

RESEARCH ARTICLE

Hair Plucking, Stress, and Urinary Cortisol Among Captive Bonobos (*Pan paniscus*)

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Hair plucking has been observed in many captive primate species, including the great apes; however, the etiology of this behavioral pattern is poorly understood. While this behavior has not been reported in wild apes, an ethologically identical behavior in humans, known as trichotillomania, is linked to chronic psychosocial stress and is a predominantly female disorder. This study examines hair plucking (defined here as a rapid jerking away of the hair shaft and follicle by the hand or mouth, often accompanied by inspection and consumption of the hair shaft and follicle) in a captive group of bonobos ($N = 13$) at the Columbus Zoo and Aquarium in Columbus, Ohio. Plucking data were collected using behavior and all-occurrence sampling; 1,450 social and self-directed grooming bouts were recorded during 128 hr of observation. Twenty-one percent of all grooming bouts involved at least one instance of plucking. Urine samples ($N = 55$) were collected and analyzed for the stress hormone cortisol. Analyses of urinary cortisol levels showed a significant positive correlation between mean cortisol and self-directed plucking for females ($r = 0.88$, $P < 0.05$) but not for males ($r = -0.73$, $P = 0.09$). These results demonstrate an association between relative self-directed hair plucking and cortisol among female bonobos. This is the first study to investigate the relationship between hair plucking and cortisol among apes. Overall, these data add to our knowledge of a contemporary issue in captive ape management. Zoo Biol. 35:415–422, 2016. © 2016 Wiley Periodicals, Inc.

Keywords: undesirable behavior; glucocorticoid; trichotillomania

INTRODUCTION

Over the last several decades, endocrinology has become an invaluable tool in the study of both wild and captive animal populations. Hormonal data have been critical to supplementing behavioral observations and have been used extensively in understanding reproductive physiology and social behavior (e.g., Muller and Wrangham, 2004; Carlstead and Brown, 2005). Physiological markers, particularly the glucocorticoid hormone cortisol, have also been used in captive studies as measures of psychosocial stress and overall well-being [Möstl and Palme, 2002]. Early research on physiological markers in non-human animals focused on domesticated taxa [for review see Palme, 2012]. The subsequent application of these techniques in zoo-housed animals has resulted in research conducted on many species including black rhinoceros [Carlstead and Brown, 2005], clouded leopard [Wielebnowski et al., 2002], polar bears [Shepherdson et al., 2013], and western lowland gorillas [Clark et al., 2012]. See Hill and Broom [2009] for

review of this literature. While these biomarkers can be used in isolation, when used in conjunction with behavioral data they provide a more complete picture of particular behavioral patterns. Additionally, biomarkers such as cortisol can help explain the etiology of stereotypic behaviors such as pacing in captive polar bears [Shepherdson et al., 2013].

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Glucocorticoids are a group of steroid hormones produced by the adrenal glands, released in response to stress [Selye, 1956; Sapolsky et al., 2000]. Cortisol and corticosterone—the most common glucocorticoids in vertebrates [Wasser et al., 2000]—can be measured from various biological substances, including blood, saliva, feces, urine, hair, and tissue samples [Sheriff et al., 2011]. Blood, saliva, and tissue samples are generally difficult to obtain for both captive and wild animals as acquiring these samples often requires anesthetizing an animal, which by itself is a stress-inducing process (but see Lutz et al., 2000). Non-invasively collected samples arguably do not induce a stress response since their collection does not require anesthetization. Samples can be collected from captive animals once they have been shifted from an enclosure, from wild animals during focal follows, or collected opportunistically. Glucocorticoids are very useful and offer a compelling and commonly used tool in animal research. First, different types of stress (acute versus chronic) can be evaluated in an individual depending on the sample type used. Second, analysis of glucocorticoids can also help identify particular aspects of the environment that are stressful, such as food scarcity. Finally, hormone dysregulation can also be linked to downstream effects on health [Glaser and Kiecolt-Glaser, 2005].

There are, however, several disadvantages to using glucocorticoids as markers of stress. One particular issue is a lag time between the perceived stressor and the excretion of glucocorticoid metabolites [Schwarzenberger et al., 1996]. This lag time is species-specific and differs based on a sample type. For most primate species, the lag time in fecal samples is approximately 24–48 hr [Schwarzenberger et al., 1996] while it is much shorter for urinary samples (less than 6 hr) [Kraan et al., 1992] and even shorter in blood and saliva samples. Another methodological challenge is that glucocorticoid levels also exhibit a circadian rhythm best known from the human diurnal pattern and its cortisol awakening response [Pollard and Ice, 2007]. Chronic stress does not necessarily always lead to elevated glucocorticoid levels but may also result in diminished or dysregulated activity of the HPA (hypothalamic–pituitary–adrenal axis) and alteration of the diurnal rhythm [Ostrander et al., 2006]. Finally, while the term “stress” is often associated with a negative response, acute physiological responses cannot be regarded as “positive” or “negative” without behavioral context [Clark et al., 2012]. Behavior such as mating, pursuit, or play may result in transiently elevated glucocorticoid levels [Broom and Johnson, 1993], yet these are not regarded as stress-induced or negative behaviors. While acute stress often requires behavioral context, chronic stress is generally considered negative given its effects on glucocorticoid dysregulation and downstream effects on health. On balance, despite the challenges of analyzing and interpreting glucocorticoid data, the results produced are essential to elucidating the impact of the physical and social environment on behavioral patterns.

In the present study, we measured glucocorticoid concentrations, specifically the hormone cortisol, and its relation to a specific undesirable behavior: hair plucking. Hair plucking, also described as hair pulling or fur pulling, has been observed in many species including mice, guinea pig, rabbit, sheep, musk oxen, and non-human primates [Reinhardt, 2005]. The behavior itself is a distinct motor pattern and is often observed during a grooming bout or occurs periodically outside of a grooming bout [Brand and Marchant, 2015]. In most species, the behavior is predominately self-directed, although it may be directed at another individual, and is of particular interest because it occurs in laboratory and captive animals [Reinhardt, 2005].

Among non-human primates, at least one individual from seven species was observed to hair pluck in a survey of British and Irish zoos [Hosey and Skynner, 2007]. Among the great apes, the behavior has been noted to occur in every captive species: orangutans (genus *Pongo*) [Zucker et al., 1978; Edwards and Snowdon, 1980], gorillas (*Gorilla gorilla gorilla*) [Pizzutto, 2007; Hill and Broom, 2009; Clark et al., 2012; Less et al., 2013], chimpanzees (*Pan troglodytes*) [Nash et al., 1999; Pomerantz and Terkel, 2009; Birkett and Newton-Fisher, 2011; Ferdowsian et al., 2012], and bonobos (*P. paniscus*) [Miller and Tobey, 2012; Brand and Marchant, 2015]. To date, few studies have directly focused on this particular behavior. Hair plucking has been most studied in laboratory-housed Rhesus macaques (*Macaca mulatta*) (e.g., Reinhardt et al., 1986; Lutz et al., 2013). The behavior is both social and self-directed and suggested to be stress-induced. Lutz et al. [2013] highlight a sex difference observed in their study; the behavior was predominately female-biased. Less et al. [2013] conducted a survey of hair plucking among western lowland gorillas housed at Association of Zoos and Aquariums (AZA) institutions across the United States. Their large sample included 36 institutions and 240 gorillas. Hair plucking was largely self-directed. The authors note that the only variable to positively correlate with hair plucking in gorillas is early exposure to the behavior indicating that observation of the behavioral pattern may contribute to developing the behavior.

While hair plucking occurred in 15% of gorillas surveyed in the Less et al. [2013] study, hair plucking in bonobos is believed to be much more prevalent within the captive population. Brand and Marchant [2015] studied hair plucking among the bonobos housed at the Columbus Zoo and Aquarium. Over a 4-month study period, 9 of the 17 bonobos (53%) were observed to hair pluck and the behavior occurred relatively frequently, during 21% of grooming bouts. The wild-born individuals and infants, however, were never observed to hair pluck themselves or another individual. No sex difference was observed in daily mean plucking scores (the proportion of grooming bouts that involved hair plucking); however, adolescent males plucked significantly more than adult males. Plucking scores were significantly lower on days when individual bonobos were

outdoors versus indoors. Grooming also occurred more frequently indoors versus outdoors, thus increased plucking rates indoors would be expected given higher grooming rates. Social conditions such as party size and composition may also contribute to the occurrence of this behavior. Additionally, it was observed that the dominant male and female engaged in self-directed hair plucking more frequently than others. The authors speculated that the stress associated with a high dominance rank may contribute to the occurrence of this behavior.

In the present study, we chose to analyze hair plucking separately in self-directed grooming bouts and social grooming bouts. While grooming is used to maintain an individual's hygiene, the hygiene of others, and thermoregulate [McFarland et al., 2016], grooming also plays a critical social role for primates [McKenna, 1978]. The functional differences in grooming may also apply to hair plucking. Many stereotypical and abnormal behaviors in socially housed captive animals are considered to be stress induced [Mason et al., 2007]. Indeed, the human equivalent of hair plucking, trichotillomania, is categorized as an obsessive-compulsive disorder and is generally thought to be stress induced [Duke et al., 2010; American Psychiatric Association, 2013]. While this may explain self-directed plucking in captive non-human primates, the etiology of social hair plucking is unknown and may vary by species. Macaques are known to socially hair pull; however, this behavior is often agonistic and is frequently directed down the dominance hierarchy [Reinhardt et al., 1986]. Social hair plucking in bonobos is not aggressive and does not result in crouching or flinching by the recipient [Brand and Marchant, 2015].

There were two research objectives for this study. First, we sought to distinguish between self-directed and social hair plucking and assess inter-individual differences in relative occurrence. The second objective was to test for a relationship between the occurrence of plucking and urinary cortisol levels. We hypothesized that individuals that frequently hair plucked would exhibit high levels of cortisol. Novak et al. [in press] examined changes in coat condition and hair cortisol among

captive rhesus macaques and found that female macaques that gained hair had reduced cortisol concentrations over an 8-month study period. Using urinary cortisol as a biomarker for physiological stress, we can determine if hair plucking is associated with chronic stress among captive bonobos.

METHODS

Study Approval

Behavioral research and hormone analyses were conducted with the approval of the Columbus Zoo and Aquarium (CZA). The CZA is accredited by the American Association of Zoos and Aquariums (AZA) and adheres to the highest standards for animal care. This research was also approved by the University of Oregon Institutional Animal Care and Use Committee (IACUC) (#11-10RA).

Study Subjects

Subjects for this study were 17 bonobos (four wild-born, 13 captive born) housed at the Columbus Zoo and Aquarium (CZA) (Table 1). Using Kano's [1992] age class definitions (infant: 0–1, juvenile: 2–6, adolescent: 7–14, adult: ≥ 15) the study subjects included four adult males, four adult females, two adolescent males, two adolescent females, one juvenile male, two juvenile females, one infant male and one infant female. The infant female was born during the study period. Four subjects (one juvenile female, one juvenile male, and two infants) were excluded from our analyses because hair plucking was never observed in these individuals.

The CZA bonobos reside in one outdoor yard and two indoor exhibits. Additionally, the zoo maintains three off-exhibit outdoor enclosures and four off-exhibit indoor enclosures. For exhibit dimensions and descriptions, see Boose et al. [2013]. The bonobos are managed using a fission–fusion management style. Bonobos are given access to one another every few days and form parties based on their preferences. All combinations are possible with the

TABLE 1. Study subjects

ID	Sex	Age class	Number of cortisol samples	Number of grooming bouts
1 (F) ^b	Female	Adult	5	308
2 (F)	Female	Adult	3	187
3 (F)	Female	Adolescent	4	109
4 (M)	Male	Adolescent	3	109
5 (F)	Female	Adult	7	108
6 (M)	Male	Adult	5	101
7 (M)	Male	Adult	2	91
8 (M)	Male	Adult	3	79
9 (M)	Male	Adult	3	78
10 (F)	Female	Adolescent	4	77
11 (M) ^a	Male	Adolescent	5	73
12 (F)	Female	Juvenile	5	61
13 (F)	Female	Adult	6	47

^aDenotes the dominant male and ^bthe dominant female.

exception of two males, who are not housed together due to previous conflicts. Three parties are typically formed which range in size from two to twelve individuals. These parties often remain stable for two to three days before changing composition.

Behavioral Data

Grooming data were collected by CMB on 49 days between May and August 2012 between 9:00 and 19:00 hr. Data were collected using a group focal, all occurrence, in 15 min sample periods [Altmann, 1974]. The active groomer, recipient of the grooming, duration of grooming bout (in seconds), and the occurrence of plucking were recorded. We defined hair plucking as a rapid jerking away of the hand or mouth to remove the hair shaft and follicle, often accompanied by inspection and consumption of the hair shaft and follicle [Brand and Marchant, 2015]. Plucking was recorded using one-zero sampling [Altmann, 1974] and thus reported frequencies are a minimum estimate of the incidence of plucking in this colony. Hair plucking that occurred outside of grooming bout was recorded ad libitum; however, the behavior occurred so infrequently outside of grooming bouts we do not include those data in this analysis. We defined a grooming bout as a period of investigation of the hair using hand, mouth, or both [Franz, 1999]. A bout was considered finished with a pause of 30 or more seconds of activity. All grooming bouts were categorized as either self-directed or social. When categorizing grooming bouts, instances in which an individual switched from self-directed to social grooming or social to self-directed grooming were only considered a new bout if the new bout persisted for longer than 15 sec (e.g., periodic events of self grooming during social grooming were not considered separate bouts or vice-versa). In this analysis, we focus on the active groomer (or hair plucker) during social grooming rather than the recipient.

Cortisol Data

Urine samples were collected as part of the keeper's routine urine collection protocol. We used samples collected during the same time period as the behavioral data (May through August 2012). The bonobos are trained to urinate when prompted and urine is collected in a container or pipetted off of a clean floor. Both salivary and urinary cortisol exhibit a circadian rhythm in bonobos [Behringer et al., 2009; Squires et al., 2015]; thus, we used a mean value of urinary cortisol per individual from samples collected during both the morning and afternoon across the study period. Samples were immediately frozen and sent at a later time to the Snodgrass Human Biology Research Laboratory at the University of Oregon and stored at -80°C until analysis. Samples were assayed using the DetectX[®] Cortisol Enzyme Immunoassay kit (Catalog numbers: K002-H5 and K003-H5) from Arbor Assays (Ann Arbor, MI). All samples were additionally assayed for creatinine using the DetectX[®]

Creatinine Urinary Detection kit (Catalog number K002-H1) from Arbor Assays and standardized to mg of creatinine in order to account for variation in urine concentration.

Statistical Analyses

All data were tested for normality using a Shapiro-Wilk test with a 0.05 level of significance. All hair plucking and cortisol data were normally distributed. We tested for interactions between sex and plucking status (individuals who hair plucked versus those that did not) using a two-way ANOVA. We correlated the number of grooming bouts that involved hair plucking with mean urinary cortisol levels per individual for self-directed grooming bouts and social grooming bouts. We calculated Pearson correlation coefficients, using a level of significance of 0.05. We discriminated by sex to test for differences between males and females. All statistical analyses were conducted using SAS[®] Version 9.4 (Cary, NC).

RESULTS

Hair Plucking

One hundred twenty-eight hours of behavioral data were collected during the study period. A total of 1450 self-directed and social grooming bouts were recorded. The percentage of plucking in grooming overall ranged from 9% to 53% across all individuals. The percentages of self-directed and social grooming bouts that involved plucking per individual are displayed in Figure 1. All individuals who hair plucked engaged in both self-directed and social hair plucking.

Cortisol Levels

Fifty-five urine samples were collected in total during the study period, averaging 4.2 samples per individual (range: 2–7). The mean inter-sample collection period was 19 days across all 13 individuals and ranged from 7 to 49 days per individual. Urinary cortisol levels varied considerably among individuals during the 4-month study period. Overall, levels ranged from 250 to 1381 pg/mg of creatinine across all individuals. Figure 2 highlights the mean level and standard error for each individual. Our comparison of mean cortisol levels between individuals who were never observed to pluck and those who did hair pluck yielded no significant difference between groups ($F = 0.94$, $df = 1$, $P = 0.35$). The difference in mean cortisol between the sexes was also non-significant ($F = 0.95$, $df = 1$, $P = 0.12$). The interaction between mean cortisol between sex and plucking status approached significance ($F = 3.75$, $df = 1$, $P = 0.08$).

Correlation Between Plucking and Cortisol Level

Correlation results are presented in Table 2. Female bonobos exhibited a strong, significant positive relationship ($P < 0.05$, $r = 0.87829$) between the number of self-directed

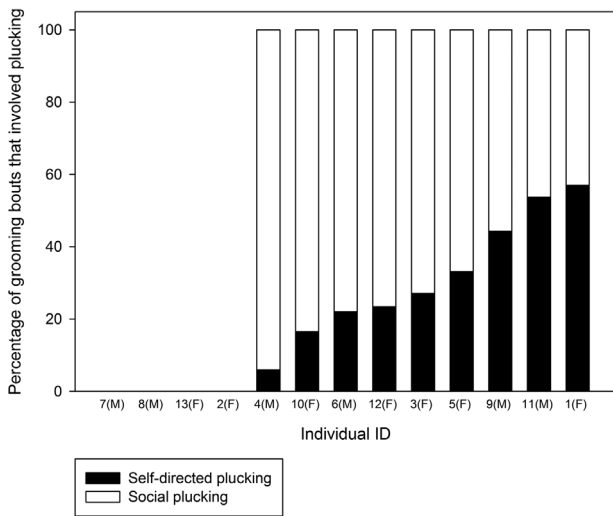


Fig. 1. Percentage of self-directed grooming bouts that involved self-directed hair plucking versus social grooming bouts that involved social hair plucking per individual.

grooming bouts with hair plucking and urinary cortisol level (Fig. 3). Individuals who self hair plucked more exhibited higher levels of cortisol. No such relationship was detected in the males ($r = -0.73$, $P = 0.09$). It should be noted that males exhibited a non-significant, yet strong, negative relationship between the variables. That is, individuals who self plucked more often had lower levels of cortisol and vice versa. No significant correlations were found among either sex between the number of social plucking grooming bouts with plucking and cortisol.

DISCUSSION

All individuals that engaged in hair plucking engaged in both self-directed and social plucking. However, there was considerable inter-individual variation in the relative frequency of each type of plucking. One variable that may

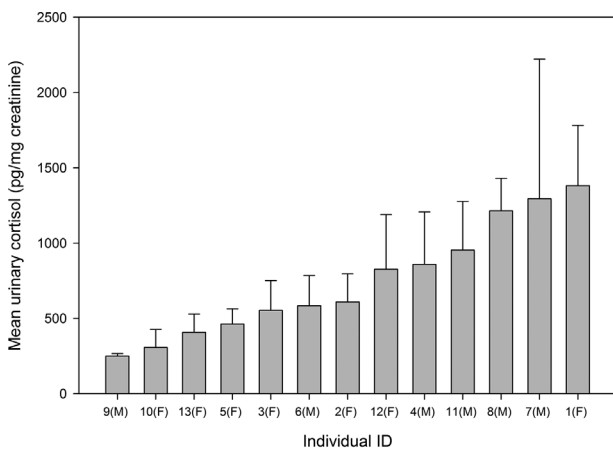


Fig. 2. Mean urinary cortisol levels per individual. Error bars represent standard error across all samples per individual.

TABLE 2. Correlation analysis

Type of plucking	Sex	<i>r</i>	<i>P</i>
Self-directed plucking	Female	0.87829*	0.0093*
	Male	-0.73208	0.0981
Social plucking	Female	0.63174	0.1280
	Male	-0.23951	0.6476

*Indicates statistically significant result ($P < 0.01$).

increase the occurrence of self-directed plucking is high dominance rank. As previously reported, self-directed hair plucking was most common in the dominant male and female individual [Brand and Marchant, 2015]. This observation may suggest stress associated with high rank [Sapolsky, 2005] as a potential factor for influencing the incidence of self-directed plucking. While lower dominance rank is often associated with higher levels of glucocorticoids, dominance instability can result in departures from this pattern [Sapolsky, 2004]. The dominance hierarchy had not changed in the 12 months preceding the start of this study; however, the highest-ranking male was the son of the second highest-ranking female, not the dominant female. This second ranking female was the previous dominant female. Despite the stability of the dominance hierarchy during our study, we speculate that inter-individual relationships may account for differences in urinary cortisol. Aside from the dominant male and female, the remaining individuals self-plucked during less than 50% of grooming bouts that involved plucking. Indeed, social plucking was more common in this group than self-directed plucking: 62% versus 38% [Brand and Marchant, 2015]. While high dominance rank may explain high frequencies of self-directed plucking, we must note that the dominant female affiliated with other adult females with relatively low frequency [Brand and Marchant, 2015]. This relative lack of female bonding and support, not uncommon among captive bonobos (see Stevens et al., 2006), may also explain greater frequencies of self-directed hair plucking compared to social plucking. Additionally, the dominant male was an adolescent during our study and we previously documented higher frequencies of plucking per male in adolescent males compared to adult males [Brand and Marchant, 2015]. Further investigation of the potential role of dominance status in self-directed hair plucking is needed.

The urinary cortisol levels among all individuals in this group of bonobos fell below the reported values for wild male bonobos, which were analyzed using a different assay [Surbeck et al., 2012]. We strongly note that caution is warranted when comparing results from different assay techniques. Captive bonobos and wild bonobos are subject to different sources of stress. Hair plucking occurred more frequently when individuals were housed indoors versus outside; however, grooming was also observed to occur more frequently indoor than outdoors [Brand and Marchant, 2015]. Hair plucking was observed very infrequently outside of grooming bouts in this colony [Brand and Marchant, 2015]; therefore, it is likely that increased hair plucking when

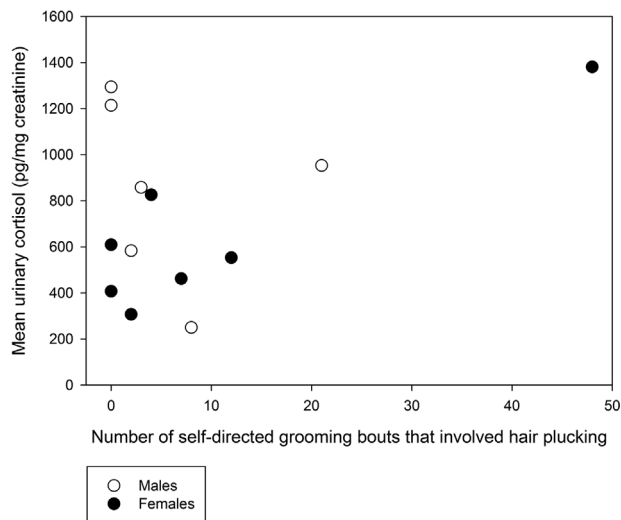


Fig. 3. Correlation between relative self-directed plucking percentage and mean cortisol levels in females ($r=0.88$, $P<.05$) versus males ($r=-0.73$, $P=0.09$). Females are represented by black circles and males by white circles.

housed indoors is the result of increased frequencies of grooming that occur indoors. While habitat differences may not influence the behavioral pattern of hair plucking, social factors such as party size and composition may affect hair plucking [Brand and Marchant, 2015]. Indeed, social stress may explain hair plucking in these captive bonobos as other undesirable behaviors, such as coprophagy and urophagy, are relatively absent from this group [Brand and Marchant, 2015]. The observation of hair plucking and the lack of other undesirable behaviors in this group may suggest a non-environmental explanation for the source of stress.

One potential confounding variable in our analyses was the reproductive status of one of the females. This female was pregnant for most of the study. In general, human females tend to show a gradual increase of cortisol over the course of their pregnancy [Jung et al., 2011]. Behringer et al. [2009] noted an increase in salivary cortisol in a pregnant bonobo female compared other group members. When ordered sequentially, urinary cortisol for this female varied over the course of the study period and was only moderately high (2047 pg/mg of creatinine) 3 days prior to parturition. Thus, it appears that female reproductive status did not impact this female's urinary cortisol levels and did not affect the results of this study.

The results of our correlation analysis potentially offers insight about the etiology of self-directed hair plucking. Female self-directed plucking and cortisol levels were significantly positively correlated. Even when the two wild-born females (who were never observed to hair pluck) are excluded from the analysis, the results remain significant. This relationship between the variables was not observed in the males. The two males with the highest mean cortisol levels were never observed to engage in hair plucking over the course of the study. Our limited sample size does not

allow us to perform a correlation between males and self-directed hair plucking when these two males are excluded. However, the plotted data indicate that their exclusion would not result in a significant correlation. Our analysis can only highlight the strength of association of this relationship and does not indicate that males and females manifest stress differently or are subject to different stressors. While these data demonstrate an association between female self-directed plucking and cortisol level, the association may be the result of other factors.

Hair plucking in captive bonobos is ethologically analogous to the human obsessive-compulsive disorder trichotillomania. The results of this study are intriguing because trichotillomania is considered to be a predominately female-biased disorder and also largely self-directed (see Duke et al. [2010] for a review). This bias may simply be the result of incomplete sampling or the tendency for men with trichotillomania to avoid treatment. While our comparison of bonobo hair plucking to trichotillomania is tenuous, we find it curious that an ethologically analogous, obsessive-compulsive behavioral pattern occurs in such closely related species. The observation of a sex bias in both species is equally fascinating yet consistent with the observation of human sex differences in response to stress [Taylor et al., 2000; Ordaz and Luna, 2012].

While correlation does not necessarily imply causation, the combination of our results with comparative human data lends support to the hypothesis that the occurrence of self-directed plucking in some individuals has an etiology associated with stress. However, it remains unclear why a self-directed behavior associated with stress would appear in both sexes and in both self-directed and social grooming. Our present study cannot answer this question. We speculate that widespread hair plucking in captive bonobos may be the result of social transmission. Social learning has been intensively studied both experimentally and in the wild; however, there is a paucity of data for zoo-housed animals. It is possible that other individuals learned hair plucking behavior from the observation of another individual; even if the behavior lacked an apparent function or purpose. While this claim is speculative, it would help explain the prevalence of this behavior. This notion is also consistent with the result from Less et al. [2013]: early exposure to the behavior may facilitate its development. Hopper et al. [2016] recently proposed social transmission as an explanation for widespread coprophagy among captive chimpanzees. A potential method for testing this hypothesis is reconstructing a history of the behavior for each institution where hair plucking is present. It is possible that specific individuals have facilitated the spread of this behavioral pattern when transferred to another institution; similar to the introduction of ant fishing to the Kasekela chimpanzee community at Gombe via female immigration [O'Malley et al., 2012].

Bonobo hair plucking is not a self-injurious behavior and does not result in any noticeable phenotypic effect aside from alopecia associated with consistent plucking [Brand

and Marchant, 2015]. We highlight two potential concerns associated with hair plucking in our previous paper: challenges to homeothermy [McFarland et al., 2016] and lack of an infant grasping substrate [Brand and Marchant, 2015]. While hair plucking is an undesirable behavior, it does not directly impact an individual's health and thus is not considered an immediate priority for intervention. We note that mitigating hair plucking is notoriously difficult; although some gorilla studies report success [Hill, 2004; Pizzutto, 2007]. In humans, trichotillomania is as equally difficult to manage even with behavioral and pharmacological treatment [Duke et al., 2010]. We also speculate that if the behavior is a result of social learning and social transmission, the behavior may prove even more challenging to mitigate or eradicate.

A major limitation of the current project is the limited number of cortisol samples per individual. Samples from one individual were collected over a relatively short time period (approximately 3 weeks). As aforementioned, cortisol exhibits a circadian rhythm and can fluctuate in response to acute stress. Furthermore, only a few studies have examined cortisol in captive bonobos (e.g., Jurke et al., 2000; Behringer et al. 2009; Squires et al., 2015). With limited data, we can only speculate about a typical cortisol profile for a zoo-housed bonobo. Future research could elucidate endocrine profiles for this species as well as examine plucking (or other undesirable behaviors) and cortisol data on a more consistent, daily basis. Another limitation is the duration of the study. While hair plucking did not vary over the course of the study period [Brand and Marchant, 2015], the behavior may exhibit seasonal differences as described in macaques [Novak and Meyer, 2009]. Future research should examine this behavior over at least 1 year.

While the present study must be viewed as preliminary based on small sample size and the limited duration of the study period, we have demonstrated a sex-biased association between relative self-directed hair plucking and urinary cortisol levels in this group of bonobos. This is the first evidence to support the etiology of this behavior as related to stress. Future research on this topic should further investigate the relationship between undesirable behaviors, such as hair plucking, and cortisol in other zoo-housed species, especially apes.

CONCLUSIONS

1. There is considerable variation in the relative occurrence of self-directed and social plucking among individuals.
2. Self-directed plucking percentages were positively correlated with urinary cortisol levels in females and there was a strong negative trend among males.
3. These results are analogous to trichotillomania, which is a predominately female disorder and is stress-induced.
4. While further investigation is necessary, we speculate that self-directed hair plucking may be a stress-induced behavior in female bonobos although social transmission

may explain the presence of the behavior across various age/sex classes.

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