Available online at www.sciencedirect.com
SCIENCE DIRECT
Behavioural Processes 71 (2006) 8–15
BEHAVIOURAL PROCESSES
www.elsevier.com/locate/behavproc

Hair barbering in mice: Implications for neurobehavioural research

A.V. Kalueff [a,*], A. Minasyan [a], T. Keisala [a], Z.H. Shah [b], P. Tuohimaa [a,c]

[a] *Department of Anatomy of the Medical School, University of Tampere, Tampere 33014, Finland*
[b] *Institute of Medical Technology, University of Tampere, Tampere 33014, Finland*
[c] *Department of Clinical Chemistry of the University Hospital, Tampere 33014, Finland*

Received 9 February 2005; received in revised form 14 July 2005; accepted 11 September 2005

Abstract

Barbering (fur/whisker trimming, the Dalila effect) is a behaviour-associated hair and whisker loss frequently seen in laboratory rodents, including mice. Here we analyse barbering behaviour in 129S1, NMRI, C57BL/6 and BALB/c mouse strains and some of their F1 hybrids. Our study shows that barbering in mice, depending on their genotype, is a complex behaviour with several distinct contexts or domains. We observed social (dominant) barbering in NMRI and C57BL/6 mice, sexual over-grooming in 129S1 and C57BL/6 mice, maternal barbering in lactating 129S1 and C57BL/6 mice, and stress-evoked barbering in F1 (NMRI × 129S1) hybrids. In contrast, aggressive BALB/c mice and their F1 progeny do not use barbering in their behaviour. We suggest that barbering may be an important complex multi-domain behaviour sensitive to various manipulations, and represent a useful index in neurobehavioural research.

Keywords: Mice; Barbering; The Dalila effect; Whisker trimming

1. Introduction

Behaviour-associated hair loss has been observed in many species including dogs, cats, horses, cattle and non-human primates (Ehrenlechner and Unshelm, 1997; McElwee et al., 1999). Described in the literature as barbering, overgrooming, whisker/hair or fur trimming, nibbling, eating (trichophagia), plucking, pulling, de-whiskering or the Dalila effect (Jackson Laboratory, 1987; Carruthers et al., 1998; Sarna et al., 2000), it has long been observed in laboratory rodents. Barbering includes plucking of fur or whiskers from cage-mates (hetero-barbering) or oneself (self-barbering), and is common in mice (Long, 1972; Strozik and Festing, 1981; Sarna et al., 2000), rats (Beare-Rogers and McGowan, 1973; Bresnahan et al., 1983) and guinea pigs (Gerold et al., 1997).

Mounting data indicate that rodent barbering may be a form of dominant behaviour (Reinhardt and Militzer, 1979) and a strong indicator of social hierarchy (Long, 1972). In groups of mice and rats, there was usually one with unbarbered whiskers, playing a dominant role in the cage (Strozik and Festing, 1981; Bresnahan et al., 1983; Sarna et al., 2000). Whisker removal itself did not alter social dominance in male mice (Van de Weerd et al., 1992), suggesting that dominance determines barbering and not the otherwise. In addition, barbering occurred even if the mice were separated by wire mesh, indicating that both animals, either actively or passively, co-operate in this behaviour (Van den Broek et al., 1993).

In mice, barbering is particularly common in some strains, especially C57BL/6 (B6) and A2G (Long, 1972; Strozik and Festing, 1981; Jackson Laboratory, 1987; Sarna et al., 2000), suggesting a strong genetic component (Hauchka, 1952; Militzer and Wecker, 1986; Van den Broek et al., 1993; McElwee et al., 1999). It may also be socially transmitted, e.g., induced in a non-barbering group after introducing a barber (Reinhardt and Militzer, 1979). Several husbandry factors have also been reported to affect barbering (e.g., diet, weanling age and enrichment; Myers, 1997; De Luca, 1997), suggesting that barbering may represent stress-evoked behavioural response (e.g., coping with inappropriate housing; Van den Broek et al., 1993), or a pathological behaviour similar to human compulsive hair pulling (Garner et al., 2004a,b).

Why the Dalila effect is so important for neurobehavioural research? First, barbering is an interesting behaviour per se, representing as essential part of rodent waking activity (Sarna et al., 2000; Whishaw et al., 2001). Second, in most cases it affects whiskers, regarded as a crucial source of sensory input

* Corresponding author. Tel.: +358 3 2156640; fax: +358 3 2156170.
E-mail address: avkalueff@inbox.ru (A.V. Kalueff).

0376-6357/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.beproc.2005.09.004

in rodents (Ahl, 1986; Staiger et al., 2000). Whisking represents an essential part of rodent behavioural repertoire (Prigg et al., 2002), as rodents actively use whiskers to locate and distinguish objects in their immediate environments, for texture discrimination, balance control, orienting and exploration (Vincent, 1912; Meyer and Meyer, 1992; Belzung, 1999; Prigg et al., 2002; Prchal et al., 2004). Therefore, altered whisker status in mice due to barbering may disorganize animal behaviours, also impairing their performance in various behavioural tests (Crawley, 1999).

Given the importance of behavioural phenotyping of various mice (Crawley et al., 1997; Greer and Capecci, 2003), including mutants with abnormal barbering (Wang et al., 2001; Holmes et al., 2002a; Long et al., 2004), further studies are necessary to understand in detail the nature and etiology of barbering. The present study sought to extend the available literature on the Dalila effect by presenting a detailed systematic ethological analysis of barbering in several mouse strains widely used in behavioural neuroscience (Crawley and Paylor, 1997; MGI, 2001; MPD, 2001).

2. Materials and methods

The mouse colony consisted of approximately 560 male and female mice (2.5–4 months old) of different strains, including 129S1 (S1), NMRI, BALB/c (BC), B6 and their F1 inter-crosses (Table 3). All mice were bred in the University of Tampere (Finland) and maintained in a standard virus/parasite-free facility, exposed to a 12-h light:12-h dark cycle. Lights were turned off at 18.00 h and on at 6.00 h. Animals were experimentally naïve and housed in the groups of 2–9 (depending on the strain). All mice were weaned at 21 days of age, and housed in clear plastic cages (425 mm × 245 mm × 185 mm, Scanbur, Sweden) on aspen chips bedding (4 mm × 4 mm × 1 mm, Tapvei Oy, Finland), with food and water freely available.

Hair loss was recorded by a highly experienced observer (intra-rater reliability >0.9) using a custom-made register. Each mouse was visually inspected on both the dorsal and ventral surfaces (Garner et al., 2004a) for at least 2 min. The following 5-point scale was used in the present study: 0, no barbering; 1, whisker removal or shortening (Figs. 1B right and 2A); 2, snout/face denuding (Fig. 1B middle); 3, individual bald patches on head and body (Fig. 1A middle); 4, multiple alopecic areas on head and/or body (Fig. 1A right); 5, severe alopecia including complete snout denuding and large pronounced alopecic areas on head and body (Fig. 2B). The observer was unaware of the genotype (except in cases when the strain could be easily recognized by coat color or body size, i.e. B6, NMRI). Hair loss was scored as barbering if the hair lesion was non-puritic, there was no scarring or scabbing around the lesion, and the animal was otherwise in good health and the fur (where present) was in good conditions (Garner et al., 2004a). For each individual strain, we analysed the number (%) of cages in which the barbering occurred and the average severity of barbering in each cage. In addition, for same-sex barbering (Experiments 1 and 3, see further) we analysed the percentages of barbers and barbered animals (of total animals of each strain). Barber animals were identified as the single intact mouse in the cage, according to (Sarna et al., 2000; Garner et al., 2004a).

In Experiment 1, we analysed social barbering in same-sex cages in BC, NMRI, B6 and S1 mice (average number of animals per cage: 2.8–4.6) housed socially for approximately 2.5 months since weaning. In Experiment 2, we examined the link between barbering and social rank, observing five cages with highly barbering NMRI strain. Twelve adult male mice (3–4 months old, previously housed individually for 1 month to stimulate inter-male aggression) were put together (two to three animals per cage). Five days later (necessary to establish social hierarchy), robust hair loss due to barbering was observed in 100% cages. These cages were observed for 1 h, recording barbering activity and aggressive encounters of each individual mouse (animals were identified by marking their tails with colors). Inter-male aggression was also assessed by analysing scarring on the hind limbs, base of the tail and rear flanks (Garner et al., 2004a). Each mouse was assessed individually for 2–4 min by the same experienced observer, and a score of 0 (intact skin) or a score of 1 (scarred/scubbed skin) were given for each of these areas. Total score was obtained from the sum of the score of each areas. Two weeks later, these mice were re-examined in order to examine altered severity of barbering and scarring in socially stabilized groups.

Experiment 3 studied sexual barbering in breeding groups (Table 2) consisting of one male and one to three females (1–4 for S1 + B6) of B6, S1, BC and NMRI strains (average female/male ratio: 2.2). Preliminary assessment of barbering in these mice was performed during the first 5 days; final observations were made 10 days after mating, as described above. Experiment 4 analysed barbering in same-sex cages (with approximately the same average animal density) of selected F1 hybrid mice (Table 3), housed socially since weaning for approximately 3 months.

In Experiment 5, using an additional mouse colony of approximately 20 adult male mice (University of Tampere, Finland), we assessed same-sex barbering in several other mouse strains, including A/J and F1 B6129SvJ (two to three animals per cage), showing interesting strain-specific patterns of barbering. Essentially the same animal housing and barbering assessment procedures were used for these animals.

In Experiment 6, based on earlier data showing barbering in lactating rats (Harkness, 2001), we assessed possible hair loss in lactating mice. Adult 3–3.5-month-old females of S1 and B6 strains ($n = 10$; five to seven pups per dam) were examined immediately after weaning, as described earlier. Experiment 7 examined the role of self-barbering in the Dalila effect, analysing the occurrence of fur barbering in S1, BC, B6 and NMRI males (3 months old, $n = 8$ in each group) housed individually for 3–4 weeks in small clear plastic cages (267 mm × 207 mm × 140 mm, Scanbur, Sweden) in the same facility.

All animal housing and experimental procedures used in this study were in full compliance with the European legislation on animal experimentation (86/609/EEC) and approved by the Ethical Committee of the University of Tampere (Finland).

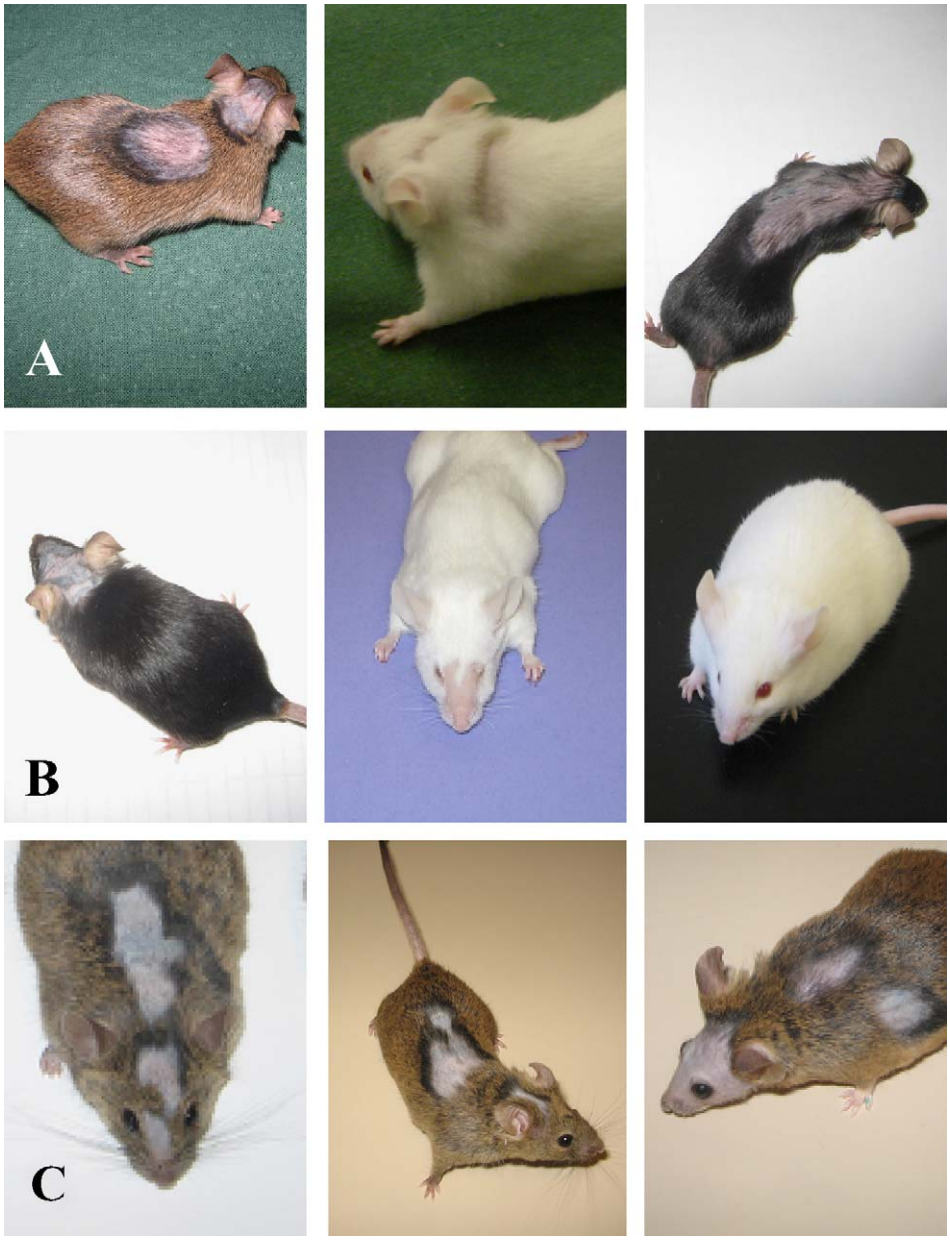

Fig. 1. Patterns of hair loss due to barbering in different mouse strains. (A) Sexual barbering by female barbers, left to right: 129S1, NMRI, C57Bl/6 males. (B) Social (dominant) barbering in same-sex cages, left to right: C57BL/6 females (whisker removal and bald patches on head and neck), NMRI females (nasal alopecia and snout denuding; see Fig. 2 for similar pattern in males), A/J males (shortened whiskers and intact fur). (C) Barbering in male mice of F1 hybrid strains, left to right: social stress-evoked barbering in NMRI-129S1 (no single barber, all mice equally affected), dominant barbering in C57BL/6-129S1 (seems to be a mixture of both parental styles, Fig. 2B and C), C57Bl/6-129SvJ mice (note severe complete face denuding specific for this strain, as well as multiple alopecic areas on the body).

3. Statistics

Data were analysed using two-way ANOVA (factors: strain, sex, Table 1) for social barbering and one-way ANOVA (factor: groups) for sexual and F1 barbering, followed by a post-hoc Mann–Whitney *U*-test. Scarring scores for NMRI mice (Experiment 2) and barbering occurrence in F1 NMRIS1 mice (Experiment 4) were analysed by Mann–Whitney *U*-test. In all tests, $P < 0.05$ was considered statistically significant.

4. Results

Overall, we found strong "social dominance" context of barbering in Experiment 1 (% barbering cages: $F(2, 35) = 6.04$, $P < 0.05$ between genotypes, $F(1, 35) = 40.2$, $P < 0.001$ between sexes, $F(2, 35) = 0.1$, $P < 0.001$ genotype × sex (Table 1). Robust dominant barbering was seen in NMRI (80–100% of cages, $P < 0.05$, *U*-test) but not BC (0%) or S1 (0–33%) adult mice socially housed since weaning. Mice of a highly aggressive BC strain (Wood, 2000; Van Loo et al., 2004; Kalueff and Tuohimaa,

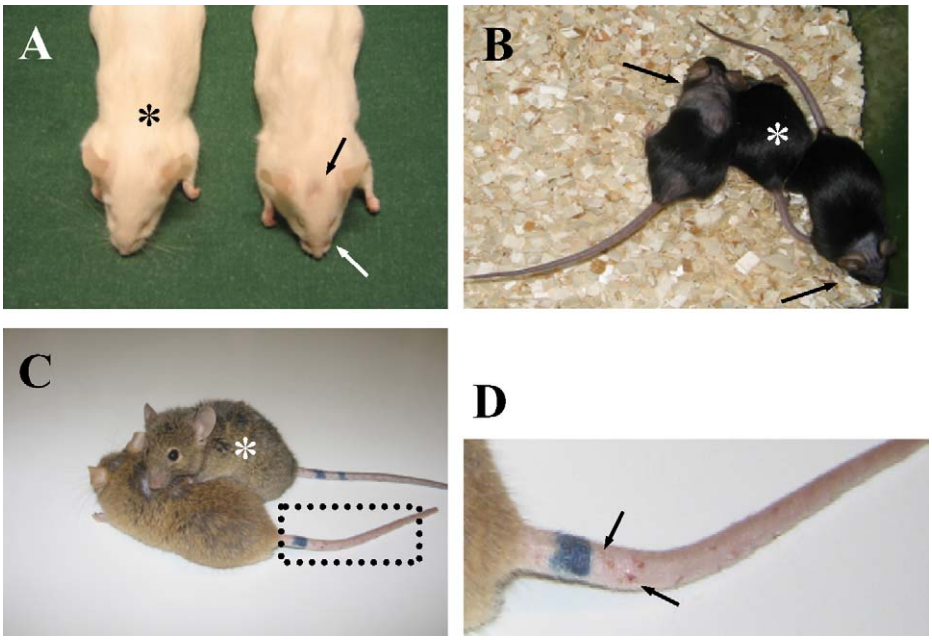

Fig. 2. Social barbering in adult male mice of different strains (dominant barbers indicated by asteriks). (A) NMRI mice. Note intact whiskers and fur in the dominant barber, and denuded snout, lacking whiskers and a bald patch between ears (indicated by arrows) in the recipient mouse. (B) C57Bl/6 mice. Note severe barbering of whiskers, head, neck and body (indicated by arrows) in two recipient animals. Barber is unaffected dominant male in the center. (C) Barbering in two F1 C57Bl/6–129S1 mice. Mouse tails are marked with colors; recipient is in subordinant prone position. Note that in some mice several biting scars (D, enlarged, indicated by arrows) could be seen on the base of their tails, indicating lower social rank. Barber is a bigger dominant male with intact fur and skin.

2005), never displayed barbering in the present study, despite active fighting and numerous scars, especially in male cages. In most cases, barbering targeted whiskers, face, head and body, and in all cages there was a single dominant animal whose fur and whiskers remained fully intact. In addition, we found interesting patterns of social barbering in several other strains, including whisker shortening in socially housed A/J and peculiar snout denuding in F1 B6129SvJ mice (Fig. 1B and C), also performed by a single intact barber (Experiment 5).

In adult NMRI mice housed socially for 5 days (Experiment 2, trial 1), barbering was observed in 100% of cages (Fig. 2A), developing within 2–5 days and including whiskers removal and snout/head denuding (average severity: 2.2 ± 0.3). During this time, active fighting occurred, and social hierarchy was established. Overall, barbers demonstrated significantly less scarring than did their barbered counterparts (average score: 0.2 ± 0.2 versus 1.8 ± 0.3, respectively; $P < 0.01$, U-test), showing clear correlation of barbering with social rank. Our 1-h homecage observations in these mice also confirmed that barbers were always the dominant animals more frequently engaged in attacking other males (barbers: 12 ± 2, non-barbers: 3 ± 1, $P < 0.05$, U-test) during the establishment of social hierarchy. Two weeks later (trial 2), pronounced barbering patterns (slightly more severe, average score: 3.1 ± 0.7) was observed in all cages, whereas no biting scars could be found in these mice, significantly differing from trial 1.

In Experiment 3, robust sexual barbering in breeding mice was seen in our experiments in S1 and B6 mice (genotype effect: $F(5, 44) = 3.6$; $P < 0.001$ (average barbering score); $F(5, 44) = 3.3$, $P < 0.05$ (% of cages with barbering); Table 2. Head, shoulders and flanks were the most barbered areas, and the overall severity was much higher compared to social barbering. In all

Table 1
Dominant (social) barbering in same-sex cages in 129S1 (S1), BALB/c (BC) and NMRI mice

Parameters	S1		BC		NMRI	
	Males	Females	Male	Females	Males	Females
Total number of animals	37	23	21	14	14	25
Number of cages used	8	6	5	4	5	8
Average animals per cage	4.6	3.8	4.2	3.5	2.8	3.2
% Cages with barbering	0 ± 0a	33 ± 21a	0 ± 0a	0 ± 0a	100 ± 0b	87 ± 13b
Average barbering score	0 ± 0a	3.8 ± 0.3b	0 ± 0a	0 ± 0a	2.4 ± 0.2b	2.1 ± 0.1b
% Barbers	0 ± 0a	9 ± 5a	0 ± 0a	0 ± 0a	36 ± 0b	28 ± 6b
% Barbered mice	0 ± 0a	30 ± 6b	0 ± 0a	0 ± 0a	64 ± 0b	62 ± 8b

Groups sharing common letters (a and b) are not statistically different ($P > 0.05$, U-test). ANOVA data (factor: strain) for male mice: average barbering score $F(2, 15) = 195.0$, $P = 0$; % barbers $F(2, 15) = 61.1$, $P = 0$; % barbered mice $F(2, 15) = 1460.0$, $P = 0$ and female mice: average barbering score $F(2, 15) = 80.0$, $P = 0$; % barbers $F(2, 17) = 4.2$, $P < 0.05$; % barbered mice $F(2, 17) = 17.3$, $P < 0.0001$.

Table 2
Sexual barbering in C57BL/6 (B6), 129S1 (S1), BALB/c (BC) and NMRI male and female mice

Breeding groups (males first)	*n*		*N*	F:M	Barbering score	% cages with barbering
	M	F				
S1 + S1	16	28	16	1.8	4 ± 1a	38 ± 13ac
S1 + B6	11	13	11	1.2	3 ± 0a	45 ± 16ac
BC + S1	5	19	5	3.2	0 ± 0b	0 ± 0b
S1 + BC	6	21	6	3.5	0 ± 0b	0 ± 0b
NMRI + S1	4	6	4	1.5	4 ± 1a	100 ± 0c
S1 + NMRI	3	5	3	1.7	2 ± 0a	33 ± 33abc

N, number of cages studied; *n*, number of animals. F:M, average female/male ratio. Groups sharing common letters (a–c) are not statistically different ($P > 0.05$, *U*-test). Note that female mice were barbers in all these experiments.

cases, barbering started with the whiskers removal (as assessed during the preliminary check), and within several days proceeded to face/snout and/or body denuding. Similar behaviour was observed when a male of one stain was kept together with female mice of other strains (e.g., NMRI + S1; S1 + B6). Interestingly, BC mice were not engaged in such barbering (Table 2), further confirming our observation that barbering is not a part of their behavioural repertoire (also see Militzer and Wecker, 1986).

Examining several hybrid mouse strains in Experiment 4, we found significant strain effect in these mice (% barbering cages: $F(9, 71) = 69.8$, $P < 0.001$; average barbering score: $F(9, 71) = 109.5$, $P < 0.0005$; % barbered animals: $F(9, 71) = 92.3$, $P < 0.0005$), with several barbering (e.g., BC × S1) and non-barbering (S1 × B6, S1 × NMRI) F1 strains (Table 3). While S1 × B6 hybrids displayed moderate 33–43% barbering (Fig. 2D), F1 derived from NMRI and S1 strains generally did not barber, if kept <5 animals per cage, showing 80–100% barbering in "overcrowded" cages containing five to nine mice ($P < 0.01$, *U*-test). In these cages, all animals were equally barbered, showing no apparent dominant barbers (Fig. 1C). Overall severity of this barbering was lower than in two previous contexts, predominantly showing snout denuding and whisker removal (scale 1–2), Table 3.

Examining "maternal" barbering in lactating mice performed by suckling pups (Experiment 6), we found that ≈25–30% of S1 and B6 mothers may display pronounced hair loss on their ventral surfaces, ranging from balding areas (B6) to complete fur removal (S1; Fig. 3). No hair loss was observed on head or dorsal surfaces of these female mice. Finally, in Experiment 7 we did not see any hair loss due to self-barbering (data not shown) in isolated mice of S1, BC, B6 and NMRI strains.

Table 3
Barbering in same-sex cages in mice of different F1 hybrid strains

Strain and sex	*n*	*N*	Av	% Cages with barbering	Barbering score	% Barbers	% Barbered animals
B6-S1 (M)	36	7	5.1	43 ± 20a	1.9 ± 0.3a	8.3 ± 2a	46 ± 17a
B6-S1 (F)	33	9	3.7	33 ± 17a	2.3 ± 0.4a	11 ± 3a	36 ± 16a
NMRI-S1 (M)	61	13	4.7	31 ± 13a	1.9 ± 0.3a	N/A	39 ± 11a
NMRI-S1 (F)	45	9	5.0	33 ± 17a	2 ± 0a	N/A	45 ± 18a
S1-NMRI (M)	23	7	3.3	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b
S1-NMRI (F)	25	7	3.6	14 ± 13ab	1.8 ± 0.1a	N/A	36 ± 36ab
S1-BC (M)	13	5	2.6	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b
S1-BC (F)	19	5	3.8	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b
BC-S1 (M)	15	4	3.8	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b
BC-S1 (F)	21	6	3.5	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b

Legend as in Table 2. M, males; F, females; Av, average number of animals per cage (*n*/*N*). N/A, data not available (in these mice in all cages where barbering was observed, all animals were equally barbered, and it was impossible to identify the barbers). Groups sharing common letters are not statistically different ($P > 0.05$, *U*-test between strains).

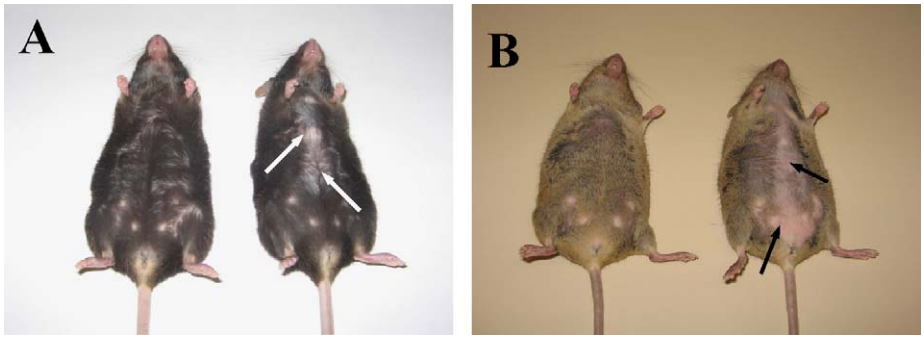

Fig. 3. "Maternal" barbering (produced by suckling pups) in lactating mice of C57BL/6 (A) and 129S1 (B) strains, photographed immediately after weaning. All dams have enlarged nipples, intact whiskers and unaffected fur on their dorsal surfaces. Note that ventral surfaces of some dams (A and B, left) may also remain unaffected, whereas pronounced alopecic areas can be seen in other females of the same strains (A and B, right, indicated by arrows): C57BL/6—balding patch with hair cut close to the skin; 129S1—large barbered area from tail to chin, including complete denuding of ano-genital region.

5. Discussion

In general, the most frequent location of hair loss observed here (snout, neck, head denuding) cannot be explained by self-barbering, clearly implying that this type of barbering did not occur in this study. Together with the lack of hair loss in single housed animals (Experiment 7), this allows to dissociate self- and hetero-barbering, clearly representing two different behavioural domains, and not a unitary phenomenon (but see Garner et al., 2004a,b). Although self-barbering may occur in some circumstances, our data suggest that it did not contribute to pronounced behaviour-associated hair loss in any of the strains examined in the present study.

Is barbering observed here a dominant behaviour? Although some researchers question this possibility (Garner et al., 2004a,b), our present findings in mice (Experiments 1 and 2; Table 1; Fig. 2) strongly support this notion, and coincide with numerous previously published studies (review in Sarna et al., 2000), showing single unaffected dominant barbers in all cages where social barbering occurred. In line with Long (1972), reporting barbering only after the social hierarchy has been established within the cage through aggression, our NMRI male mice (Experiment 2) displayed robust barbering after 2–5 days of active fighting in all cages. This barbering was always performed by a dominant mouse, the bigger animal with intact hair and skin, to subordinant losers (usually displaying numerous scars). Similar phenomenon was observed in F1 B6S1 males (Fig. 2), confirming clear correlation between barbering and social rank. Notably, mice are known to co-operate in barbering (Van den Broek et al., 1993), while the barber is as likely to approach as to be approached by a recipient (usually adopting a subordinate immobile posture, Sarna et al., 2000). In our study, all NMRI recipients did not try to escape, and were immobile in a prone posture, with eyes closed and ears pulled back. In contrast, NMRI male barbers performed barbering and allo-grooming by holding the recipient's head or restrained the recipient by laying on top of it (also see Fig. 2C for similar behaviour in F1 B6S1 mice). In NMRI females, social barbering was also robust (Table 1, Fig. 1B), and although similar dominant/subordinant postures were observed, their barbering was not accompanied by fighting; see similar data in (Sarna et al., 2000) for B6 mice.

Our homecage observations in NMRI mice also showed strong association between barbering and allo-grooming, since all barbering episodes observed here ended with an intense face/head allo-grooming performed by a barber. This confirms that barbering may arise as a product of grooming activity (Militzer and Wecker, 1986; Sarna et al., 2000), whose biological role evolved from mutual body care to maintaining social hierarchy in colonies. Since B6 and NMRI mice are known as relatively non-aggressive strains (MPD, 2001), we suggest that their intensive use of barbering in established groups (e.g., during long-term social housing; Table 1; Sarna et al., 2000; Garner et al., 2004a) serves to substitute aggression. Indeed, while both barbering and scarring were observed in newly established NMRI groups (Experiment 2), these mice showed pronounced barbering and no scarring 2 weeks later, when stable social organization was established. This suggests that barbering, and not aggression, may be an essential tool in some strains to maintain social hierarchy once it was established.

In line with this, S1 mice displayed mild barbering and moderate aggression (own homecage observations), whereas aggressive BC mice did not barber (Table 1). Moreover, no barbering was observed during mating of BC and S1 mice, and in their F1 progeny (also characterized by poor barbering (Table 3) and high aggressiveness; own homecage observations). Not surprisingly, ByJ sub-strain of BC mice shows both low aggression (Wood, 2000) and robust barbering (Jackson Laboratory, 1987). Taken together, all these observations support the idea that strain aggressiveness may negatively correlate with barbering activity (aggression: BC > F1 BCS1 > S1 > F1 S1NMRI ≫ NMRI; barbering: BC = F1 BCS1 = S1 < F1 S1NMRI ≪ NMRI, such as reported here).

In addition to social (dominant) barbering observed in same-sex cages in both males and female mice, we found robust sexual barbering in some mouse strains (Table 2). This context differed markedly from social barbering seen in same-sex cages because it occurred without fighting and did not reflect dominance (i.e. males were always barbered by females, apparently subordinant members of breeding groups). In addition, here we report "maternal" barbering produced in lactating S1 and B6 females by sucklings (Fig. 3), which was unique in targeting ventral body surfaces, usually unaffected by other barbering contexts described here. Previously reported in lactating rats (Harkness, 2001), this phenomenon is now confirmed in mice, further contributing to "ethological richness" and complexity of rodent barbering.

Several interesting observations can be made on behavioural genetics of barbering. For example, non-barbering BC genotype was generally preserved in F1 (Table 3), while crossing low-barbering S1 mice with high-barbering phenotype (NMRI) led to altered barbering patterns in F1 hybrids (lower social context, higher environmental context, Table 3). In contrast, B6 × S1 hybrids displayed moderate-barbering (Table 3; Fig. 1C) and mixed cutting styles of both parental strains (Fig. 2B and C). Together, these data suggest that BC genes are stronger than S1 genotype in influencing the mouse barbering, whereas S1 background may interact with B6 in an additive manner. Finally, NMRI and S1 backgrounds seem to interplay (having equally strong effects) in F1 progeny, whose barbering contexts differed markedly from both parental strains.

Importantly, distinct types of hair removal by barbers have been described in the literature (Sarna et al., 2000). While hair trimming is painless and does not affect follicle and skin receptors, plucking the whiskers out induces pain, affects follicular integrity and disrupts signaling between the receptors and nerve terminals (Prchal et al., 2004). In our study, mice did not show hair plucking, demonstrating "painless" whisker-cutting (accompanied by snout denuding). This is particularly evident in A/J mice with shortened whiskers, and B6129SvJ hybrids, whose extremely sophisticated barbering style may not be attributed to hair plucking (Fig. 1B and C). Collectively, this underlines the heterogeneity of both hair-loss styles

and hair-removing behaviours in different mouse strains (Sarna et al., 2000; see Figs. 1–3 for the diversity of barbering patterns observed in the present study).

Can barbering be a form of stress response? Indeed, snout denuding was almost invariably seen in "overcrowded" cages with F1 NMRIS1 mice (Table 3), but was not seen in these mice kept two to four per cage. Clearly, this pattern of barbering was highly sensitive to environmental stress, and differed from all barbering contexts reported previously, confirming the mouse barbering sensitivity to various external factors (also see: De Luca, 1997; McElwee et al., 1999 for discussion).

Interestingly, the percentage of hair-barbering varies widely from strain to strain. For example, the BC mice showed no barbering (Table 1), in contrast to ≈20% of B6 and A/J (Long, 1972; Landau et al., 2001), ≈75% of A2G (Strozik and Festing, 1981), and ≈80–100% of NMRI mice (Table 1). Sarna et al. (2000) have recently reported that B6 mice may demonstrate individual "cutting styles". In our study, mice also displayed strain- and context-specific cutting (Figs. 1 and 2), further supporting the idea of complexity and multi-factorial nature of barbering. For example, given the regional specificity of pheromonal release, and their role in social, sexual, maternal and stress-evoked rodent behaviours (Makarchuk and Kalueff, 2000; Kiyokawa et al., 2004), different pheromones may control barbering, underlying its complex patterning in various strains in different contexts (Figs. 1–3).

Several neurobehavioural consequences of barbering, especially devibrissation, may include altered cortex plasticity (Maier et al., 2003), "tonic" modulation of neuronal excitability (Prchal et al., 2004), social and motor activity (Ehrenlechner and Unshelm, 1997) and emotional reactivity (Kozlovskii and Prakh'e, 1995; Kozlovskii et al., 1997). In addition, barbering (an important part of mouse agonistic interactions; Jackson Laboratory, 1987) may be impossible in hairless mice with mutation-induced hair/skin anomalies (e.g., Kuljis, 1992; Kalueff et al., 2004a,b). Unable to establish social hierarchy through barbering, such mice may develop non-specific pathological behaviours, including impaired cognitions, exploration and social interaction. Moreover, several known mouse mutations display aberrant barbering phenotypes (MGI, 2001; Sirito et al., 1998; Glynn et al., 2003). For example, poor-barbering mutants show impaired social interaction, representing genetic models of human abnormal social behaviours (Lijam et al., 1997; Long et al., 2004; Kassed and Herkenham, 2004). In contrast, mutants with increased barbering (e.g., Holmes et al., 2002a,b) display predictably lower aggression. Taken together, these findings indicate the potentially important behaviour-modulating role of barbering in rodents.

In conclusion, we view barbering as an essential part of mouse social, sexual and maternal behaviour, in some strains representing an important behavioural phenotype (also see: Jackson Laboratory, 1987). We suggest that the Dalila effect is a complex behavioural phenomenon with multiple mechanisms, underlying neural substrates, forms and contexts, collectively underlying the utility of rodent barbering analysis as a rich source of information about normal and abnormal brain functions.

Acknowledgements

This research was supported by the grants from Tampere University, the Medical Research Council of Tampere University Hospital and the Academy of Finland.

References

Ahl, A.S., 1986. The role of vibrissae in behavior: a status review. Vet. Res. Commun. 10, 245–268.

Beare-Rogers, J.L., McGowan, J.E., 1973. Alopecia in rats housed in groups. Lab. Anim. 7, 237–238.

Belzung, C., 1999. Measuring rodent exploratory behavior. In: Cruzio, W.E., Gerlai, R.T. (Eds.), Handbook of Molecular-Genetic Techniques for Brain and Behavior Research, vol. 13. Elsevier, Amsterdam, pp. 738–749.

Bresnahan, J.F., Kitchell, B.B., Wildman, M.F., 1983. Facial hair barbering in rats. Lab. Anim. Sci. 33, 290–291.

Carruthers, E.L., Halkin, S.L., King, T.R., 1998. Mouse barbering: investigations of genetic and experimental control. Anim. Behav. Soc. Abstr., 41.

Crawley, J.N., Paylor, R., 1997. A proposed test battery and constellations of specific behavioral paradigms to investigate the behavioural phenotypes of transgenic and knockout mice. Horm. Behav. 31, 197–211.

Crawley, J.N., Belknap, J.K., Collins, A., Crabbe, J.C., Frankel, W., Henderson, N., Hintzemann, R.J., Maxson, S.C., Miner, L.L., Silva, A.L., Wehner, J.M., Wynshaw-Boris, A., Paylor, R., 1997. Behavioral phenotypes of inbred mouse strains: implications and recommendations for molecular studies. Psychopharmacology 132, 107–124.

Crawley, J.N., 1999. Behavioral phenotyping of transgenic and knockout mice: experimental design and evaluation of general health, sensory functions, motor abilities, and specific behavioral tests. Brain Res. 835, 18–26.

De Luca, A.M., 1997. Environmental enrichment: does it reduce barbering in mice? AWIC Newslett. 8, 7–8.

Ehrenlechner, S., Unshelm, J., 1997. Whisker trimming by mother cats. Appl. Anim. Behav. Sci. 52, 281–285.

Garner, J.P., Dufour, B., Gregg, L.E., Weisker, S.M., Mench, J.A., 2004a. Social and husbandry factors affecting the prevalence and severity of barbering ("whisker trimming") by laboratory mice. Appl. Anim. Lab. Sci. 89, 263–282.

Garner, J.P., Weisker, S.M., Dufour, B., Mench, J.A., 2004b. Barbering (fur and whisker trimming) by laboratory mice as a model of human trichotillomania and obsessive-compulsive spectrum disorders. Comp. Med. 54, 216–224.

Gerold, S., Huisinga, E., Iglauer, F., Kurzawa, A., Morankic, A., Reimers, S., 1997. Influence of feeding hay on the alopecia of breeding guinea pigs. Zentral. Veterinarmed. Arch. 44, 341–348.

Glynn, D., Bortnick, R.A., Morton, A.J., 2003. Complexin II is essential for normal neurological function in mice. Hum. Mol. Genet. 12, 2431–2448.

Greer, J.M., Capecci, M.R., 2003. Hoxb8 is required for normal grooming behaviour in mice. Neuron 33, 23–34.

Harkness, J.E., 2001. What is your diagnosis? Hair loss in lactating rats. Barbering by damor sucklings. Lab. Anim. 30, 21–22.

Hauchka, T.S., 1952. Whisker-eating mice. J. Hered. 43, 77–80.

Holmes, A., Murphy, D., Crawley, J., 2002a. Reduced aggression in mice lacking the serotonin transporter. Psychopharmacology 161, 160–167.

Holmes, A., Yang, R.J., Murphy, D., Crawley, J., 2002b. Evaluation of antidepressant-related behavioral responses in mice lacking the serotonin transporter. Neuropsychopharmacology 27, 914–923.

Jackson Laboratory, 1987. Alopecia (loss of hair) in C57BL/6J and related strains. JAX Notes 431, 1–2.

Kalueff, A.V., Tuohimaa, P., 2005. Contrasting grooming phenotypes in three mouse strains markedly different in anxiety and activity (129S1, BALB/c and NMRI). Behav. Brain Res. 160, 1–10.

Kalueff, A.V., Lou, Y.-R., Laaksi, I., Tuohimaa, P., 2004a. Increased anxiety in mice lacking vitamin D receptor gene. Neuroreport 15, 1271–1274.

Kalueff, A.V., Lou, Y.-R., Laaksi, I., Tuohimaa, P., 2004b. Increased grooming behaviour in mice lacking vitamin D receptors. Physiol. Behav. 82, 405–409.

Kassed, C.A., Herkenham, M., 2004. NF-kB p50-deficient mice show reduced anxiety-like behaviors in tests of exploratory drive and anxiety. Behav. Brain Res. 154, 577–584.

Kiyokawa, Y., Kikusui, T., Takeuchi, Y., Mori, Y., 2004. Alarm pheromones with different functions are released from different regions of the body surface of male rats. Chem. Senses 29, 35–40.

Kozlovskii, V.L., Prakh'e, I.V., 1995. Diazepam eliminates the anxious state induced by amputation of the vibrissae (a model for assessing anxious behavior). Zh. Vysh. Ner. Deiat. 45, 1057–1061.

Kozlovskii, V.L., Mosin, A.E., Ivakina, L.V., 1997. The effect of calcium channel blockers on anxiety evoked by amputation of the vibrissae in rats. Eksp. Klin. Farmakol. 60, 10–12.

Kuljis, R.O., 1992. Vibrissaeless mutant rats with a modular representation of innervated sinus hair follicles in the cerebral cortex. Exp. Neurol. 115, 146–150.

Landau, J.M., Wang, Z.-Y., Yang, G.-U., Ding, W., Yang, C., 2001. Inhibition of spontaneous formation of lung tumors and rhabdomyosarcomas in A/J mice by black and green tea. Carcinogenesis 19, 501–507.

Lijam, N., Paylor, R., McDonald, M., Crawley, J.N., Deng, C.-X., Herrup, K., Stevens, C.J., Maccaferti, G., McBain, C.J., Sussman, D.J., 1997. Social interaction and sensorimotor gating abnormalities in mice lacking Dvl1. Cell 90, 895–905.

Long, S.Y., 1972. Hair-nibbling and whisker-trimming as indicators of social hierarchy in mice. Anim. Behav. 20, 10–12.

Long, J.M., LaPorte, P., Wynshaw-Boris, A., 2004. Expanded characterization of the social interaction abnormalities in mice lacking Dvl1. Genes Brain Behav. 3, 51–62.

Maier, D.L., Grieb, G.M., Stelzner, D.J., McCasland, J.S., 2003. Large-scale plasticity in barrel cortex following repeated whisker trimming in young adult hamsters. Exp. Neurol. 184, 737–745.

Makarchuk, N.E., Kalueff, A.V., 2000. Olfaction and behaviour. KSF, Kiv, 148 pp.

McElwee, K.L., Boggess, D., Miller, J., King, L.E., Sundberg, J.P., 1999. Spontaneous alopecia areata-like hair loss in one congenic and seven inbred laboratory mouse strains. J. Investig. Dermatol. Symp. Proc. 4, 202–206.

Meyer, M.E., Meyer, M.E., 1992. The effects of bilateral and unilateral vibrissotomy on behavior within aquatic and terrestial environments. Physiol. Behav. 51, 877–880.

Militzer, K., Wecker, E., 1986. Behavior-associated alopecia-areata in mice. Lab. Anim. 20, 9–13.

MGI, Mouse Genome Informatics Database (http://www.informatics.jax.org), 2001. The Jackson Laboratory, Bar Arbor, Mainne, USA, July 2005.

MPD, Mouse Phenome Database (http://aretha.jax.org), 2001. The Jackson Laboratory, Bar Arbor, Mainne, USA, May 2005.

Myers, D.D., 1997. C57BL/6J update—C57BL/6J skin lesion problem eliminated. JAX Mice Animal Health Bull.

Prchal, A., Albarracin, A.L., Decima, E.E., 2004. Blockage of vibrissae afferents. I. Motor effects. Arch. Ital. Biol. 142, 11–23.

Prigg, T., Goldreich, D., Carvell, G.E., Simons, D.J., 2002. Texture discrimination and unit recordings in the rat whisker/barrel system. Physiol. Behav. 77, 671–675.

Reinhardt, W., Militzer, K., 1979. Schnurrbartbeishen" (whisker trimming) und sozialer rang bei mausen. Z. Versuchstierkd. 21, 83–91.

Sarna, J.R., Dyck, R.H., Whishaw, I.Q., 2000. The Dalila effects: C57BL6 mice barber whiskers by plucking. Behav. Brain Res. 108, 39–45.

Sirito, M., Lin, Q., Deng, J.M., Behringer, R.R., Sawadogo, M., 1998. Overlapping roles and asymmetrical cross-regulation of the USF proteins in mice. Proc. Natl. Acad. Sci. U.S.A. 95, 3758–3763.

Staiger, J.F., Bisler, S., Schleicher, A., Gass, P., Stehle, J.H., Zilles, K., 2000. Exploration of a novel environment leads to the expression of inducible transcription factors in barrel-related columns. Neuroscience 99, 7–16.

Strozik, E., Festing, M.F.W., 1981. Whisker trimming in mice. Lab. Anim. 15, 309–312.

Van de Weerd, H.A., Van den Broek, F.A.R., Beynen, A.C., 1992. Removal of the vibrissae in male mice does not influence social dominance. Behav. Processes 27, 205–208.

Van den Broek, F.A.R., Omzight, C.M., Beynen, A.C., 1993. Whisker trimming behaviour in A2G mice is not prevented by offering means of withdrawal from it. Lab. Anim. 27, 270–272.

Van Loo, P.L., Van der Meer, E., Kruitwagen, C.L., Koolhaas, J.M., Van Zuphen, L.F., Baumans, V., 2004. Long-term effects of husbandry procedures on stress-related parameters in male mice of two strains. Lab. Anim. 38, 169–177.

Vincent, B.S., 1912. The function of vibrissae in behaviour of white rat. Behav. Monogr. 1, 7–81.

Wang, Y., Tan, J., Sutton-Smith, M., Ditto, D., Panico, M., Campbell, R.M., Varki, N.M., Long, J.M., Jaeken, J., Levinson, S.L., Wynshaw-Boris, A., Morris, H.R., Le, D., Dell, A., Schachter, H., Marth, J.D., 2001. Modeling human congenital disorder of glycosylation type IIa in the mouse: conservation of asparagine-linked glycan-dependent functions in mammalian physiology and insights into disease pathogenesis. Glycobiology 11, 1051–1070.

Whishaw, I.Q., Metz, G.A.S., Kolb, B., Pellis, S.M., 2001. Accelerated nervous system development contributes to behavioral efficiency in the laboratory mouse: a behavioral review and theoretical proposal. Dev. Psychobiol. 39, 151–170.

Wood, P.A., 2000. Phenotype assessment: are you missing something? Comp. Med. 50, 12–15.