ASSESSMENT OF GNAWING BEHAVIOR OF THREE RODENT SPECIES ON AUTOMATIC SPEED CONTROL MECHANISM DIAPHRAGMS FROM GM AUTOMOBILES

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ABSTRACT: General Motors and the A. C. Rochester Company, a subsidiary of General Motors (GM), has found that the rubber diaphragms on automatic speed control mechanisms (servos) were gnawed by unknown rodents. House mice (*Mus musculus*), *Peromyscus spp.*, and eastern chipmunks (*Tamias striatus*) were used to test gnawing behavior on 4 kinds of diaphragms. Diaphragms with or without a rodent proof cure formula, which are used by GM, did not influence the gnawing of all test rodent species. Diaphragms with a lubricant (Paricin) were more attractive to gnawing by house mice than diaphragms without a lubricant. Five objects with different texture were used to detect gnawing preference of house mice and 3 objects were used on Peromyscus. The textures of diaphragms and nylon discs were not significantly preferred by house mice compared to the textures of corks and wood blocks. Rubber stoppers were gnawed less than wood blocks and corks by house mice and Peromyscus, but the differences were not significant. Results indicate that the presence of a rigid and protrusive edge on the diaphragms was a critical factor in attracting rodent gnawing. To test this possibility, diaphragms on servos supported by aluminum piston heads with 3 different beveled edges were presented to captive *Peromyscus*. The amount of gnawing was not significantly different among the diaphragms supported by the different piston heads. Once the gnawing was initiated, continued gnawing was thought to be dependent on the texture of objects.

Proc. East. Wildl. Damage Mgmt. Conf. 7:187-194. 1997.

Damage resulting from the gnawing behavior of rodents (*Rodentia spp.*) has been reported to occur on food packaging, telephone cables, wires, plastic piping, rubber, lead, and even steel (Meehan, 1984). Automotive parts such as tires, hoses, wires, belts, bumper and trim guards, etc. are also gnawed by rodents. Porcupines (*Erethizon dorsatum*) are infamous for gnawing on almost all non-metallic automotive parts. Rodents also demonstrate relative preferences for some materials. Texture seems to be a major determining factor (Geyer and Cummins, 1980; Cooper and Trowill, 1974).

The purpose of this study was to determine what factors influence the gnawing damage by rodents on rubber diaphragms on automatic speed control mechanisms (servos) in General Motors Company (GM) automobiles. Factors tested included type of material, the cure of the rubber, the lubricant used on the rubber to facilitate servo assembly, and the beveling on the edges of the servo piston heads that support the rubber diaphragm.

MATERIALS AND METHODS:

Test Species

Laboratory house mice (*Mus musculus*), wild trapped *Peromyscus spp.* (including deer mice and white-footed mice), and wild trapped eastern chipmunks (*Tamias striatus*) were chosen because sufficient numbers could be obtained, because they are widely-distributed across the U.S., and because these species have been observed by the authors in automobiles. Nests, food caches, food remains, droppings, and gnawed automotive parts have also been observed in automobiles.

Thirty house mice were purchased from Michigan State University (MSU) Laboratory Animal Resources. Twenty *Peromyscus* and fourteen chipmunks were caught from a field on the MSU campus. All animals were held in captivity at MSU according to MSU standards for care of laboratory animals. Chopped newspapers were used instead of wood shavings for bedding because the small wood particles might satisfy the gnawing desires of rodents. All animals were fed *ad libitum*.

The *Peromyscus* and chipmunks were not separated as to age or sex. All the house mice were 3 weeks old males.

Test Material

Wood, corks, rubber stoppers, and nylon discs were chosen to compare to currently used servo diaphragms (standard cure with lubricant) to test whether the diaphragm is preferred by rodents for gnawing. Wood, cork, rubber, and nylon were chosen because they have no known nutritive value to rodents and because rodents are known to gnaw on all of these materials. The wood blocks were about 45.9 cm^3 and were bought from a pet shop because they were known to be highly preferred by pet rodents (mice, hamsters, gerbils, etc.). The corks and rubber stoppers were about 40.17 cm^3 and 26.11 cm^3 respectively, and were purchased from MSU general stores. The nylon discs were about 11.55 cm^3 and were purchased from a local pet store.

Four kinds of servo diaphragm formulations were used. The formulations were standard cure with lubricant (S-W), rodent proof cure with lubricant (R-W), standard cure without lubricant (S-WD), and rodent proof cure without lubricant (R-WO). The standard cure was ethylene propylene norbordene rubber (EPDM) accelerated with a Thiuram type accelerator. The rodent cure was also EPDM but accelerated with a thiazoles type accumulator. The lubricant was methyl hydroxystearate (trade name Paricin #1). All diaphragms were provided by GM.

Procedure:

Wood blocks, corks, rubber stoppers, nylon discs and S-W diaphragms were used to test whether the texture of different objects would influence the gnawing preference of rodents.

Twenty house mice were chosen randomly. Ten of them received nylon discs and ten received S-W diaphragms which had been cut into small round discs with the same diameter as the nylon discs. Nine house mice and nine *Peromyscus* were randomly chosen to be part of three test groups of 3 mice each for each species. The first group received objects in the following order: wood block, cork, and rubber stopper. The second group received objects in the following order: cork, rubber stopper and wood. The third group was given objects in the order of rubber stopper, wood, and cork. All objects were put into cages for three days. The time interval between different objects being placed into the cages was about 1 day. The degree of gnawing was rated 0-10, "0" meaning no gnawing was found, "1" meaning approximately 0% up 10% gnawing, "2" meaning approximately 10% up to 20% gnawing,.... and so on. Data were recorded daily.

Four kinds of diaphragms (S-W, R-W, S-W/O, and R-W/O) were placed in the center of each test animal's cage to test whether the two factors (with or without rodent cure and with or without lubricant) would influence rodent gnawing on diaphragms.

Each diaphragm was fixed on a special designed "servo simulator" which was made from a used soup can and an aluminum ring used on real servos. This servo simulator provided the resistant edge supporting the diaphragm similar to the aluminum piston head that is pressed by a spring into the diaphragm on the real servo.

Thirty house mice, 20 *Peromyscus*, and 14 chipmunks were used. Animals of each species were randomly divided into 2 groups. The cages of the first group received diaphragms in the following order: S-W, R-W, S-W/O, and R-W/O. The second group was given diaphragms in the order of R-W, S-W, R-W/O. Each diaphragm was put in a cage for three days. Due to the different availabilities of four diaphragms from GM, the time interval between different diaphragms in the cages ranged from 1 to 13 days. Gnawing damage was recorded using the following scales: "O", the diaphragm was not gnawed; "1", the diaphragm was nibbled or gnawed slightly but not gnawed through; and "2", the diaphragm was gnawed through.

To compare the gnawing difference of house mice gnawing on small diaphragm discs cut from S-W diaphragms and S-W diaphragms fixed on servo simulators, the rating schemes were unified to be: "O", the diaphragms were not gnawed; and "2", the diaphragms were gnawed.

After testing for the effects of the diaphragm, its cure, and its lubricant, it became apparent that the structure supporting the diaphragm might have a greater effect on rodent gnawing than other factors. In a functioning servo, a spring pushes an aluminum disc, or piston, into the diaphragm. To test if the piston shape does influence gnawing on the diaphragm, GM provided 30 servos, with pistons having differently beveled edges: 10 slightly beveled, 10 moderately beveled, and 10 sharply beveled. Each of the servos was placed in a cage with a *Peromyscus spp*. Each cage also had food, water and shredded paper as in previous tests. Technical problems resulted in variation of the number of days each servo was in each cage. As a second test, all servo diaphragms that were ungnawed in the first test were placed in a cage with the one individual *Peromyscus* that did the most gnawing in the first test. Each servo was left in the cage for 3 days.

Data Analysis

For house mice, nonparametric Kruskal-Wallis ANOVA was used to compare the rodent gnawing on 5 objects: wood blocks, corks, rubber stoppers, nylon discs, and S-W diaphragm discs. For *Peromyscus*, non-parametric Friedman ANOVA for related samples was used to compare the rodent gnawing on 3 objects: wood blocks, corks, and rubber stoppers. The multiple-comparison method was conducted as described by Daniel (1978). Kruskal-Wallis ANOVA was also used to test the difference of gnawing of house mice and *Peromyscus* on wood blocks, corks, and rubber stoppers, which were presented in different orders.

Three dimension chi-square was used to test whether the diaphragm with rodent-proof cure and lubricant influenced rodent gnawing on diaphragms. In the case that significant effect was found, chi-square was used to test the effect of lubricant and rodent-proof cure respectively. It was not possible to test the order effect on rodent gnawing on diaphragms because the time interval among diaphragms presented to animals ranged too widely.

Chi-square test was used to compare the gnawing difference of house mice on small S-W diaphragm discs and S-W diaphragms on servo simulators.

The exact probability test was used to compare the gnawing difference on diaphragms supported by aluminum piston heads having edges with 3 different amounts of beveling.

RESULTS

House mice gnawed more on wood blocks and corks and less on nylon discs and S-W diaphragms (Kruskal-Wallis $\chi^2 = \chi_{kw}^2 = 42.85$, P 0.005). *Peromyscus* gnawed most on the corks and least on the rubber stoppers, but there was no significant difference among them ($\chi_{kw}^2 = 3.0$, non-significant).

The gnawing on objects presented in different orders was not significantly different for wood block, cork, and rubber stopper with *Peromyscus*. House mice gnawed rubber stoppers significantly more when the stoppers were presented third instead of first ($\chi_{kw}^2 = 6.2$, df = 2, $p<0.05$).

The rodent-proof cure and the lubricant of the diaphragms did not have significant effect on the gnawing of *Peromyscus* ($\chi^2 = 4.488$, df = 2) (Table 1) and chipmunks (($\chi^2 = 2.489$, df=1) (Table 2). However, they had significant effect on house mice ($\chi^2 = 11.638$, df = 2, $p<0.05$) (Table 3).

The presence of the lubricant was the factor that had a significant effect on the gnawing of house mice on diaphragms ($\chi^2 = 6.762$, df =2, $p<0.01$) (Table 4).

The diaphragms without the lubricant seemed less attractive than those with the lubricant and the rodent-proof cure had no significant effect (χ^2 = 0.375, df = 2). When the results for diaphragms with the standard and rodent-proof cure are combined, 31 of 60 diaphragms without the lubricant were gnawed while 42 out of 60 diaphragms with the lubricant were gnawed.

The comparison of the gnawing damage by house mice on the small discs cut from S-W diaphragms and S-W diaphragms on the servo simulator showed that 23 out of 30 (76.7%) diaphragms on servo simulators were gnawed while only 4 out 10 (40%) small diaphragm disc were gnawed. The difference was significant (χ^2 = 4.596, df = 1, $p<0.05$).

All of the gnawing damage that occurred happened on the exposed edge of the diaphragms on servo simulators. There was no damage found on the smooth area on top side of diaphragms. This phenomena was identical to that observed on the 12 real servos submitted by GM for inspection.

The house mice and *Peromyscus* not only gnawed on the diaphragm edge but also on the aluminum ring on the servo simulations. The teeth marks on the edge of aluminum rings were clear and intensive.

In the comparison of the amount of gnawing on the diaphragm as an effect of the amount of beveling on the edge of the supporting aluminum disc, or piston, the diaphragm over the moderately beveled edge, was gnawed most 60% (Table 5). The diaphragm supported by most beveled edge, C, was gnawed least, 30%, and the diaphragm supported by least beveled edge was gnawed at an intermediate level 40% (Table 5). When this same test was conducted with just one *Peromyscus*, the results were similar - 83.3% of diaphragms gnawed that were supported by the least beveled edge, 100% of diaphragms gnawed that were supported by the moderate beveled edge, and 57.4% of the diaphragm gnawed that were supported by the most beveled edge (Table 6). None of these results were significantly different, however.

DISCUSSION AND CONCLUSION

It is unlikely that the rodents in this study gnawed to obtain nutrition because all animals were fed ad libitum, but still gnawed extensively on the wood blocks, corks, rubber stoppers, nylon discs, and rubber diaphragms which contained no or limited nutrition. Although the lubricant composed of different hydroxyl waxes might provide some nutrients, they are probably very limited.

Diaphragms with the lubricant were gnawed more than diaphragms without the lubricant by house mice. This suggests that not using the lubricant might decrease the gnawing damage caused by house mice, but more than half of the diaphragms without lubricant were gnawed by mice (31 out of 60). Furthermore, the lubricant does not affect the gnawing of *Peromyscus* or chipmunks, and its effect on *Peromyscus* was opposite that of the house mice, but the difference was not significant. Therefore, the lubricant is not the major factor which attracts rodents to gnaw on diaphragms.

The rodent-proof cure, which was thought to be a small animal or rodent repellent by GM company, did not provide significant repulsion for any of rodent species in this study to gnaw on diaphragms.

The diaphragm was significantly not preferred by house mice compared to the corks and the wood blocks. Also, the rubber stoppers were not attractive for gnawing to either house mice or *Peromyscus*, although gnawing on rubber stoppers by both house mice and *Peromyscus* was not significantly less than those on corks and wood blocks. The house mice gnawed more on the rubber stoppers which had a texture similar to the diaphragms than on diaphragm discs. Also, house mice gnawed significantly more on diaphragms fixed on the servo simulator rather than on the small discs cut from the diaphragm. This difference probably occurred because the size and shape of rubber stoppers and servo simulators provided a more rigid and protrusive edge than the diaphragm disc did. It is unlikely, therefore, that rodents gnawing on the diaphragm of the servo of speed control mechanisms under auto hoods is done to gain nutrition and that the chemical components or texture of diaphragm are attractive to rodents.

In this study, the fact that all gnawing damage started on the edge of various objects suggests that the protruding edge of objects is closely related to rodent gnawing.

To gnaw effectively rodents must be able to get an object or part of it between their upper and lower incisors (Drummond, 1971). The protruding edge would certainly allow rodents to do so. The fact that rodents gnawed the edge of the aluminum rings around the servo simulator implied rodents gnaw on objects because of the protruding edge in addition to their preference for the texture of objects.

Roberts and Carey (1965) concluded that the gnawing behavior, like other behaviors such as eating and drinking, will not be performed without the appropriate goal objects having a protruding edge for gnawing, even when the gnawing "readiness" was evoked by electric stimulation on the hypothalamus. They observed that if no acceptable objects were available, only exploratory-like locomotion was displayed, and when rats contacted a protruding edge, the gnawing movements were performed.

The gnawing behavior of rodents may be similar to other stereotypic behaviors such as eating, grooming, and mating which are elicited by either internal or external stimulus or both. Although the natural stimuli to elicit gnawing behavior are still unclear, when gnawing readiness is evoked by certain stimulus, the object with a protruding edge seems to be essential for initiation of gnawing behavior. The result of this study, where only 40% of diaphragm discs were gnawed by house mice while 76.7% of similar diaphragms on servo simulators were gnawed, supports this conclusion. This difference in gnawing could be explained by the presence of the extensive protruding and resistant edge on the servo simulator. This obvious protrusive edge was unavoidable and the resistance provided by the supporting material made taking bites and pulling away pieces easy and possibly satisfying to the mice. The discs cut from the diaphragm had an edge, but the edge was not as extensive and protrusive. Roberts and Carey (1965) also proposed that the factor that determined continuing gnawing behavior after a rodent contacted a protruding edge was whether a fragment could be pulled away against moderate resistance. Because the discs probably moved away from the mice when they first attempted to bite, and towards them after they bit and tried to pull away, gnawing was probably more difficult and less satisfying.

Texture is another factor that determines whether a fragment can be pulled away against moderate resistance. The better the texture contributes to moderate resistance, the more extensive the gnawing. These relationships probably explain why the wooden blocks and corks were gnawed more extensively than the nylon discs, diaphragm discs, and the diaphragms on the servo simulators.

Although all the diaphragms on the servos with pistons having varying edge beveling had a protruding edge, the protruding edge was least supported by the piston with the most beveled edge. Therefore, the *Peromyscus* may have had more difficulty gnawing on this least supported protrusive edge because it moved away from their incisors as they attempted to gnaw on it. Although the least supported edge was least gnawed, this result was not significantly different from the others because of small and incomplete sample size.

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Table 1. Chi-square test for the effect of diaphragm lubricant and rodent-proof cure on gnawing by *Peromyscus*.

		Lubricant	
Cure	Gnawing scale	With	Without
Standard	0	15	11
	1	2	6
	2	3	3
Rodent-proof	0	15	13
	1	2	5
	2	3	2

$\chi^2 = 4.488$, df = 2, n.s.

Table 2. Chi-square test for the effect of diaphragm lubricant and rodent-proof cure on gnawing by chipmunks.

		Lubricant	
Cure	Gnawing scale	With	Without
Standard	0	9	9
	1	5	5
Rodent-proof	0	7	11
	1	7	3

$\chi^2 = 2.489$, df = 1, n.s.

Table 3. Chi-square test for the effect of diaphragm lubricant and rodent-proof cure on gnawing by house mice.

		Lubricant	
Cure	Gnawing scale	With	Without
Standard	0	7	15
	1	16	10
	2	7	5
Rodent-proof	0	11	14
	1	9	14
	2	10	2

$\chi^2 = 11.638$, df = 2, $p<0.005$

Table 4. Chi-square test for the effect of lubricant on gnawing by house mice.

	Gnawing Scale			
Lubricant	0	1	2	Total
With	18	25	17	60
Without	29	24	7	60

$\chi^2 = 6.762$, df = 2, $p<0.01$

Table 5. Gnawing damage by *Peromyscus spp.* in trial 1 to 3 alternative designs (A, B, C)[a] of automatic speed control mechanisms (servos)

Mouse #	A	B	C
1.	2[b]	0	0
2.	2	0	1
3.	0	1	1
4.	0	2	2
5.	0	2	0
6.	0	0	0
7.	2	2	0
8.	2	2	2
9.	0	2	2
10.	0	2	0
% gnawed through -broken	40%	60%	30%

[a]Servo design - A = piston with slightly beveled edge, B=piston with moderately beveled edge, C=piston with highly beveled edge.

[b]0= ungnawed, 1=gnawed, 2= gnawed through, broken but not broken.

Table 6. Ungnawed servos from trial one exposed to one *Peromyscus* sp. that gnawed most frequently.

A[a]	B	C
2[b]	2	0
2	2	2
0	2	2
2		2
2		0
2		2
		0
83.3% Gnawed through-broken	100%	57.4%

[a]Servo design - A = piston with slightly beveled edge, B=piston with moderately beveled edge, C=piston with highly beveled edge.

[b]0= ungnawed, 1=gnawed, 2= gnawed through, broken but not broken.