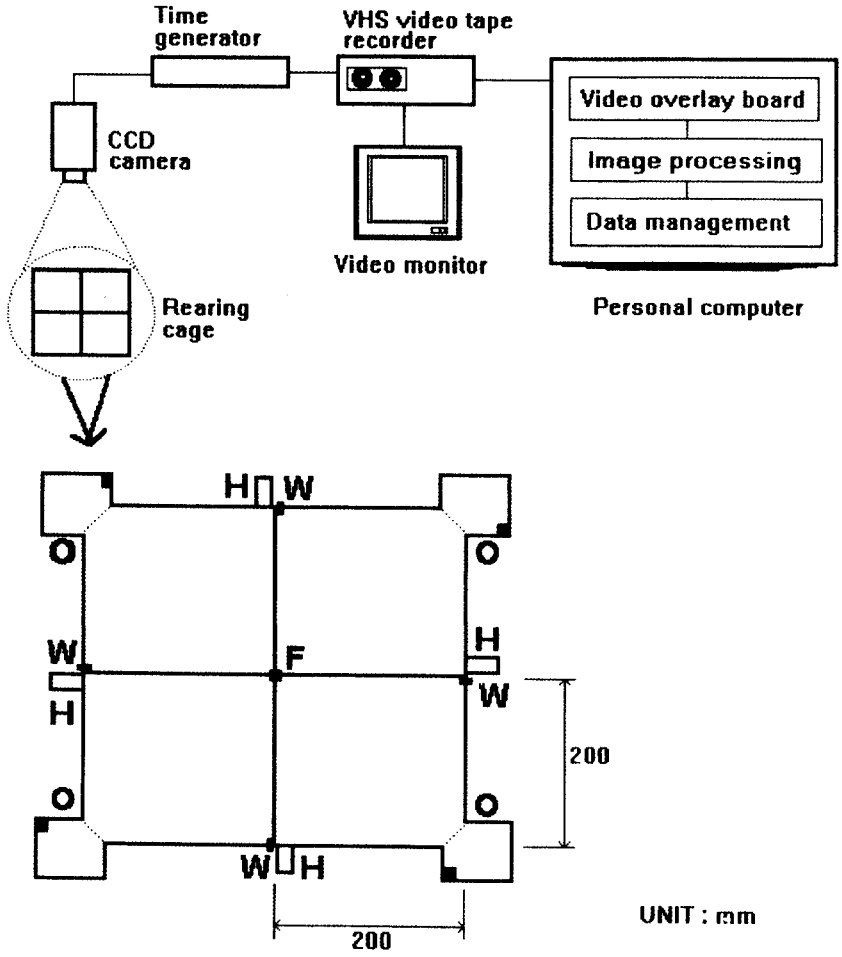

Fig. 1. Diagram of the rearing cage for the German cockroach and the observation system in semi-natural conditions. (F; food, O; other individuals, H; harborage, and W; water).

white CCTV (Kukjae Electronics Co. Ltd. Superserips; IVC-841) and scanned continuously every 0.25 second during the observation time. The image was digitized by using a video overlay board (Seodu Media Inc. Superserips; MTV -Pro), and sent to a computer for analysis. The software for recognition and location of the test individual through image processing was written with assistance of Computer Vision Lab., Department of Electronics Engineering, Pusan National University. For quantitative analysis of the observed data t-test, nested ANOVA, and Principal Component Analysis (Norusis 1986) were conducted. Probability for significance in t-test and ANOVA was expressed up to three significant digits after the decimal point in this report (e. g. p= 0.000).

RESULTS

Duration of presence within harborage

Table 1 shows the time spent within harborage in different 3 hour (h) time blocks by *or* and KNIH German cockroach males. Each 3 h time block of photo- and scotophase represents a 3 h interval after the light was "on" and "off", respectively. Times within harborage of the test insect is expressed in percents (out of 3 h duration) in each time block. Individual means for each 3 h time block were first obtained during the observation period. Subsequently these means were averaged again for all the tested individuals (Table 1). Standard deviations (SD) shown in Table 1 were calculated from the individual means.

High standard deviations indicated large variations among tested individuals in visits to and times spent within harborage (Table 1). Averages for *or* males showed that they stayed longer in the harborage (46.9% of the total observation time) than at other microhabitats such as the places for feeding, drinking and neighbor insects. At the latter places they were present for only a short time, usually less than 5% of the observation time. Behavior at the other microhabitats will be discussed elsewhere. The time spent within harborage by *or* strain males showed a diel difference. The males stayed shorter during the scotophase than during the photophase

Table 1. Within-harborage time (percents out of 3 h duration) and visiting frequency (number of visits per 3 h) of the *or* mutant and the KNIH strain of the German cockroach in different 3 h time blocks during a day (number of individuals of mutant; 28, number of individuals KNIH strain; 20)

Phase		Within-harborage time (%)		Visiting frequency	
		Mean	(SD)	Mean	(SD)
or Mutant					
Photophase	1	64.57	(34.61)	16.98	(8.52)
	2	63.73	(38.21)	16.71	(10.94)
	3	60.50	(36.24)	15.43	(8.31)
	4	49.69	(35.09)	14.89	(9.87)
Sub-average		59.62	(36.04)	16.00	(9.41)
Scotophase	1	32.75	(26.26)	24.14	(18.21)
	2	31.45	(25.53)	24.34	(17.93)
	3	35.45	(35.77)	22.09	(19.16)
	4	37.26	(30.99)	17.73	(10.31)
Sub-average		34.23	(29.64)	22.08	(16.40)
Average		46.92	(32.84)	19.04	(12.91)
KNIH Strainn					
Photophase	1	77.35	(28.20)	18.35	(6.72)
	2	76.88	(31.45)	17.83	(8.15)
	3	72.54	(31.64)	15.90	(6.33)
	4	64.94	(32.93)	14.90	(6.79)
Sub-average		72.93	(31.06)	16.74	(7.00)
Scotophase	1	51.54	(33.26)	16.60	(15.59)
	2	46.92	(31.11)	16.78	(12.28)
	3	45.63	(36.76)	18.15	(13.38)
	4	51.90	(36.72)	18.30	(9.41)
Sub-average		49.00	(34.46)	17.46	(12.67)
Average		60.96	(32.76)	17.10	(9.83)

(averages of 34.2% and 59.6%, respectively). There was a significant difference between scoto- and photophase when the data for photo- and scotophases for each individual were paired and analyzed by a t-test (p=0.000). During photophase, the shortest time spent within harborage was at the end of photophase (P4) (49.7% within harborage). In contrast, from P1 to P2, the *or* males stayed longer, with 63.7~64.6% within harborage. Similar trends were observed in times spent within harborage by KNIH strain males (Table 1). The total time spent within harborage by KNIH strain males

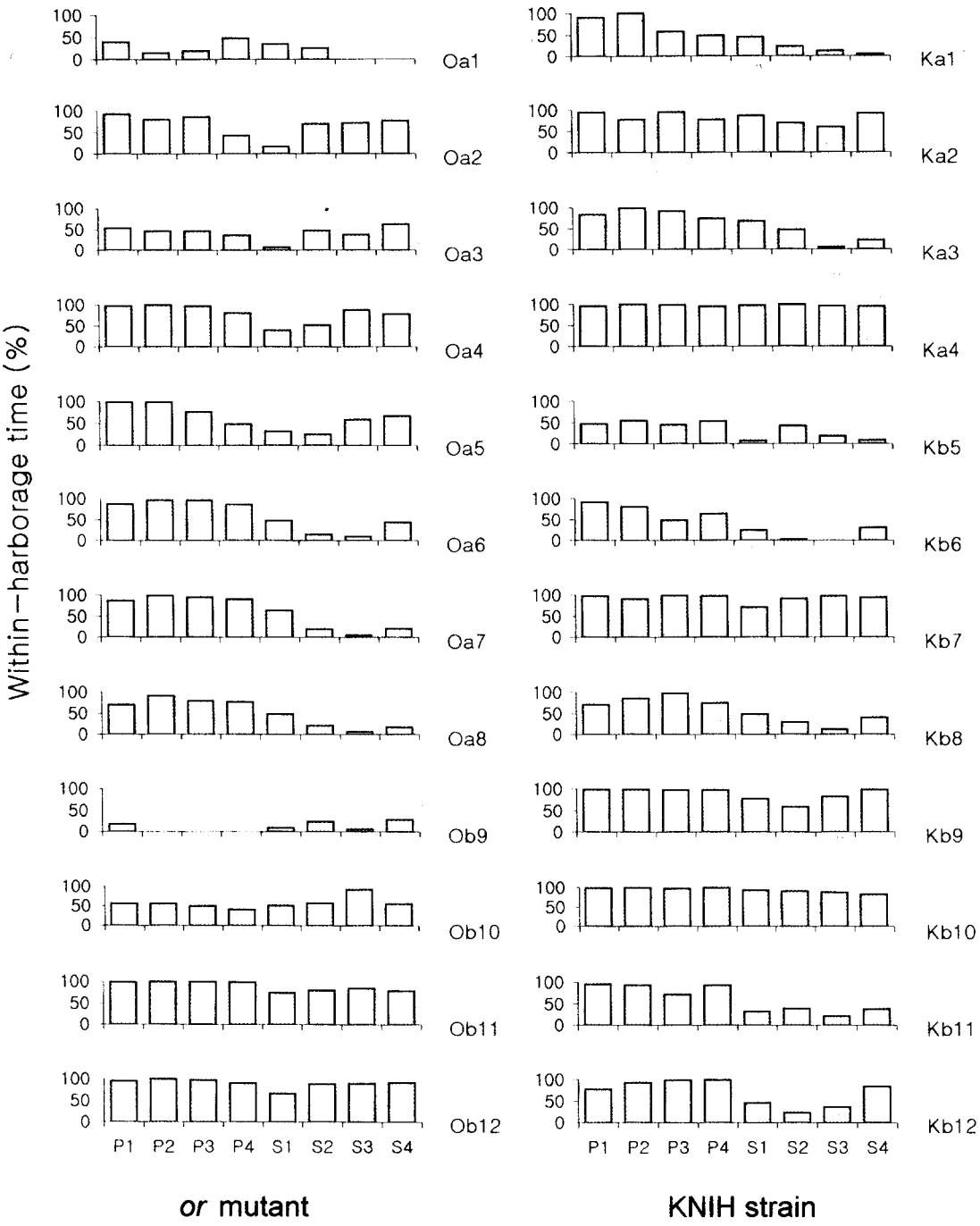

Fig. 2. Examples for males of the *or* mutant and the KNIH strain of the German cockroach in the within-harborage time (percents in 3 h duration) in each 3 h time block in a day when reared in semi-natural conditions. The second character (e. g. "a" in Oa1) in the name of observed individual represents the source of maternal line while the third numerical digit designates each individual. Values on the Y axis are percents of the presence time in averages for each individual. The units on the X axis represent photophase 1, 2, 3 and 4, and scotophase 1, 2, 3 and 4 sequentially from left to right.

(61.0% of the observations time) was slightly longer than for *or* males. They stayed longer than *or* males in both photophase and scotophase, with 72.9% and 49.0 % of the observation time respectively. Similarly to the *or* strain, the difference between photophase and scotophase was significant when the mean within-harborage times were paired and t-test was conducted (p=0.000). Also similar to the *or* strain, the within-harborage time was shortest at P4 and appeared longer in the early photophase.

Fig. 2 shows examples of the temporal pattern of within-harborage time of some individuals in each 3 h time block. There were variations among individuals, and the temporal patterns were diverse. Although the mean duration of time in harborage appeared longer in photophase than scotophase (Table 1), some individuals also appeared to spend a long time at harborage in scotophase (e. g., Ob10 and Ka4 in Fig. 2). Although individual variations appeared to be high, similar temporal patterns were observed among some individuals from the same maternal origin, both in the *or* and KNIH strain. (e. g., the group of {Oa2 and Oa3}, {Oa6, Oa7 and Oa8}, and {Ob11 and Ob12} in the *or* strain, and {Kb6 and Kb8} in the KNIH strain in Fig. 2).

When ANOVA was conducted in the nested model (strain; fixed, maternal origin; random) and the mean duration of within-harborage time in percents of photo- and scotophases for each individual were paired, the difference in maternal origins was highly significant (p= 0.000). Between strains, however, the difference was not significant (p=0.109) (Table 2). When the time within harborage was separately tested in photo- and scotophase, the frequency of visits during photophase was not significantly different between strains (p=0.415),

Table 2. Test of significance in nested ANOVA (strain; fixed, maternal origin; random). Within-harborage time (and visiting frequency) in photo- and scotophases were paired and separated (number of individuals of *or* mutant; 28, number of individuals of the KNIH strain; 20, number of tested strains; 2, number of tested maternal origins; 6 in the *or* mutant and 4 in the KNIH strain)

Paired (Pillais test*)

Source of variation	Value	Approximate F	Hypothesis DF	Error DF	Significance (p)
Within-harborage time					
Strain	0.11	2.36	2.00	37.00	0.109
Maternal origin	0.84	3.44	16.00	76.00	0.000
Visiting frequency					
Strain	0.17	3.91	2.00	37.00	0.029
Maternal origin	1.13	6.17	16.00	76.00	0.000

Separate

Source of variation	Hypothesis SS	Error SS	Hypothesis MS	Error MS	F	Significance (p)
Within-harborage time						
Strain						
Photophase	478.05	26717.96	478.05	703.10	0.68	0.415
Scotophase	2628.23	22572.42	2628.23	594.01	4.42	0.042
Maternal origin						
Photophase	20505.10	26717.96	2563.14	703.10	3.65	0.003
Scotophase	14362.65	22572.42	1795.33	594.01	3.02	0.010
Visiting frequency						
Strain						
Photophase	41.25	1103.79	41.25	29.05	1.42	0.241
Scotophase	646.86	3099.49	646.86	81.57	7.93	0.008
Maternal origin						
Photophase	1434.99	1103.79	179.37	29.05	6.18	0.000
Scotophase	5371.03	3099.49	671.38	81.57	8.23	0.000

* This method is explained in Norusis (1986).

while in scotophase it was significantly different (p= 0.042) (Table 2). Between maternal origins, visiting frequency was significantly different during both photo- and scotophases.

Visiting frequency

While the time within harborage represented the quiescent phase of the test insect, the locally active phase of the test insect around the harborage may be expressed by visiting frequency. Visiting frequency in this study was defined as the number of entering the area of the harborage during each 3 h time block. Whenever a tested insect newly entered into the harborage, it was counted as one visit. The averages and standard deviations for visiting frequency were obtained in a similar manner to the time within harborage as previously mentioned: visiting frequency was averaged for each individual during the observation period, and subsequently averaged again for all the observed individuals for each 3 h time block (Table 1).

Visiting frequency also showed a high degree of individual variation and among microhabitats, it was highest at the harborage, showing 19.0 (number of visits per 3 hour) in the *or* strain. Diel differences in visiting frequency were also observed in the *or* strain; averages higher at scotophase with 22.1 and lower at photophase with 16.0. Visiting frequencies were significantly different (p=0.008) when the data were paired and the t-test was conducted as mentioned in the case of within-harborage times.

Similar to the *or* strain, visiting frequency in the KNIH strain showed high individual variation (Table 1). The total visiting frequency was 17.1, slightly lower than in the *or* strain. Visiting frequency was slightly higher in scotophase than in photophase, respectively with 17.5 and 16.7. In contrast to the *or* strain, diel differences did not appear clearly. When a t-test was conducted on the paired data in a similar manner to the *or* strain, the difference between scoto- and photophases was not significantly different (p=0.755).

Fig. 3 shows examples of temporal patterns in visiting frequency at the harborage for individuals in each 3 h time block. Similarly to the times within harborage, variations were observed among individuals, and some individuals from the same maternal origin showed similar temporal patterns (e. g., the group of {Ob9, Ob10 and Ob12} in the *or* strain and {Kb 11 and Kb12} in the KNIH strain in Fig. 3).

In a similar manner to the within-harborage times, nested ANOVA was conducted while the visiting frequency of photo- and scotophases for each individual was paired. The maternal difference was highly significant (p=0.000) (Table 2). In contrast to the time within harborage, the difference between strains was also significant (p=0.029). When the data for photo- and scotophase was separate, visiting frequency in the photophase was not significantly different between the strains (p= 0.241), while in scotophase it was different (p=0.008).

Principal Component Analysis

Since the collected data for temporal patterns could compose a multivariate data set consisting of time within harborage (or visiting frequency) in eight different 3 h time blocks for each individual, we tried to investigate the degree of association of individual data by multivariate analysis in overall terms. By considering the mean within-harborage time as variables, and individuals as sample units, Principal Component Analysis (PCA; Colgan, 1978; Legendre & Legendre, 1983; Norusis, 1986) was conducted. Generally, in a Q type to represent associations among observed individuals (Fig. 4) (percent of variation; 47.7% for component I and 22.8% for component II), the sample units, where each point represented one individual, dispersed widely. This reflected the high degree of individual variation as mentioned before (Table 1, Fig. 2). Although the points dispersed widely, some individuals were clustered together very close as shown on component I and II in Fig. 4. Among these some individuals were progenies from the same maternal origins (e. g., the group of {Oa2 and Oa3}, {Oa6, Oa7 and Oa8}, {Od18 and Od20}, and {Oe21, Oe23 and Oe24} in Fig. 4). This closeness of sample units in PCA reflected similarity in temporal patterns of individuals, and could be actually observed in some examples in Fig. 2 (see {Oa2 and Oa3}, and {Oa6, Oa7 and Oa8}). PCA of the within-harborage

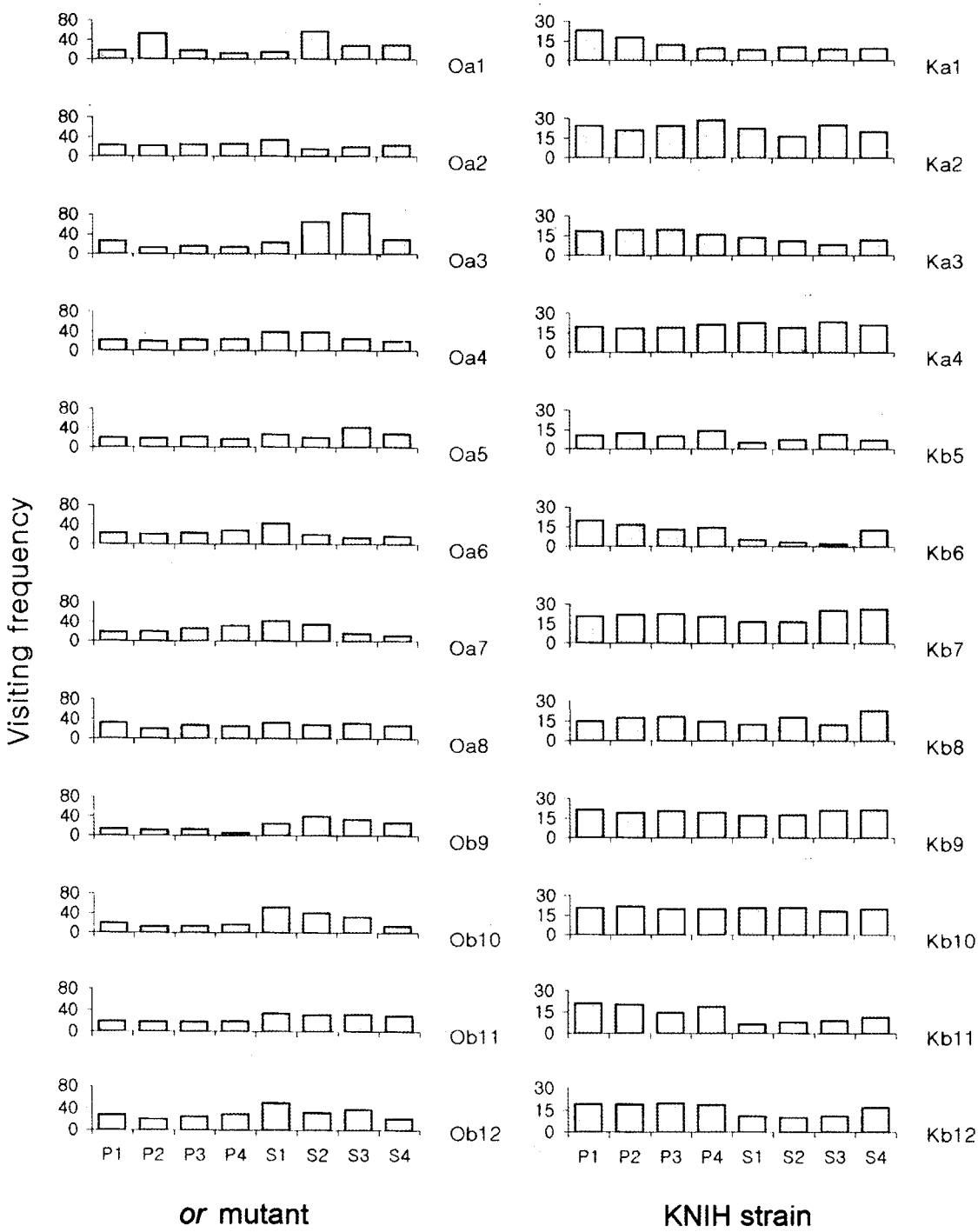

Fig. 3. Examples for males of the *or* mutant and the KNIH strain of the German cockroach in visiting frequency (number of visits in 3 h duration) at harborage in each 3 h time block in a day when reared in semi-natural conditions. The name of the observed individuals is the same as listed in Fig. 2. Values on the Y axis are visiting frequency while those on the X axis represent photophase 1, 2, 3 and 4, and scotophase 1, 2, 3 and 4 sequentially from left to right.

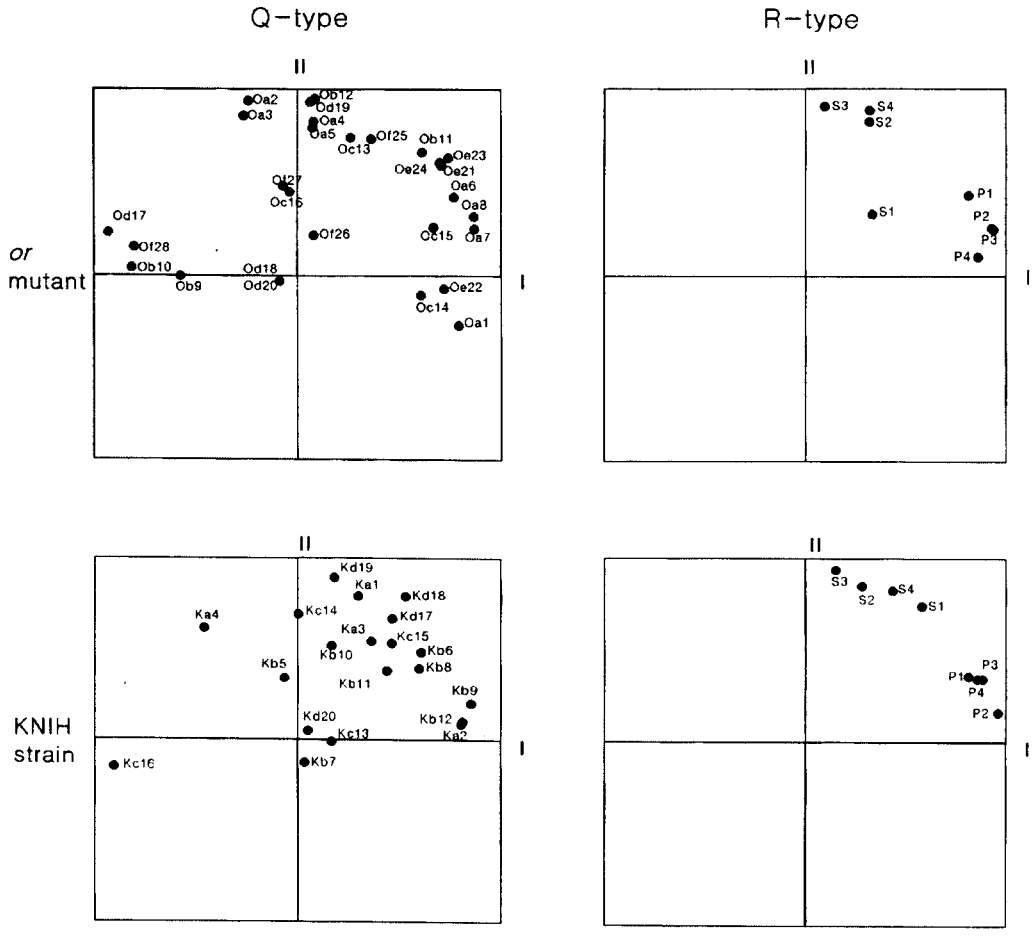

Fig. 4. PCA (Q and R types) on component I and II on different individuals of the male German cockroach with within-harborage time in different 3 h time blocks in a day. The name of observed individuals in Q type and the name of 3 h time blocks in R type are same as listed in Fig. 2.

time was also conducted on the KNIH strain (Fig. 4) (percent of variation; 50.8% for component I and 17.2% for component II). The points appeared to be dispersed widely, but some individuals from the same maternal origin were grouped closely (e.g., the group of {Kb6 and Kb8}, and {Kb9 and Kb12} in Fig. 4).

PCA was also conducted to investigate the associations among the 3 h time blocks in R type (Fig. 4) (percent of variation; 66.1% for component I and 17.6% for component II in *or* strain, 71.6% for component I and 15.6% for component II in KNIH strain). The time blocks in scoto- and photophases were grouped together in both strains. This suggested the existence of a diurnal pattern within the total variation of within-harborage time, although individual variations appeared diverse (Fig. 2). The grouping appeared more closely in the KNIH strain. Among the 3 h time blocks those in photophase tended to be grouped more closely than in the scotophase in both strains.

When PCA was also conducted on visiting frequency to represent associations among individuals (Q type; Fig. 5), the points were dispersed more widely than in the case of the within-harborage time (Fig. 4). Similar to the case of within-harborage time, some individuals from the same maternal origins were grouped together (e. g., group of {Ob10 and Ob12}, and {Oe23 and Oe24}

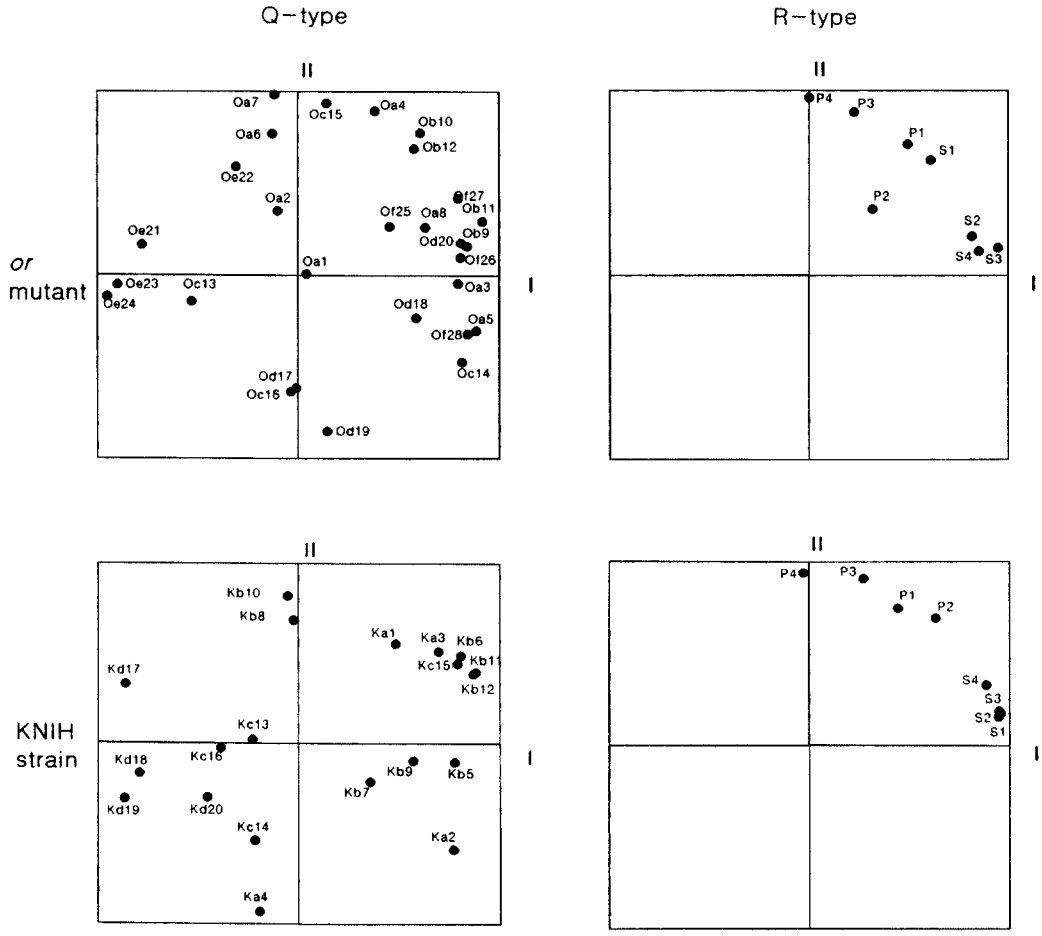

Fig. 5. PCA (Q and R types) on component I and II on different individuals of the male German cockroach with the visiting frequency in different 3 h time blocks a day. The name of observed individuals in Q type and the name of 3 h time blocks in R type are same as listed in Fig. 2.

for the *or* strain (percent of variation; 43.1% for component I and 29.9% for component II), and {Kb6, Kb11 and Kb12} for the KNIH strain (percent of variation; 43.6% for component I and 19.0% for component II) in Fig. 5). In R type, time blocks in scoto- and photophase were grouped together in the *or* and KNIH strain (Fig. 5) (percent of variation; 63.2% for component I and 18.2% for component II in the *or* strain, 68.2% for component I and 20.9% for component II in the KNIH strain), suggesting existence of a diurnal pattern in visiting frequency, as shown in the case of the time within harborage.

DISCUSSION

The diel difference in within-harborage time in both the KNIH and *or* strains undoubtedly reflect the well known circadian rhythm of the German cockroach. Adult males are more active than other age/sex classes (Metzger, 1995; Denzer *et al.*, 1987; Sommer, 1975), which accounts, in part, for times spent in other parts of the test area. Of the two activity peaks reported in adult males, the major peak during scotophase probably corresponds to the relatively lower percentages of males within harborage during mid-scotophase. No clear evidence was found of a sharp decrease in activity after the

major peak. A secondary peak just before photophase may have been reflected in the comparatively low percentage of males within harborage at P4 in both strains.

Under similar experimental conditions, but in collective rearing, Denzer *et al.* (1987) observed the German cockroach in groups, reporting that male adults during the light-on period were nearly as active as during the light-off period. In this study of solitary rearing, visiting frequency of male adults of the German cockroach showed similar results with Denzer *et al.* (1987) in the KNIH strain. The means of activity around harborage at photophase were similar to that at scotophase (not statistically different, Table 1). PCA analysis (Fig. 4), however, suggested the existence of a weak diurnal association in visiting frequency in the KNIH strain, although the average values were not statistically different in photo- and scotophase. In the *or* strain, diel difference was clearly observed: lower during photophase and higher during scotophase, corresponding to the circadian rhythm seen in within-harborage times. The diel difference in visiting frequency clearly appeared in the *or* strain in solitary rearing. Visiting frequencies of the two strains differed at the end of scotophase (S4) especially, e. g., low in the *or* strain and high in the KNIH strain. We do not know whether the low frequency was characteristic of *or* mutants or whether a strain difference related to origin (Korea vs Florida, USA) was involved.

Although the activity of the German cockroach was in general reflected in within-harborage time, the local activity around the harborage did not show clear associations with the within-harborage time on the individual basis. Initially, it was assumed that if the test insect stays longer in the harborage, the visiting frequency might decrease accordingly, since the test insect would be more in quiescent phase if it stays longer in harborage. In this study, in order to eliminate the adding effect -- i. e., as the test insect stays longer in a harborage, the total number of visits would accordingly increase as the duration increases --, we measured visiting number as a rate, expressed in a frequency in 3 h time unit. When within-harborage time in each time block was compared with the corresponding visiting frequency for each individual (Fig. 2 and 3), however, apparently no consistent relationship was observed.

When collectively compared to each other as shown in Table 1, visiting frequency seemed to reflect the state in previous time blocks in the phases of changing light. In early photophase, for example, times within harborage were relatively long but visiting frequencies were high. In this case, the insects maybe continued to be active locally around the harborage although the light had been already turned on. At the end of photophase (P4) the reverse situation occurred, the within-harborage time was shorter than during earlier photophase, but visiting frequencies were relatively low. In this case, the insects may have still kept a tendency not to move around much although within-harborage time had already been decreased. Further study may be needed to investigate relations of within-harborage time and local activity.

Differences between the KNIH and *or* strain in within-harborage times and visiting frequencies suggested that the KNIH strain was slightly less active than the *or* strain. This was not entirely due to a strain difference. Analyses that took maternal origins into account, indicated that much of the variation was due to differences between lines from different females. Similarity in within-harborage times, as well as visiting frequencies, was related to maternal origin in both strains. This suggested that daily temporal patterns in these behaviors might be under genetic control. However, individuals from the same maternal origin that showed similar patterns in within-harborage times did not necessarily show similar temporal patterns in visiting frequency. Further study is needed to verify whether the difference comes from environmental impacts or from genetic control.

Since the multivariate analysis compresses the multi-dimensional data to several dimensions for comprehensive understanding for readers, it simply shows a general trend of association among sample units or variables. Although individuals having similar patterns were located closely as mentioned previously, it was also observed that some individuals, whose temporal pattern apparently appeared differently, were also

grouped closely. Although the apparent similarity between individuals from the same maternal origins indicated that the temporal pattern may have genetic characteristics, further verification by genetic experiments would be necessary to verify this. This study, however, demonstrated and proposed a necessity of observing behavior in a continuous and systematic way.

Another difficulty in studying the systematic observation on continuous behavior was, that it produced a large amount of data and usually carried a high degree of variation, probably including some level of noise. In each day the data for within-harborage time and visiting frequency appeared in a variable way for each individual. Although the data in average (Table 1) showed some coherences such as diel difference, longer duration at the end of photophase, etc., much variability were embedded in the data for each individual in each scanning time. This might be further investigated with theoretical methods dealing with random effects and stochastic processes to extract information out of individual variability. The individual variability then could be further related to variability produced in collective rearing. For the next step of study, individuals whose behavior have been recorded and patterned may be subsequently reared in groups, -- i. e., grouping of individuals showing similar temporal patterns as well as grouping of individuals showing different patterns, or any type of combinational groupings --, and could be observed collectively. This could help to segregate variability produced in different levels of groupings in the German cockroach, and could perhaps explain the existence of some exceptionally high variability observed in collective rearing (e. g., Sommer 1975).

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