The Old School, Brewhouse Hill, Wheathampstead,
Hertfordshire AL4 8AN, UK

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Do gorillas regurgitate potentially-injurious stomach acid during 'regurgitation and reingestion?'

SP Hill

Centre for Animal Welfare and Anthrozoology, Department of Veterinary Medicine, University of Cambridge, Madingley Road, Cambridge CB3 0ES, UK; email: research@chesterzoo.org

Abstract

*Regurgitation and reingestion (R/R) of foodstuffs is a common abnormal behaviour in captive western lowland gorillas (*Gorilla gorilla gorilla*) and certain other non-human primates, but it is not part of their normal feeding mechanism. It is similar to a behavioural problem seen in humans, human rumination syndrome (HRS), which can occur in association with anxiety or a poor relationship with a caregiver. Patients with HRS often regurgitate stomach acid with the food matter which can result in clinical problems; until this study, it was not known if stomach acid is regurgitated by gorillas also. Thus, samples of regurgitated matter were collected opportunistically and non-invasively, and pH was measured using an electronic meter. Results were compared with the pH of samples of the original food eaten by the gorillas, and show that regurgitated food has significantly higher acidity than the originally-ingested meal. By comparison, samples of saliva were collected from gorillas opportunistically, in the absence of recent ingestion, and were found to be alkaline and, thus, saliva should not have contributed to the increased acidity of regurgitated matter. The results imply that stomach acid is being regurgitated, as in human patients with potentially-injurious rumination syndrome, and it is indicative of sub-optimal welfare. Causes and effects of R/R should be investigated further, to lead to potential treatment and prevention and to promote the welfare of captive gorillas.*

Keywords: *abnormal behaviour, acidity, animal welfare, human rumination syndrome, regurgitation and reingestion, western lowland gorilla*

Introduction

Animals on farms, or in laboratories, zoos and sanctuaries, may face environmental challenges that their species will not have encountered during most of their evolution, or only very recently in domestication (Knierim *et al* 2001). Thus, captive animals may be poorly equipped to adapt to certain aspects of captivity that fail to meet the needs of the species in general, and individuals in particular, in optimal ways and these require further investigation.

It is widely accepted that the presence of abnormal behaviours in the repertoires of animals, including humans, can indicate a problem with welfare. Abnormal behaviours can be defined as those that differ in pattern, frequency or context from those which are shown by most members of the species under conditions that would allow a full behavioural range (Broom & Johnson 2000), and are usually maladaptive. Animal welfare can be defined as the state of an animal as regards its attempts to cope with its environment (Broom 1986), can be measured on a sliding scale from very poor to very good, and can be assessed scientifically (Broom & Johnson 2000). When an animal has difficulty in coping with its environment, or is failing to cope, its welfare is considered to be poorer than that of an individual with less severe (or no) difficulty in coping (Broom & Johnson 2000).

Western lowland gorillas (*Gorilla gorilla gorilla*) may develop an abnormal behaviour in captivity, known as regurgitation and reingestion (R/R). Regurgitation refers to the voluntary, retrograde movement of food or drink from the oesophagus or stomach to the mouth, hand or floor (Lukas 1999), and reingestion occurs if the animal subsequently consumes the regurgitated matter. Thus, R/R differs from vomiting, as the latter is a reflex behaviour elicited by autonomic activity and is preceded by hypersalivation, contractions of abdominal muscles and nausea (Strombeck 1979). Gorillas may also regurgitate their ingested faeces after coprophagy, if they have already regurgitated their stomach contents to an extreme (Hill 2004).

Potential consequences for human health have been observed in humans with a similar affliction to R/R, known as human rumination syndrome or HRS (American Psychiatric Association 1994), and can include clinical problems of dental erosion, oesophageal motor disorders, ulcers, oesophageal strictures and pulmonary aspiration; some of these problems are associated with the regurgitation of stomach acid. HRS in infants can be fatal as a result of malnutrition and dehydration (Thame *et al* 2000). Prior to this study, it was not known if stomach acid was being regurgitated by gorillas also, and so my aim was to compare the acidity of regurgitated food with that of the originally-

ingested meal, using non-invasive means. If the pH of regurgitated food is shown to be lower than that of the original meal, it would imply that stomach acid is being regurgitated and R/R might be harmful to physical health in the long-term, as in people with HRS. Zoos and sanctuaries should then take steps to ensure that the need for R/R is removed or reduced.

As well as the acidity of the regurgitated matter itself, knowledge of the pH of healthy gorilla saliva is also important to this study: one of the normal functions of saliva in healthy animals is to neutralise food being masticated. Thus, an increase in the acidity of regurgitated food, compared with the acidity of the original meal, would indicate the presence of stomach acid in the regurgitated matter, whereas if saliva was also acidic, an increase in acidity of regurgitated matter may simply be a product of saliva acidity. In people of normal health, saliva is well-documented as having a pH of approximately 6.5–7.5 (pH of resting saliva between 6.5–6.9, and of stimulated saliva between 7.0–7.5); pH of saliva is considered very low if < 6.3 (resting) and < 6.8 (stimulated) (Birkhed & Heintze 1989). There are no published data on salivary pH of healthy gorillas, but saliva from healthy gorillas at Taronga Zoo, Australia, has been measured at pH 8.4 (M Finnigan, personal communication 2003). Saliva samples were measured in the current study, to verify that healthy gorilla saliva is not acidic and, thus, unable to contribute to an increased acidity of regurgitated matter.

Materials and methods

Study sites and subjects

Samples of saliva, meals and subsequently-regurgitated matter were obtained opportunistically from otherwise-healthy gorillas at Howletts and Port Lympne Wild Animal Parks, UK, in July and August 2003. At the time of this study, more than 60 gorillas were housed in several family, bachelor or nursery groups, in large, complex indoor (up to 1,500 m^3) and outdoor (up to 3,000 m^3) cages with a floor substrate of thick straw and many climbing- and nesting-structures. Some gorilla groups at Port Lympne also had access to large, open-air 'garden' enclosures. Scatterfeeds of fruit and vegetables and, occasionally, browse, would be given to each group several times daily, with morning drinks and snacks, and afternoon drinks and main meals, given to individuals separately, as part of the normal routine.

Collection and measurement of samples

To measure salivary pH, saliva samples (n = 5) were taken from two adult females and three infant/juvenile males, in the absence of recent ingestion. These animals were encouraged to lick a colour-fixed pH indicator stick (pH-Fix 0-14, Fisherbrand® FB33003, Fisher Scientific UK Ltd, Loughborough, UK), held to their mouths safely through the cage bars. When the colour stabilised, pH was determined by comparison with the indicator's colour chart.

To prepare for measurement of the pH of the original meal ingested, a 'mock' meal would be compiled, comprising food or drink items from the same batch being given to the gorillas, for comparison with the acidity of subsequently-regurgitated matter. Food and drink items measured in this study included skimmed milk, water, mixed fruit and vegetables, peanuts, natural yoghurt and bread. If not already liquefied, the mock meal would then be liquidised for several seconds, using a domestic liquidiser (Kenwood Ltd®, Havant, Hampshire, UK), to simulate mastication of food (but without the neutralising effects of saliva).

For practical reasons, different methods had to be used for measuring salivary pH versus pH of food/drink (original and regurgitated). Each mock meal was measured for pH, using the appropriate methods (Hanna Instruments®, Instruction Manual HI 8417-HI 8519 HI 8520-HI 8521) for a microprocessor bench-top pH-meter (HI 8417, Hanna Instruments®, Padova, Italy). This pH-meter provides automatic temperature compensation for both calibration and measurement. Prior to use, the pH-meter was re-calibrated, using a two-point calibration for greatest accuracy, and fresh buffers were used. In between the measurement of each sample, the pH-electrode and temperature probe were washed with distilled water and dried with a clean paper towel, to prevent contamination.

Samples of subsequently-regurgitated food or drink were collected during morning and afternoon feeds, when gorillas were separated from each other for a short time, in indoor 'bedrooms,' as part of their normal husbandry routine. If R/R was observed, a sample would be obtained shortly after being voided, if the individuals could be shut out of the bedroom for safety. Only one sample was collected from each gorilla at any one meal, even if the animal regurgitated more than once. Samples that were likely to be contaminated with urine or other substances were not collected. Each sample was homogenised with a clean spatula, and a small amount of the homogenised sample would then be collected into a sterile pot, for immediate measurement of pH using the same microprocessor bench-top pH-meter as previously described.

Data analysis

The results are used to test the null hypothesis that there would be no significant difference between the acidity of regurgitated matter and the acidity of the original meal. These two measures are matched and analysed using the non-parametric, two-tailed Wilcoxon signed ranks test for small samples (n < 15), with no tied values between matched pairs (Siegel & Castellan 1988).

Results

All saliva samples tested in this study were alkaline, ranging from pH 8–9 (8.4 [± 0.19], n = 5). All regurgitated samples were acidic, with values ranging between pH 4.45–5.98 (5.12 [± 0.14], n = 11) and, in all cases, the pH of regurgitated matter was lower (ie more acidic) than that of the original meal consumed (pH 4.62–7.00, 6.43 [± 0.24], n = 11), which was significant (Wilcoxon signed ranks test: $T+ = 66$, $P = 0.001$; Figure 1).

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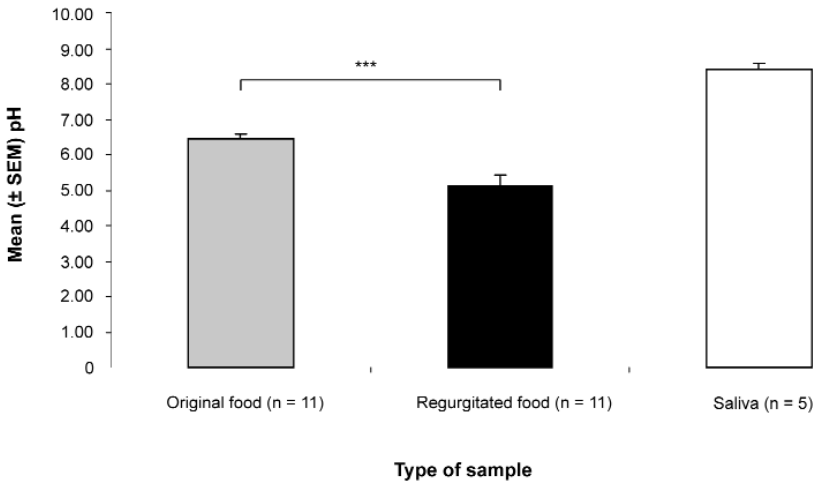
Figure 1

Mean (± SEM) pH of samples of regurgitated matter compared to the mean (± SEM) pH of the meal ingested originally. *** $P = 0.001$. Salivary pH is shown for general comparison.



Discussion

R/R and HRS differ from 'true' rumination in Ruminantia and Tylopoda (camels, llamas and alpacas), which have compartmentalised stomachs (eg Randall *et al* 1997): apes have simple stomachs and are not anatomically-adapted to including R/R as part of a normal feeding process. HRS in adults with mental retardation, or in infants, has been linked to a failed interaction between the patient and their caregiver (Malcolm *et al* 1997; Wagaman *et al* 1998; Thame *et al* 2000), and this may be a causal factor of R/R in captive gorillas also (Gould & Bres 1986). HRS has also been linked to a state of anxiety in otherwise mentally-healthy adults (Landis & Lambroza 2001). Many factors are thought to contribute to R/R in gorillas, including temporal, seasonal, gustatory, social, individual, medical and nutritional variables (eg Hediger 1964; Akers & Schildkraut 1985; Gould & Bres 1986; Lukas 1999; Lukas *et al* 1999), and Hill (2004) has suggested that further investigation of R/R in gorillas could benefit from using knowledge of causation in humans.

Considering that R/R is such a common abnormal behaviour in captive gorillas (Akers & Schildkraut 1985), relatively little is currently known about it. Similar abnormal behaviour to R/R and HRS has been reported in other captive apes, including chimpanzees (*Pan troglodytes*) (Baker & Easley 1996). There are no known reports of R/R in mountain or lowland gorillas in the wild, but it could be expected to occur in nature if conditions became insufficient to meet gorillas' needs.

In people, HRS is classified as an eating disorder (American Psychiatric Association 1994), but it is not necessarily associated with attempted weight control (Malcolm *et al* 1997). There are potential consequences for health in human patients (Thame *et al* 2000), due partly to regurgitation of stomach acid. In comparison, R/R has been described as potentially self-injurious (Baker & Easley 1996), but Lukas (1999) reports that there are no known instances of direct health problems occurring in gorillas as a result of it. In light of the evidence in this study, that stomach acid is being regurgitated in R/R, future research should be carried out to investigate the presence or absence of similar clinical signs in gorillas that regularly display this behaviour: such analysis was beyond the scope of this study and, at present, we may only speculate as to the potential health problems that may result.

Certain dental conditions, which may indicate damage caused by R/R, can be commonly seen in captive gorillas — in particular in older animals — as a result of inappropriate diet, occurring either in the present or historically. Furthermore, periodontal disease is known to occur in gorillas, but none can be attributed to regurgitation; bulimism in humans causes loss of enamel and dentine, but not primary periodontal disease (P Kertesz, personal communication 2008). The potential for oesophageal damage in gorillas, as is another known problem in people with HRS, would be hard to assess as the required procedure is highly invasive. It would be useful for further understanding of R/R, if an assessment of the extent of any internal physical damage could be made either in deceased gorillas that used to perform R/R regularly or, opportunistically, in living animals undergoing endoscopy or other relevant procedures.

Case-control studies could be useful for investigating R/R as a risk factor for increased morbidity, but data recorded on gorilla life-histories are likely to be limited, especially for older animals, or those that have been moved between different collections. Thus, the quality and quantity of records will vary between zoos, and data kept in zoo records may be inconsistent (Fidgett *et al* 2008). HRS can be potentially fatal in human infants, due to malnutrition and dehy-

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dration (Thame *et al* 2000), but it is not expected that R/R should affect mortality rates in young gorillas. Although potential mortality due to R/R is yet to be investigated, the age at which R/R begins to occur regularly in young gorillas is believed to be around five years, and onset of (infrequent) R/R is first reported at a median age of three years (2–6.5 years, n = 9), (Gould & Bres 1986).

As well as practical challenges in measuring consequences to health in gorillas that perform R/R, other aspects of sample collection must be overcome. The gorillas used in the present study had not been trained for sample collection and, therefore, there were a number of occasions where it was not possible to collect any regurgitated matter, either because reingestion occurred too quickly, or because the sample could not be collected safely. Safety was also an issue for the collection of saliva samples and, thus, not all saliva samples were from the same gorillas whose regurgitated matter had also been analysed. Nevertheless, as the gorillas had no known health problems during this study, their saliva is believed to be representative of healthy gorillas.

As a direct result of the sampling difficulties, individuals of different age- and sex-classes were used in the different parts of this study but, based on knowledge of human salivary pH, this should not adversely influence results. There is no constant difference in salivary pH between sexes in people, although females tend to have smaller salivary glands than males. Thus, human females have slightly lower secretion rates than males and therefore the pH is 0.1–0.3 units lower, although this has no clinical significance (J Tenovuo, personal communication 2008). Human salivary glands develop to full maturity by 14–16 years of age and, prior to that, the pH can be slightly lower (pH 6.5–7.0). The pH of stimulated saliva remains constant up to the age of 80+ years in healthy individuals, with no major changes expected in either sex (although many females experience a postmenopausal decline in salivary flow rate, with an associated slight reduction in pH as well) (J Tenovuo, personal communication 2008). All saliva samples from gorillas in this study were alkaline, regardless of age or sex.

As positive reinforcement training for medical procedures is becoming more commonplace in zoos, future research on R/R could involve subjects who have been trained to give samples of saliva and regurgitated matter, which would facilitate a larger-scale investigation of the behaviour. Furthermore, insufficient quantities of saliva could be obtained in this study for measurement with the pH-meter (as the electrode had to be inserted 4 cm into the sample in order to achieve a reading), whereas some gorillas could be encouraged to lick pH indicator sticks instead, without endangering the handler (and without eating the stick). Indicator sticks were not suitable for measuring the original or regurgitated food, due to its consistency and colour. Thus, indicator sticks were used to measure salivary pH, and the pH-meter for measuring food. Results from the indicator sticks were tested for consistency against the pH-meter, by using both methods to measure fresh buffers; consistent results were obtained, although the pH-meter is recognised as being the most sensitive method.

Animal welfare implications

This study has demonstrated that regurgitated matter is more strongly acidic than the original food ingested by gorillas, suggesting that stomach acid is present in the regurgitated material, which was previously unconfirmed. Thus, R/R has the potential to be an injurious behaviour, as with HRS in people, and further research will be necessary to test whether there is an association between regurgitation of acid and clinical health problems in gorillas. Motivation for engaging in R/R is not yet understood fully, and it would be constructive to use human cases as a model, as well as to consider the needs of captive gorillas more carefully (Hill 2004), to improve captive care.

Zoos and sanctuaries in which R/R is seen should attempt to reduce the occurrence of this and other abnormal behaviours, by first attempting to understand the motivation behind this behaviour in individuals that do it, as there may be different welfare-related causes, before seeking to address these issues experimentally. This can be tested using targeted environmental enrichment efforts and other husbandry changes, the efficacy of which should be assessed scientifically. Animal welfare should be assessed on a case-by-case basis, as welfare is the state of an individual (Broom 1986). Enrichment efforts should be targeted at encouraging or reducing particular behaviours, in relation to the needs of individuals. In cases where particular enrichment efforts do not reduce abnormal behaviours, such as R/R, it could be because those particular efforts were biologically meaningless in attempting to address the factor(s) underlying those behaviours, for those individuals in question. In such cases, the abnormal behaviour could still be adopted, in an attempt to fulfil a particular need; if different enrichment efforts had been tested, targeting a different need, the results may have been different.

Rooney and Sleeman (1998) investigated the effects of certain enrichment devices, including burlap rags, cardboard boxes and paper bags containing food and browse, on the behaviour of captive gorillas, but their efforts failed to reduce R/R significantly. This may simply be a product of the way in which their behavioural categories were analysed, rather than a real failure of the enrichment efforts themselves, but it could also be the latter. Rooney and Sleeman (1998) amalgamated R/R with coprophagy, but the latter behaviour is regarded as normal in wild gorillas, albeit with perhaps less frequency than is sometimes seen in captivity (Akers & Schildkraut 1985) and, so, if enrichment efforts did not reduce abnormal behaviours, it could be because the overall result for the combined behaviours was somewhat neutralised.

Sabater Pi (1993) reports that western lowland gorillas at Rio Muni, Equatorial Guinea, spend 72% of the day foraging and feeding, but opportunities to do these behaviours are usually more limited in captivity, because of factors, such as the amount of food available, intra-group competition, and individual consumption rates (Akers & Schildkraut 1985). Hill (2004) was able to virtually eliminate R/R in two gorillas at a German zoo by using

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enrichment efforts designed specifically to increase the opportunities for feeding and foraging over a longer period of time. Those findings support the conclusion of Lukas *et al* (1999), in which gorillas may engage in R/R to prolong the feeding period, and Hediger (1964), who suggested that R/R enables the quantity of food available to be increased artificially. Similarly, Akers and Schildkraut (1985) and Gould and Bres (1986), reported that R/R increased the daily ingestion time in gorillas. Moreover, Gould and Bres (1986) found that, by feeding browse to the gorillas, R/R decreased and overall ingestion time increased. The limited research on R/R does seem to support the notion of it fulfilling a 'need to feed' in some individuals (Hill 2004), although other potential causes, such as boredom and self-stimulation, should not be overlooked either.

Thus, in the light of evidence that stomach acid is being regurgitated during R/R, captive gorilla environments should be investigated further. Efforts should be made to reduce or remove the need to perform abnormal behaviours, like regurgitation and reingestion, by trying to target the cause of these behaviours, even in animals that have done them over a long period of time. Regardless of each individual's reason for doing R/R, whether general anxiety, a poor relationship with a caregiver, a lack of control over the feeding environment, or something else entirely, this behaviour is maladaptive and biologically inappropriate. Knowledge of HRS, and of R/R in gorillas, indicates that this is a behavioural problem that should be addressed further, and that may have clinical consequences for those individuals that do it.

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