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Research Article

Effects of Rubberized Flooring on Asian Elephant Behavior in Captivity

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Six Asian elephants at the Oregon Zoo were observed to determine the effects of a poured rubber flooring substrate on captive Asian elephant behavior. Room utilization also was evaluated in seven rooms used for indoor housing, including Front and Back observation areas. Data were collected in three phases. Phase I (Baseline Phase) examined elephant behavior on old concrete floors. In Phase II (Choice Phase), elephant behavior was observed in the Back observation area where room sizes were comparable and when a choice of flooring substrates was available. Phase III (Final Phase) examined elephant behavior when all rooms in both observation areas, Front and Back, were converted to rubberized flooring. Room use in both observation areas remained stable throughout the study, suggesting that flooring substrate did not affect room use choice. However, there was a clear pattern of decreased discomfort behaviors on the new rubber flooring. Normal locomotion as well as stereotypic locomotion increased on the new rubber flooring. In addition, resting behavior changed to more closely reflect the resting behavior of wild elephants, which typically sleep standing up, and spend very little time in lateral recumbence. Overall, these findings suggest that the rubber flooring may have provided a more comfortable surface for locomotion as well as standing resting behavior. It is suggested that poured rubber flooring may be a beneficial addition to similar animal facilities. Zoo Biol 26:51–61, 2007.

Keywords: behavior; elephant; foot; flooring; preference

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INTRODUCTION

It has been estimated that 50% or more of captive elephants suffer from foot problems at some point in their lives and that untreatable foot infections are one of the major reasons for euthanization [Mikota et al., 1994; Fowler, 2001]. Abscessation or cracking of the sole or toenails, overgrowth of the cuticle, toenails or sole, foot rot, and softening and degeneration of the sole and skin of the foot are just of few of the serious ailments that a captive elephant may face [Fowler, 2001]. The causes of these problems are numerous and may be attributed to many different aspects of the captive environment.

One environmental aspect in particular that may contribute to the foot problems of captive elephants is that of flooring substrate. Prolonged periods of contact with concrete flooring have been implicated by zookeepers, veterinarians, and curators as one of the primary causal agents of elephant foot problems [Dimeo-Ediger, 2001]. Ninety-one percent of North American zoos have concrete flooring [Dimeo-Ediger, 2001], presumably for reasons of practicality and durability. It has been suggested that this hard, unyielding surface can cause the soles to crack and abscesses to form in the nails or on the pad of the foot [Buckley, 2001; Roocroft and Oosterhuis, 2001]. Anecdotal evidence suggests that elephants maintained on natural substrates have less foot problems [Gage, 2001]. Similarly, rubber flooring in dairy facilities has been linked to reduced incidence of lameness and foot problems in cows [Bergsten and Frank, 1996; Vokey et al., 2001].

In response to this issue, some facilities throughout the world have begun to build new elephant enclosures or change existing elephant exhibits to include natural substrates and surfaces that are softer and more insulated for walking and lying [Schwammer, 2001; Clubb and Mason, 2002]. However, these substrates have not been scientifically evaluated to determine their effects on foot health and behavior of elephants. Although the long-term effects on foot health of softer, more yielding surfaces may not be determined for years, the immediate effects of flooring surface on elephant behavior can be evaluated immediately. Therefore, the first objective of the current case study was to evaluate the impact of a new flooring surface on the behavior of captive elephants. The second objective was to evaluate the elephants' use of this new flooring substrate.

MATERIALS AND METHODS

Subjects

Six elephants at the Oregon Zoo were observed for this case study. The male subjects were two adult bull elephants, Packy (48 years, 6,010 kg) and Rama (20 years, 3,107 kg), both born in captivity and maintained individually. The female subjects were maintained as a herd but observed as individual subjects. Sung-Surin or "Shine" (25 years, 3,744 kg) and Rose Tu (9 years, 1,350 kg) were both born in captivity. Pet (48 years, 3,398 kg, the matriarch) and Chendra (8 years, 630 kg) were both wild-born.

Facility and Procedures

Elephants at the Oregon Zoo had two outdoor yards, the front yard (650 m^2) and the back yard (3,035 m^2). The outdoor yard substrate consisted of 91 cm of sand. Indoor housing consisted of a multi-room barn, of which seven rooms were used in this study (Fig. 1).

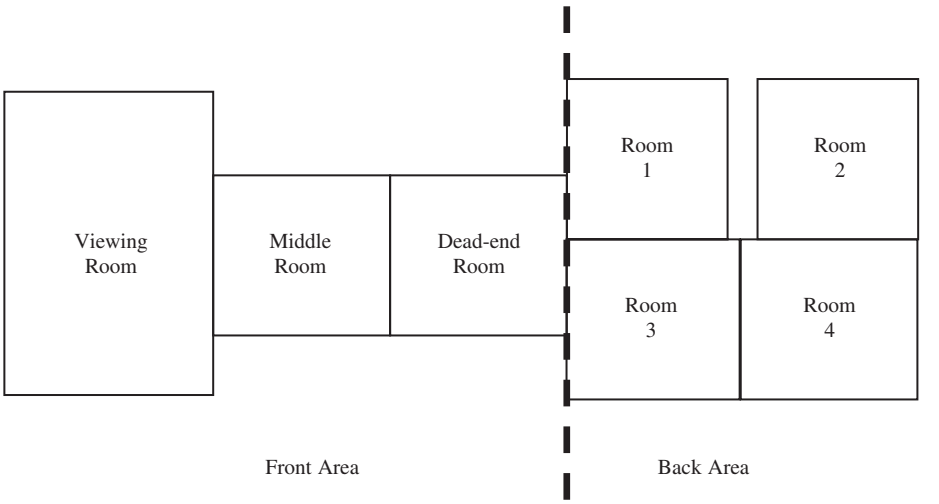

Fig. 1. Seven rooms of the elephant barn used for this study.

The seven rooms in the barn used for housing were divided into two observation areas. The "front observation area" consisted of a Viewing room (15.6 m × 6 m), a Middle room (6.3 m × 4.5 m), and a Dead-end room (6.3 m × 5.3 m) (Fig. 1). The "back observation area" consisted of Rooms 1 and 2 (6 m × 4.8 m) and Rooms 3 and 4 (6 m × 5.7 m). Six of seven rooms used for observation (Middle room, Dead-end room, Rooms 1–4) had concrete floors before the commencement of the study. The Viewing room of the front observation area had an older and deteriorated version of rubberized flooring that needed to be replaced.

During observation periods, one male elephant or the female herd was placed in a single observation area with access to all rooms in the defined observation area. Subjects were fed consistently at 11:00, 18:00, and 24:00 hr throughout the course of the study in addition to their other scheduled feedings that were not part of the observational periods. Water was provided ad lib in all rooms throughout the course of the study.

Phases of the Study

Closed circuit video cameras were used to record elephant behavior at three stages of this project. Phase I ("Baseline Phase") consisted of examining elephant behavior on old concrete floors, except for the Viewing room in the Front observation area, which had old rubberized flooring. Phase II ("Choice Phase"), was conducted only in the Back observation area and consisted of observing elephant behavior when two of the rooms (1 and 4) were poured with the new rubberized flooring whereas the other two rooms (2 and 3) retained their existing concrete flooring. A Choice phase evaluation was not carried out in the Front observation area due to the differences in room size as well as the fact that the Viewing room had existing old rubber flooring. Phase III ("Final Phase") of the study consisted of observing elephant behavior when all rooms in both observation areas were poured with new rubberized flooring.

Flooring Substrate and Installation

The rubberized flooring substrate used for this study was developed by Intracor/Familian International (Portland, OR) to be a seamless, cushioned, non-porous, non-toxic, non-skid substrate that would be durable enough to withstand the weight of Asian elephants. Before installation began, the floor was cleaned, dried, and then primed. A mixture of rubber granules and Intracor Playflex 8805, an aromatic urethane binder, was troweled onto the floor from 0.95–2.54 cm thick to give slope to the drains and then left to cure overnight. Two coats of Intracor Gymflex 8881, a 100% urethane-based material, was mixed with rubber dust and then poured and spread at 0.32-cm thickness onto the rubber base for strength and left to cure overnight. Next, an elastomeric polyurethane base coat was applied by roller at approximately 1 L/1.8 m^2. A sand aggregate was then sprinkled on the wet surface to add traction and this was left to cure. Finally, the loose aggregate was removed from the surface and a single component aliphatic top coat was rolled onto the surface at approximately 1 L/1.8 m^2 and left to cure.

Video Recording Schedule

To accommodate the husbandry duties of the elephant keeper staff and avoid unnecessary disruption of the normal daily routine, elephants were videotaped for 3 hr during the day (11:00–14:00 hr) and 12 hr at night (18:00–06:00 hr). Forty-five hours (3 days each consisting of 15 hr) of data were collected from each observation area during each of the three observation phases (Baseline, Choice, and Final) for a total of 135 hr of videotaped behavior per individual for the entire duration of the study. Trained research volunteers, recruited from the zoo's intern program as well as the Oregon State University Animal Behavior Group were used to code the videotapes. Each observer was required to pass an index of concordance, inter-observer reliability test [Martin and Bateson, 1994] at 80% or above, before being allowed to code data.

Sampling Scheme

Videotaped behaviors were sampled by coding for 5 continuous min at the beginning of each hour and each half hour for each individual subject using the software program Jwatcher (Version 0.9, Built 2000-11-09, Copyright © 2000, Daniel T. Blumstein, Christopher S. Evans and Janice C. Daniel, Macquarie University, Sydney, Australia). Observations were made only when the subjects were in sight, the keepers were not present, and the subjects had full access to all rooms in the observation area.

The behaviors focused on were locomotion, resting behavior (both standing and lying rest), foot-lifting behavior (lifting of a foot for purposes other than locomotion such as shifting weight from a particular foot to relieve pressure), exploratory behavior (use trunk or foot to touch/explore environmental features), and stereotypic behavior (pacing and swaying).

Statistical Analysis

Separate activity budgets were created for daytime (11:00–14:00 hr) and nighttime (18:00–06:00 hr) observation periods and represent the percent of observation time subjects spent performing the various behaviors. Baseline (control)

behavioral observations were compared to Final phase (treatment) observations. Paired *t*-tests were used to detect differences in locomotion, resting, discomfort, exploratory and stereotypic behaviors for each of the six subjects before and after the installation of the new rubber flooring. Elephants were observed resting both recumbently and while standing so the category of resting behavior was subdivided into lying rest and standing rest. Lying rest (recumbence) was observed only during the nighttime observation periods.

An ANOVA with a post-hoc Bonferroni test was used to compare room use in each observation area in each of the study phases. The females were analyzed as a group and the males were analyzed individually because they were observed individually.

RESULTS

Behavioral Data

Behavioral data were collected in both observation areas and are presented in Table 1.

Room Utilization in the Back Observation Area

Room utilization was evaluated in the Back observation area during all three phases of the study (Baseline phase = concrete in all four rooms, Choice phase = concrete in Rooms 2 and 3, and rubber flooring in Rooms 1 and 4, Final phase = rubber flooring in all four rooms) (Table 2).

Females showed an overall preference for Room 2 during the day and Room 3 during the night in all three phases of the study. Packy preferred Room 1 during the daytime across the three observation periods as well as the Baseline nighttime observation period. Rama did not show a strong preference for any of the four rooms across the three observation periods in the Back observation area.

Room Utilization in the Front Observation Area

Room utilization in the Front observation area is illustrated in Table 3. A Choice phase evaluation was not carried out on the Front observation area due to the differences in room size as well as the fact that the Viewing room had existing old rubber flooring.

The females showed an overall preference for the Viewing room during all observation phases in the Front observation area except for the Final phase, daytime observation period in which the Dead-end room was used the most. Packy also preferred the Viewing room to all other rooms in the Front observation area during all observation periods. Likewise, Rama preferred the Viewing room in all observation periods in the Front observation area apart from the Final phase daytime observation period.

DISCUSSION

The first objective of this study was to investigate any behavioral changes that occurred as a result of the new rubberized flooring by comparing behavior during the Baseline phase (old flooring) to behavior during Final phase (new rubberized

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TABLE 1. Activity budgets for all six subjects[a]

		Exploratory		Foot-lifting		Locomotion		Stereotypy		Standing Rest		Lying Rest	
		Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final
Backrooms Daytime	Chendra	7.1	2.1	0.0	0.0	10.2	9.5	21.4	23.3	12.6	30.9		
	Rose Tu	15.7	3.7	0.2	0.0	4.1	11.6	0.0	0.0	47.8	59.4		
	Shine	5.9	3.5	0.1	0.1	9.4	9.4	26.7	5.6	32.7	53.4		
	Pet	5.1	0.4	0.6	0.0	0.9	4.3	0.0	0.0	61.3	65.4	N/A	
	Rama	11.9	10.5	1.4	1.0	8.7	15.4	45.4	62.3	9.6	1.9		
	Packy	13.1	11.8	1.1	4.5	4.0	9.1	55.3	28.9	17.0	32.2		
	Mean	9.8	5.4	0.6	0.9	6.2	9.9	24.8	20.0	30.2	40.5		
	SD	4.4	4.7	0.6	1.8	3.8	3.6	22.8	24.0	21.0	23.6		
		$P<0.05$				$P<0.05$				$P<0.05$			
Backrooms Nighttime	Chendra	3.5	2.4	0.1	0.0	10.6	5.9	3.9	1.1	31.5	34.9	26.1	29.1
	Rose Tu	6.8	4.7	0.5	0.1	5.3	4.5	0.0	0.0	43.9	42.5	21.7	24.9
	Shine	3.3	3.1	0.1	0.0	5.4	7.4	0.9	12.9	46.4	38.0	20.6	13.1
	Pet	4.8	0.9	0.8	0.7	2.3	1.8	0.0	0.0	55.7	71.8	12.5	0.0
	Rama	5.4	7.2	0.7	0.5	6.8	12.6	28.3	58.7	11.1	10.1	22.5	8.6
	Packy	10.9	11.1	0.9	2.3	5.7	5.6	28.7	22.7	37.4	36.2	0.0	0.0
	Mean	5.8	4.9	0.5	0.6	6.0	6.3	10.3	15.9	37.7	38.9	17.2	12.6
	SD	2.8	3.7	0.3	0.9	2.7	3.6	14.2	22.9	15.4	19.7	9.6	12.3
						no significant changes							
Frontrooms Daytime	Chendra	3.2	0.2	0.0	0.0	18.8	11.8	37.2	12.7	11.5	48.0		
	Rose Tu	8.4	0.4	0.1	0.0	19.6	11.8	0.0	0.0	37.5	63.2		
	Shine	4.7	0.8	0.3	0.1	20.9	14.2	10.5	53.8	30.3	6.8		
	Pet	11.6	0.3	1.0	0.0	4.0	4.2	0.0	0.0	38.7	63.0	N/A	
	Rama	7.6	9.3	0.6	0.4	17.9	23.0	33.6	56.7	17.8	4.7		
	Packy	3.9	1.7	2.3	2.1	29.5	4.3	30.3	50.2	19.4	16.3		
	Mean	6.6	2.1	0.7	0.4	18.5	11.6	18.6	28.9	25.9	33.7		
	SD	3.2	3.6	0.9	0.8	8.2	7.0	17.1	27.5	11.3	27.5		
						no significant changes							
Frontroom Nighttime	Chendra	2.0	0.8	0.0	0.0	9.4	8.2	12.9	26.4	9.9	26.8	34.9	17.4
	Rose Tu	2.4	0.1	0.2	0.0	8.0	5.9	0.0	0.0	19.5	55.5	37.6	16.3
	Shine	3.9	2.0	0.8	0.0	11.1	7.5	6.4	24.7	18.0	29.7	17.3	12.5
	Pet	7.6	1.0	3.1	0.1	1.9	2.2	0.0	0.0	42.1	71.0	12.3	1.7
	Rama	2.9	3.3	0.3	0.7	6.7	9.7	25.7	52.1	14.0	20.2	34.8	10.1
	Packy	6.1	1.9	1.1	0.6	6.9	12.8	16.7	39.4	29.6	25.4	17.5	0.0
	Mean	4.2	1.5	0.9	0.2	7.4	7.7	10.3	23.8	22.2	38.1	25.7	9.7
	SD	2.2	1.1	1.1	0.3	3.1	3.6	10.1	20.9	11.8	20.3	11.2	7.3
		$P<0.05$						$P<0.05$		$P<0.05$		$P<0.05$	

[a]The Oregon Zoo (2003).

TABLE 2. Room use in the back observation area[a]

		Percent of observation time spent in room[b]					
		Day			Night		
		Baseline	Choice	Final	Baseline	Choice	Final
Females	Room 1	23.3^{A}	17.4^{A}	15.5^{A}	18.0^{A}	18.2^{A}	12.9^{A}
	Room 2	45^{B}	60.9^{B}	53.0^{B}	26.5^{A}	34.9^{A}	16.5^{A}
	Room 3	23.7^{A}	13.2^{A}	19.8^{C}	49.0^{B}	42.6^{A}	57.0^{B}
	Room 4	8.3^{A}	8.5^{A}	11.7^{A}	6.7^{C}	4.2^{A}	13.7^{A}
Rama[c]	Room 1	32.0	46.5	17.2	11.3	22.7	33.0
	Room 2	19.5	18.6	61.3	28.4	33.5	20.8
	Room 3	26.8	7.8	5.3	52.9	24.3	19.9
	Room 4	21.7	27.1	16.1	7.4	19.5	26.3
Packy[c]	Room 1	29.4	44.9	42.5	38.6	22.1	22.1
	Room 2	17.6	25.3	26.8	28.7	41.0	25.5
	Room 3	26.7	12.1	16.2	18.3	16.6	27.0
	Room 4	26.3	17.8	14.4	14.4	20.2	25.4

[a]The Oregon Zoo (2003).
[b]Data within a column with different superscripts differ $P<0.05$; shaded areas indicate rooms with rubber flooring; non-shaded areas indicate rooms with concrete flooring.
[c]Statistical analysis was not carried out on the male subjects.

TABLE 3. Room use in the front observation area[a]

		Percent of observation time spent in room[b]			
		Day		Night	
		Baseline	Final	Baseline	Final
Females	Viewing room	53.6^{A}	38.4^{A}	79.9^{A}	69.4^{A}
	Middle room	21.1^{B}	13.6^{B}	6.9^{B}	11.9^{B}
	Deadend room	25.4^{B}	48.0^{C}	13.2^{B}	18.6^{B}
Rama[c]	Viewing room	52.1	30.2	82.4	54.1
	Middle room	18.6	30.8	11.5	14.5
	Deadend room	29.4	38.9	6.1	31.3
Packy[c]	Viewing room	60.3	63.3	70.0	68.4
	Middle room	17.1	19.9	22.8	22.4
	Deadend room	22.7	16.8	7.1	9.2

[a]The Oregon Zoo (2003).
[b]Data within a column with different superscripts differ $P<0.05$; shaded areas indicate rooms with rubber flooring; non-shaded areas indicate rooms with concrete flooring.
[c]Statistical analysis was not carried out on the male subjects.

flooring). Several changes were observed in the behavior of the elephants between the two phases.

In the Back observation area, there were three significant behavioral changes, all during the daytime. Locomotion and standing rest increased, whereas exploratory behavior decreased. In the Front observation area, there were four significant behavioral changes, all of which occurred during the night. These included an

increase in stereotypic behavior, an increase in standing rest, a decrease in lying rest, and a decrease in exploratory behavior.

There are at least two possible explanations for the observed trend in stereotypic behavior. The first explanation is that the environmental change of the new flooring substrate may have been a stressful or aversive event for the elephants, and that they attempted to cope with it by engaging in stereotypic behavior (specifically pacing and swaying in this study). This notion is supported by Ödberg's hypothesis [1978] that stereotypic behavior functions as a coping mechanism for stressful conditions. It is possible that the installation of new flooring and the disruption of their environment during this process may have contributed to the observed increase in stereotypic behavior. In addition, the odor from the new flooring may have been aversive to the elephants and may likewise have contributed to the observed increase in stereotypic behavior. During the installation, and for several days after, there was a strong rubber odor in each of the rooms of the elephant barn. Efforts were made to properly ventilate the areas before testing. It is possible, however, that the elephants were able to detect lingering odor that was undetectable to humans, and were disturbed as a result.

A second explanation for the increase in stereotypic behavior is the possibility that the new rubberized flooring simply afforded the elephants a more comfortable surface on which to carry out stereotypic locomotion behavior that was already part of their individual behavioral repertoires. The stereotypic behaviors that were carried out by the four individuals were abnormal locomotion behaviors that included swaying on all four feet and pacing. This idea is further supported by the significant increase in normal locomotion behavior that occurred in the Back observation area.

Another significant behavior change was the change in resting behavior in the Front and Back observation areas. Lying rest decreased in the Front, whereas standing rest increased in both the Back and Front observation areas. Although most elephants lie down at some point during the night, elephants in the wild spend a majority of their resting/sleeping budget in a standing position [McKay, 1973; Tobler, 1992]. McKay [1973] reported that Asian elephants in Ceylon were infrequently observed lying down to rest for only 3.4–4.8 hr/day. This may suggest that standing sleep/rest is more common than lying sleep/rest for wild Asian elephants. If standing is the preferred sleeping position of wild Asian elephants, then it would seem that the elephants in this study began carrying out resting behavior that resembles that of wild Asian elephants. This may have occurred because the new rubberized flooring provided a more comfortable surface for standing resting behavior by alleviating pressure on the feet and joints while resting in the standing position.

Although not statistically significant, another behavioral change worth mentioning was a trend observed in foot-lifting behavior. In both observation areas during both the day and night, foot-lifting decreased in a majority of the subjects. Presumably, the softer flooring relieved pressure on the feet and joints, perhaps decreasing the need to shift weight from a particular foot.

Exploratory behavior was categorized as any behavior that involved using the trunk or foot to touch/explore any surrounding feature excluding self and conspecifics. In both observation areas, this behavior decreased. One possible explanation is that there may have been a lingering odor from the rubber substrate.

As stated previously, there was a strong rubber odor in each of the rooms of the elephant barn during the installation process and for several days after. The elephant's trunk is its olfactory organ and rests close to the ground. If an unpleasant or aversive odor from the new rubber flooring was detectable, it follows that the elephants would avoid or decrease behaviors such as exploration that would increase contact between the trunk and the floor.

The second objective of this study was to evaluate the elephants' use of the new rubberized flooring substrate versus the old flooring substrate by comparing room use. Room use in both of the observation areas remained relatively stable throughout the course of the study. In the Front observation area, the Viewing room was used most in comparison to the other two rooms. This implies that the animals had strong room preferences before the study and although a slightly increased use of the other two available rooms was achieved once the entire area had been installed with rubberized flooring, the overall preference for the Viewing room remained strong. This room may have been preferred for several reasons such as its larger size, taller ceiling, better lighting, proximity to keeper staff room, etc. This room also had an existing rubber floor (an older version of the Natural Path Elephant Flooring) before the initiation of this study, perhaps making it the preferred room at Baseline.

The many differences in the rooms of the Front observation area made it difficult to determine whether or not the new rubberized flooring had any effect on room preference there. In the Back observation area, however, the four rooms were very similar in size, shape, lighting, etc. and all had concrete floors before the study. This area provided better conditions for testing room preference before and after the installation of the new Natural Path Elephant Flooring. Yet, in the Back observation area, preferences also remained relatively stable. The females and Packy preferred the same rooms in the Final phase as they did in the Baseline phase. The females seemed to have a very strong preference for Room 2 during the daytime and Room 3 during the nighttime. Packy showed a preference for Room 1 in the daytime throughout all three phases of the study as well as the Baseline nighttime observation period. Rama was the only subject who did not show room preferences in the Back observation area.

When the subjects were given a choice between flooring substrates, the females showed a preference for Room 2 during the day and Room 3 at night that were the concrete-floored rooms. However, during the Baseline (all rooms concrete) and Final (all rooms rubber) phases the females also preferred these rooms. It is unlikely, therefore, that they were making room choices based on flooring substrate. Rather, it seems that they had pre-existing room preferences and that these preferences remained relatively stable regardless of flooring substrate. The males both spent more time in Room 1 (rubber) during the day and Room 2 at night (concrete) during the Choice phase again suggesting that neither flooring substrate was preferred.

Despite these observations, the fact that the concrete-floored rooms were used to a greater extent by the females during the day and night and by the males at night during the Choice phase should be addressed. One possibility is that concrete may have been the preferred substrate during this phase because of its thermodynamic properties. This study was conducted during the summer months, and temperatures in the barn may have been high enough to warrant thermo-

regulatory behavior, such as choosing to be in a concrete-floored room (that was presumably cooler) versus a rubber-floored room. However, because the female elephants' preferences for Rooms 2 and 3 were constant regardless of flooring substrate, it is more likely that their choice to spend more time in these rooms was influenced by other factors, as previously suggested, such as size of the room, lighting, etc.

These results suggest that a majority of the elephants had strong room preferences in both observation areas before the commencement of this study, and these generally did not change as a result of flooring substrate. The consistency of room preference regardless of flooring substrate, shown by the elephant subjects in this study, may indicate that familiarity with the rooms influenced their room choices. Prior experience has been shown to influence animals' choices in preference testing [Dawkins, 1976; Petherick et al., 1990]. This may have been the case for the elephants used in this study.

CONCLUSIONS

Room use by the elephants in this study remained relatively constant in both observation areas regardless of flooring substrate indicating no strong preference for either flooring substrate. Behaviorally however, there were differences between the flooring substrates. There was a pattern of increased gross motor movement on the new rubberized flooring that included both normal and stereotypic locomotion behavior. Resting behavior also showed marked changes with an increase in standing rest and a decrease in lying rest. Additionally, there were decreases in exploratory and foot-lifting behavior as a result of installing new rubberized flooring.

These results must be interpreted cautiously given the limitations of study, especially in regard to the small number of subjects that were available. Bearing this in mind, we suggest that Natural Path Elephant Flooring or similar flooring substrates may be beneficial to elephant-keeping facilities in promoting locomotion behavior as well as providing a softer, more yielding surface for standing rest. However, because the softer flooring seemed to facilitate abnormal locomotion behavior as well, care should be taken to adequately enrich the captive environment in newly floored areas. Because odor may have been aversive to the animals in this study, it would be advisable for other institutions to ventilate adequately after installation.

Elephants' unique anatomy, enormous size, impressive strength, and length of life, require that they maintain healthy feet and joints to live to their full life expectancy. Therefore, every effort should be made to determine the impact that environmental conditions have on foot health to create captive conditions that promote healthy feet. Future flooring substrate studies should investigate the effects of moisture, confinement, diet, exercise, and weight on foot health. Furthermore, studies that look at the long-term effects of housing elephants on different flooring substrates should be initiated. Whenever it is feasible, scientific studies should be implemented at elephant facilities as environmental conditions are altered so that the merits of these changes can be shared with the elephant-keeping community.

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