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The utility of voluntary weighing in captive group-living rhesus macaques (Macaca mulatta)

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Abstract

*Bodyweight is an important health and welfare indicator for captive non-human primates (NHPs). Bodyweight can be measured during routine handling procedures, which cause stress. Alternatively, animals can be trained to step onto a scale, but training success varies greatly between individuals. Being able to weigh animals regularly without having to handle or train them is thus desirable for monitoring animal health and welfare. This study investigates the utility, ie the participation, reliability and time investment, of voluntary weighing in captive NHPs living in large social groups. Subjects of the study were 92 rhesus macaques (*Macaca mulatta*) housed in four social groups at the Biomedical Primate Research Centre in Rijswijk, The Netherlands. A scale was placed in their home enclosure during several sessions. Individuals were unwilling to step onto an unbaited scale. When likeable food items were used to attract individuals to the scale, 68% of them stepped onto the scale. Age and dominance rank did not affect stepping onto the scale, whereas exploratory tendency and social group did. The level of agreement between bodyweight by voluntary weighing and bodyweight measured during sedation was very high. These results show that the majority of rhesus macaques in social groups can be weighed voluntarily and that voluntary weighing is reliable. When optimising and further developing the method, voluntary weighing can form a valuable tool in the captive management of NHPs.*

Keywords: *animal welfare, bodyweight, captive management, macaque, social housing, voluntary weighing*

Introduction

Bodyweight is an important health and welfare indicator for captive non-human primates (NHPs) (Terranova & Coffman 1997). Hence, every research facility housing NHPs includes bodyweight measurements in their animal management programme (Bauer *et al* 2010). Bodyweight can quickly change when animals become sick, ie macaques that suffer disease may lose up to 30% of their bodyweight in 17 days (Bronson *et al* 1982). Furthermore, stress can lead to changes in bodyweight (Schapiro *et al* 2012). The detection of these bodyweight changes, which may signal underlying welfare problems, requires regular bodyweight measurements (Jennings *et al* 2009).

Bodyweight can be measured during routine handling procedures, such as when animals are relocated or during health checks. This usually means the animals have to be caught and sedated prior to being weighed, which causes stress to both animals and staff (Balcombe *et al* 2004; Suleman *et al* 2004). Moreover, anaesthesia can have several side-effects (Horne 2001). Since stress and sedation of animals should be avoided as much as possible, this method does not allow frequent weighing. Colony animals (ie animals not involved in experimental studies) are therefore weighed only once or a few times per year (Bauer *et al* 2010). A possible solution allowing more frequent weighing may be to let animals step onto a scale voluntarily.

At present, positive reinforcement training is often used to enable animals to co-operate voluntarily in various husbandry and veterinary procedures (Desmond & Laule 1994; Prescott *et al* 2005). Common marmosets (*Callithrix jacchus*) and cotton-top tamarins (*Saguinis oedipus*) are relatively quickly and easily trained for weighing, while being in their family group (Sánchez *et al* 1999; Layne & Power 2003; McKinley *et al* 2003). This may be more challenging with other NHPs, like macaques. While macaques are housed at many facilities, only one study reports training group-housed macaques for weighing (Reinhardt 1990). However, this study did not train weighing within the social group. Instead, the macaques were trained to be

Table 1 Group characteristics and data collection in the study groups.

Group	Size	Gender	Matrilines (n)	Mean (± SEM); range (min–max) age (years)	Date scale sessions	Date health check
Chloor	n = 18	18F, 0M	1	7.4 (± 0.9); 3.3–15.4	Dec 2019 + Jan 2020	28th Oct 2019
Bertha	n = 27	27F, 0M	3	9.2 (± 1.1); 2.7–21.4	Feb 2020	7th Feb 2020
Grey	n = 24	23F, 1M	1	7.4 (± 0.9); 3.0–17.1	July 2020	17th July 2020
Marieke	n = 23	22F, 1M	1	7.9 (± 1.1); 2.5–18.9	Feb 2021	9th Nov 2020

individually captured in a transport box and weighed in a separate room away from their group members.

Macaques may be more difficult to train in their social group, because they live in large groups with strict dominance hierarchies. Individuals vary greatly in their response to training (Coleman *et al* 2005) and training success can be influenced by individual characteristics such as age, dominance rank and personality. In general, younger (Lacreuse *et al* 2005), higher-ranking (Drea & Wallen 1999; Kemp *et al* 2017) and more exploratory individuals (Coleman *et al* 2005; Wergård *et al* 2016) are trained more easily. As a result, training all individuals in a social group is time-consuming and it may not be possible to train all group members. For example, station-training of group-housed rhesus macaques (*Macaca mulatta*) — average group size, six individuals — took, on average, 3 h per individual and 26/30 individuals were trained successfully (Schapiro *et al* 2003). In larger groups, the success rate may even be lower and the time investment higher.

These disadvantages of training may be prevented by voluntary weighing, ie the animal itself decides to step onto a scale and prior training is not required. Voluntary weighing is not a new concept, as it has previously been used in studies on (semi-) wild ungulates, birds and NHPs. It has been applied to Alpine ibex (*Capra ibex*), bighorn sheep (*Ovis canadensis*), mountain goats (*Oreamnos americanus*), king penguins (*Aptenodytes patagonicus*) and dark-eyed juncos (*Junco hyemalis*) (Le Maho *et al* 1993; Vézina *et al* 2001; Bassano *et al* 2003; Gendreau *et al* 2005). Wild toque macaques (*Macaca sinica*) and free-ranging Japanese (*Macaca fuscata*) and rhesus macaques have also been weighed successfully using baited scales (Hazama 1964; Mori 1979; Dittus 1998; Zhang *et al* 2016). Wild immature yellow baboons (*Papio cynocephalus*) were even weighed without feeding or baiting the scale (Altmann & Alberts 1987). Therefore, voluntary weighing may be applicable to captive, group-living NHPs.

This study aims to determine whether voluntary weighing can be a valuable tool to monitor health and welfare of captive NHPs living in large social groups. We therefore investigated the utility, ie participation, reliability and time investment, of voluntary weighing in captive rhesus macaques living in naturalistic groups. We determined participation in four groups. The reliability of the method was tested by comparing bodyweight measured during voluntary weighing to bodyweight measured during sedation. We also checked whether the same individual characteristics that often affect training success can predict which individuals are more likely to participate in voluntary weighing. In addition, the time investment required for voluntary weighing in large social groups was addressed.

Materials and methods

Study animals and housing

Study animals consisted of 92 rhesus macaques of Indian origin living in four socially stable groups at the Biomedical Primate Research Centre (BPRC) in Rijswijk, The Netherlands. The groups were established for the purpose of breeding between 1996 and 2002 but were not active breeding groups at the time of this study, ie they did not contain an adult male. The groups contained one or several matrilines and were formed by adhering to natural group dynamics (females stay in their natal group, while males three years and older are removed to prevent inbreeding). Table 1 shows the characteristics of each study group and data collection per group. Each group had free access to large interior (72 m^2; 2.85 m high) and exterior (250 m^2; 3.1 m high) enclosures. The interior enclosure contained sawdust bedding, which was replaced regularly while the exterior facility had sand bedding and natural plant growth was possible. The enclosures were enriched with a large variety of items, such as climbing structures, fire hoses, car tyres, slides and a swimming pool (Vernes & Louwerse 2010). Animals were fed daily with monkey chow (Ssniff, Soest, Germany) in the morning and vegetables, fruit or a grain mixture in the afternoon. Drinking water was available *ad libitum* via automatic water dispensers.

Measuring bodyweight during sedation

Bodyweight of individuals in the BPRC breeding colony is measured once per year during the annual health check. After an overnight fast, the animals were sedated with an intramuscular injection of 10 mg kg^{-1} ketamine (100 mg ml^{-1}; Ketamine 10%, Alfasan, Woerden, The Netherlands) in combination with 0.05 mg kg^{-1} medetomidine (1 mg ml^{-1}; Sedastart, AST Farma, Oudewater, The Netherlands), which was reversed after the health check with 0.25 mg kg^{-1} atipamezole (5 mg ml^{-1}; Sedastop, AST Farma, Oudewater, The Netherlands). Bodyweight was measured to the nearest 0.1 kg during the health check and hereafter will be referred to as sedated bodyweight (SBW).

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Figure 1

Showing the location of the scale on the ground within the interior of one of the macaque home enclosures. Only part of the enclosure is visible.

Voluntary weighing

The scale used for voluntary weighing, a Kern EOB 60K-2LF (Kern, Balingen, Germany), is a wireless scale with a remote display, which was 'monkey-proof' as it did not contain any wires, screws or buttons. This scale is especially suitable for weighing animals, because the scale calculates an average value to obtain a stable bodyweight. Since the display automatically shuts down after 3 min of inactivity, observers had to be present to manually restart the display. Additional weight was added to the bottom of the scale to ensure that it could not be lifted or moved. During voluntary weighing, the remote display was kept outside of the enclosure, while the scale was placed inside the home enclosure. The scale was placed on the ground or in a corridor, which was located approximately 1 m above the ground (Figure 1). Before placing the scale in the enclosure, the sawdust bedding was swept aside if necessary. The observers sat a minimum of 2 m away from the scale.

During almost 11 h of try-out sessions with an unbaited scale in the Chloor-group, only one female stepped onto the scale. From this, we concluded that the individuals were not motivated enough to step onto an unbaited scale. Thereafter, small amounts of likeable food items (eg apple syrup, jam, lemonade, raisins and ice cubes filled with fruit) were applied onto and close to the scale to attract individuals. Most of the food items were applied prior to each session, while lemonade was also re-applied during the sessions with a syringe. In the other groups, the scale was baited from the first day it was made available.

Data were collected from each group during several sessions, which took place between December 2019 and February 2021 and varied in duration between 1.5 and 3.5 h per session. Individuals were habituated to the presence of one or two observers, who replenished some of the food items when they were consumed. The frequency of stepping onto the scale, frequency of weighing and bodyweights were scored for each individual. Stepping onto the scale was recorded only when the individual's body was located entirely on the scale, including all four limbs. The mean bodyweight by voluntary weighing was calculated per individual and will be referred to as voluntary bodyweight (VBW).

Two cameras (JVC Everio GZ-R15BE, JVC, Yokohama, Japan) filmed the display and scale throughout all the sessions. When bodyweight or stepping events were missed during live observations, videos were checked to enable completion of the data. Not all stepping events resulted in bodyweight measurements. For example, when an animal walked over the scale too fast, it was not possible to obtain a reliable bodyweight. Also, individual weighing was not possible when multiple individuals sat on the scale together. As a result, bodyweight was not measured for one female from the Grey-group, even though she did step onto the scale. Eventually, 897 bodyweight measurements were recorded from the 1,345 stepping onto the scale events. After a session, the scale would occasionally be left in the enclosure to facilitate habituation but was always removed at the end of each day.

Table 2 The mean (± SEM) and range of the efficiency of voluntary weighing per social group, measured as participation per group and stepping rate and latency per participant.

Group	Participation	Total stepping events (n)	Total observation time	Stepping rate of participants	Latency of participants
Chloor	n = 13; 72%	258	12 h, 15 min	1.6 (± 0.6); 0.2–6.6	7 h, 01 min (± 1 h, 12 min); 0 h, 27 min–11 h, 45 min
Bertha	n = 18; 67%	419	20 h	1.2 (± 0.3); 0.1–5.3	8 h, 53 min (± 1 h, 21 min); 0 h, 27 min–18 h, 37 min
Grey	n = 9; 38%	113	22 h, 30 min	0.6 (± 0.1); 0.0–2.4	15 h, 02 min (± 2 h, 33 min); 1 h, 52 min–21 h, 49 min
Marieke	n = 23; 100%	555	7 h, 10 min	3.3 (± 0.5); 0.3–9.7	1 h, 54 min (± 0 h, 20 min); 0 h, 44 min–6 h 20 min

Dominance rank

All occurrence observations took place in all groups to score submissive behaviour, concerning bared teeth, making room, giving ground and escape (Appendix 1; see supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Submissive behaviour was used to calculate the dominance hierarchies with MatMan in R (Netto *et al* 1993). Submissive behaviour was observed 1,516 times in the Chloor-group, 2,042 times in the Bertha-group, 2,749 times in the Grey-group and 2,535 times in the Marieke-group. Dominance hierarchies were significantly linear and highly consistent in all groups (Chloor-group: $h' = 1$; $P < 0.005$, DCI = 0.977, 0% unknown relationships; Bertha-group: $h' = 0.924$; $P < 0.005$, DCI = 0.988, 5% unknown relationships; Grey-group: $h' = 0.982$; $P < 0.005$, DCI = 0.968, 1% unknown relationships; Marieke-group: $h' = 0.895$; $P < 0.005$, DCI = 0.992, 9% unknown relationships). Dominance rank was re-scaled by dividing absolute dominance rank by group size to correct for the fact that groups varied in size.

Exploratory tendency

Exploration is a personality trait that is often measured using novel object tests (Carter *et al* 2012; Massen *et al* 2013). Exploratory tendency was measured in all groups by exposing individuals to a novel feeding method, concerning a new construction for distributing the monkey chow. Individuals were divided into three exploration categories based on their latency to first approach and exploratory behaviour towards the novel feeding method. The first category contained individuals that immediately started using the novel feeding method, ie within the first 5 min (high exploratory tendency; n = 35). The second category of individuals did this within 30 min (medium exploratory tendency; n = 31), while individuals from the third category took more time to explore the novel feeding method (low exploratory tendency; n = 26).

Data analysis

Besides participation per group, latency and stepping rate of participants were used to measure the efficiency of voluntary weighing. Latency was the time it took an individual, after the scale was made available, to step onto it for the first time. Stepping rate per individual was calculated by dividing the total number of times an individual stepped onto the scale by the total amount of time the scale was available to the group. Since the data contained too many zeroes to comply with the assumptions for linear regression, we used the binary occurrence of stepping onto the scale (1 = yes, 0 = no) rather than the stepping rate for the analysis. A binary logistic regression model was used to test whether age, dominance rank, exploratory tendency or group ID could predict which individuals were more likely to participate in voluntary weighing.

Reliability of voluntary weighing was tested by checking the level of agreement between VBW and SBW with an intra-class correlation coefficient (ICC). Spearman correlations were used for all other correlations. Some individuals had VBWs available in both the morning (before 1200h) and the afternoon (after 1200h) of the same day. A paired samples *t*-test was used to test whether VBW differed between time of day. We checked whether reliability of voluntary weighing could be improved by testing which factors influenced bodyweight deviation, which was calculated as VBW minus SBW. A linear regression model with age, dominance rank, number of bodyweight measurements and group ID as predictor variables was used to test this.

Two adult females were excluded from the analyses on reliability as they were recovering from illness and showed increased bodyweight after veterinary treatment. Descriptive statistics in the results are reported as means (± SEM). Data were analysed statistically with IBM SPSS Statistics version 26. The significance level was $\alpha = 0.05$ and all tests were two-tailed.

Ethical statement

Since the annual health check is a veterinary management procedure, this study did not perform any invasive or experimental procedures that would require ethics approval according to European Directive 2010/63 or Dutch law. This study complied with guidelines for the ethical use of animals in applied ethology studies (Sherwin *et al* 2003) and was approved by BPRC's Animal Welfare Body (IvD 017A).

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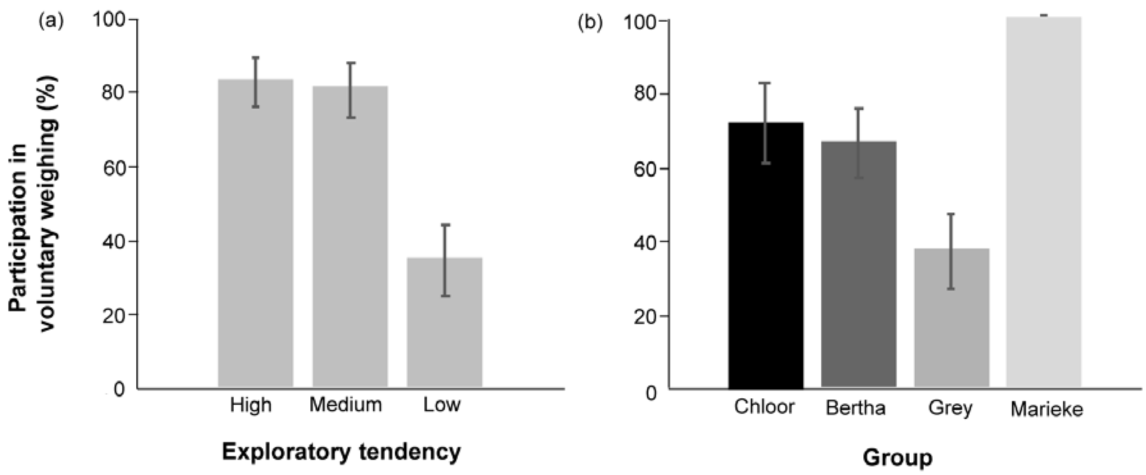
Figure 2



Showing the effects of (a) exploratory tendency and (b) social group on the participation in voluntary weighing.

Results

Participation and time investment

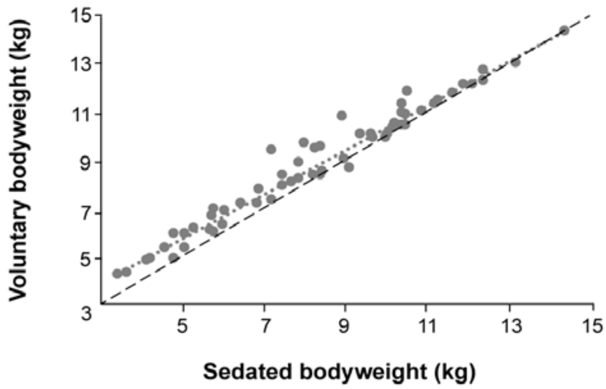
This study found that 63 out of 92 (68%) rhesus macaques participated in voluntary weighing when the scale was baited. It took individuals, on average, 6 h and 50 min (± 46 min) to step onto the scale for the first time. The mean stepping rate of participants was 2.0 (± 0.3) times per h. In total, 1,345 events of stepping onto the scale were recorded within a total time of almost 62 h. The efficiency of the voluntary weighing method was highly variable per group (Table 2).

Participation in voluntary weighing occurred independent of age (logistic regression, $\chi^2 = 0.911$, n = 92; $P = 0.340$) and dominance rank (logistic regression, $\chi^2 = 0.330$, n = 92; $P = 0.566$). The likelihood of an individual stepping onto the scale significantly differed between exploration categories (logistic regression, $\chi^2 = 11.098$, n = 92; $P = 0.004$) and between groups (logistic regression, $\chi^2 = 7.902$, n = 92; $P = 0.048$). Individuals with a low exploratory tendency were less likely to step onto the scale compared to individuals with high and medium exploratory tendencies (Figure 2[a]). Additionally, individuals from the Grey-group were less likely and individuals from the Marieke-group more likely to step onto the scale compared to individuals from the other groups (Figure 2[b]).

Reliability of voluntary weighing

Sedated bodyweight (SBW) varied between 3.45 and 14.4 kg and was highly correlated to age (Spearman correlation, $r = 0.780$, n = 92; $P < 0.005$). Voluntary bodyweight (VBW) ranged from 4.15 to 14.3 kg and was, on average, 0.44 (± 0.07) kg (6.9 [± 1.0]%) higher than SBW. All individuals from the Chloor-group had higher VBW than SBW, while 12 out of 18 individuals from the Bertha-group, six out of eight individuals from the Grey-group and 20 out of 22 individuals from the Marieke-group had a higher VBW

Figure 3



Showing the relationship between voluntary bodyweight (VBW) and sedated bodyweight (SBW), the dashed black line represents perfect agreement.

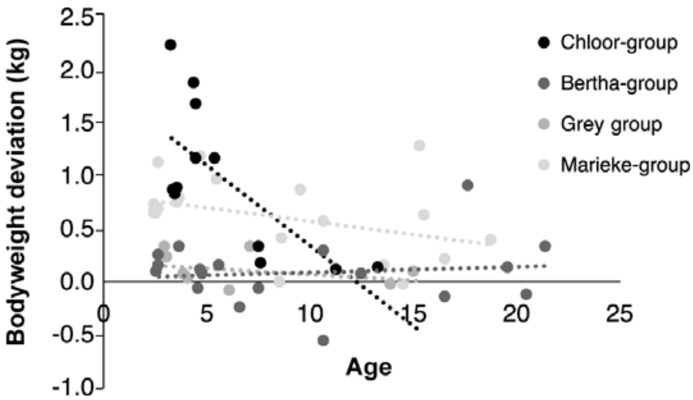
than SBW. The level of agreement between VBW and SBW was very high with ICC = 0.966 ($F_{59,59} = 97.60$; $P < 0.005$, 95% CI [0.835; 0.987]) (Figure 3). VBW was significantly higher in the afternoon compared to the morning (paired samples *t*-test, $t = -5.191$, n = 13; $P < 0.005$). VBW increased, on average, 0.145 kg (range 0–0.4 kg) from morning to afternoon, which corresponds to a relative increase of 1.7% (range 0–4.3%).

Bodyweight deviation (ie VBW minus SBW) was independent of dominance rank (GLM, $F_{1,50} = 0.757$; $P = 0.388$) and the number of bodyweight measurements (GLM, $F_{1,50} = 0.908$; $P = 0.345$). Bodyweight deviation was higher in younger individuals (GLM, $F_{1,50} = 11.793$; $P < 0.005$) and differed per group (GLM, $F_{3,50} = 18.059$; $P < 0.005$). Bodyweight deviation was significantly higher in the Chloor- and Marieke-group compared to the Bertha- and Grey-group (Table 3). There was also a significant interaction effect between age and group in the model (GLM,

Table 3 Mean (± SEM) and range of bodyweight deviation and bodyweight deviation relative to sedated bodyweight per social group.

Group	Size	Bodyweight deviation (kg)	Relative bodyweight deviation (%)
Chloor	n = 12	0.92 (± 0.20); 0.10–2.18	12.1 (± 2.6); 0.9–30.3
Bertha	n = 18	0.07 (± 0.07); –0.57–0.87	1.0 (± 0.7); –6.2–8.3
Grey	n = 8	0.10 (± 0.05); –0.10–0.30	1.5 (± 0.8); –0.7–4.4
Marieke	n = 22	0.61 (± 0.02); –0.05–1.23	10.9 (± 1.5); –0.4–22.8

Figure 4



Showing deviation in bodyweight (ie VBW minus SBW) relative to age per group.

$F_{3,50}$ = 7.331; $P < 0.005$), which implies that the relationship between age and bodyweight deviation differed per group. There was no correlation present between age and bodyweight deviation in the Bertha-group (Spearman correlation, n = 18, r = –0.083; P = 0.744), Grey-group (Spearman correlation, r = –0.347, n = 8; P = 0.399) or Marieke-group (Spearman correlation, r = –0.357, n = 22; P = 0.103). In contrast, there was a significant negative correlation between age and bodyweight deviation in the Chloor-group (Spearman correlation, r = –0.676, n = 12; P = 0.016). Younger individuals thus had higher bodyweight deviation compared to older individuals in the Chloor-group, but not in the other groups (Figure 4).

Long-term participation in voluntary weighing

Voluntary weighing was repeated in the Grey-group three months after the initial scale sessions. The nine individuals that participated during the initial scale sessions were again weighed voluntarily within two sessions of 3 h each. Furthermore, two additional individuals stepped onto the scale within these 6 h.

Discussion

This study aimed to determine whether voluntary weighing can be a valuable tool to monitor health and welfare of captive NHPs living in large social groups. We therefore assessed the utility, ie participation, reliability and time investment, of voluntary weighing in captive group-housed rhesus macaques. Although individuals were not willing to step onto an unbaited scale, 63 out of 92 individuals (68%) were weighed voluntarily when likeable food items were applied to the scale. When one group was tested again after three months, the same individuals (and two additional ones) still stepped onto the scale within a much shorter time-period than before. Furthermore, voluntary weighing resulted in reliable bodyweight measurements.

Participation in voluntary weighing

The overall level of participation in voluntary weighing was 68%. Previous studies found participation rates between 21 and 71% in free-ranging rhesus macaques (seven groups; Zhang *et al* 2016), while bodyweights of more than 90% of the individuals were obtained in free-ranging Japanese macaques (one troop; Mori 1979). Approximately 85% of immature yellow baboons in the wild were measured after presenting the scale two or three times a week for almost a year (two groups; Altmann & Alberts 1987). Although participation was somewhat lower in our study on captive rhesus macaques, the wild studies took a much longer period for weighing individuals, namely several weeks to months. Participation rates may thus be higher when extending the weighing period. Another way to increase participation rates may be to use more scales simultaneously, which provides more opportunities to step onto a scale.

To the authors' knowledge, there have been no studies reporting on the participation and success rate of training macaques in large social groups. Station- and target-training are very successful (87–97%) when training macaques in pairs and small groups (2–9 individuals per group; Schapiro *et al* 2003; Fernström *et al* 2009; Kemp

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et al 2017). In our breeding colony, which houses macaques in large naturalistic groups, participation in oral syringe training was, on average, 47% (range 24–66%) per session. Although 87% of the individuals participated at least once, only 65% (range 30–95%) were trained successfully (n = 14 groups, 9–27 individuals per group; unpublished data). Besides, training success depends very much on dominance rank as high-ranking individuals often monopolise training (Schapiro *et al* 2003), biasing the sample. In contrast, we found that voluntary weighing occurred independently of dominance rank. Therefore, voluntary weighing may yield data on a similar number of individuals as scale training, but likely measures partly different individuals.

Predicting participation

Individual characteristics, such as age, dominance rank and exploratory tendency, may determine who steps onto the scale and so it may be possible to predict which individuals are more likely to participate in voluntary weighing. An age effect with younger individuals being more likely to step onto the scale was expected, but not found. Although the highest stepping rates were indeed measured for young individuals, there were several juveniles that did not step onto the scale at all. As a result, individuals of different ages were equally likely to participate in voluntary weighing. This contrasts with studies indicating that younger individuals are usually more exploratory and attracted towards novelty (rhesus macaques: Insel *et al* 2008; vervet monkeys [*Cercopithecus aethiops*]: McGuire *et al* 1994).

Since there was only one scale in the enclosure during the sessions and high-ranking individuals usually have priority of access to restricted resources (Boccia *et al* 1988; Brennan & Anderson 1988), high-ranking individuals were expected to monopolise the scale. However, no association between dominance rank and stepping onto the scale was found. This is in contrast with wild toque macaques, where low-ranking individuals were under-represented at the baited weighing scale as a result of competition by high-ranking individuals (Dittus 1998). Initially, the novelty of the scale may have decreased competition, thereby providing an opportunity for low-ranking individuals to step onto the scale. In addition, the relatively long time-period the scale was available — namely at least 90 min per session — may have reduced monopolisation of the baited scale.

Exploratory tendency was measured by exposing individuals to a novel feeding method and, as expected, more exploratory individuals were more likely to step onto the scale. When individuals have similar behavioural responses in different contexts, personality traits may be involved, since personality is defined as individual differences in behaviour that are consistent over time and across situations (Réale *et al* 2007; Freeman & Gosling 2010). The reaction towards the novel feeding method and stepping onto the scale both seem to reflect an individual's exploratory tendency and may therefore be considered a personality trait. Thus, exploratory tendency measured by novel object tests can be used to predict which individuals are more likely to participate in voluntary weighing.

Finally, the likelihood to step onto the scale differed per group. Participation was significantly lower in the Grey-group and higher in the Marieke-group compared to the other groups. The efficiency of voluntary weighing thus differs per group. Inter-group variation in the ratio of measured individuals was also apparent in free-ranging rhesus macaques (Zhang *et al* 2016).

Reliability of voluntary weighing

The level of agreement between voluntary (VBW) and sedated bodyweight (SBW) was high, indicating voluntary weighing results in reliable bodyweights. This complies with previous studies that also tested the reliability of voluntary weighing (Vézina *et al* 2001; Bassano *et al* 2003). VBW was, on average, 0.44 kg higher compared to SBW, but there were considerable differences in bodyweight deviation between the four groups. Bodyweight deviation was higher in the Chloor- and Marieke-group compared to the Bertha- and Grey-group. These findings can be explained by two limitations in the study design, both of which are related to the timing of the measurements.

First, the time of day may have confounded the data, as individuals were heavier in the afternoon compared to the morning. Some individuals even increased VBW by 0.4 kg, which amounts to 3–4% of their bodyweight, from morning to afternoon. Bodyweight of immature yellow baboons was 6% higher in the evening, after a day of feeding, compared to the morning (Altmann & Alberts 1987). In free-ranging Japanese macaques, a maximum daily increase in bodyweight of 0.3 kg was found, which corresponds to a relative increase of 3–4% (Kurita 1999). This study concluded that the increase in bodyweight resulted from food intake during the day and this should be considered when collecting bodyweight data (Kurita 1999). As SBW was always measured in the morning when the animals were fasted, whereas VBW was measured during the day while the monkeys had access to food, this may have confounded the data. Since we were unaware of this confounding effect at the beginning of the study, most sessions in the Chloor-group were performed in the afternoon, which provides a partial explanation for the relatively large bodyweight deviation in this group.

Secondly, the difference between SBW and VBW may be due to natural body growth. SBW was measured two to three months prior to the scale sessions in the Chloor- and Marieke-group. There was thus a considerable time-period between the two measurements in these groups. At six years of age, female rhesus macaques reach skeletal maturation and bodyweight increase flattens (Schwartz & Kemnitz 1992). Since many individuals were yet to reach skeletal maturation, they were still growing, and their bodyweight still increased. Accordingly, VBW was higher than SBW in the Chloor- and Marieke-group, especially in the younger individuals, due to the time-period between the measurements. In contrast, VBW and SBW were collected around the same time in the Bertha- and Grey-group, so growth of juveniles was not a problem there. Thus, higher VBW relative to SBW does not

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represent false bodyweights, but most likely reflects individuals' real bodyweights that have increased as a result of food intake and/or natural body growth over time.

Time investment in voluntary weighing

The current study took a considerable amount of time. Setting up the scale and cameras, baiting the scale, observing and coding the videos (if necessary) took approximately 100 h in total. On average, 1 h and 35 min of time investment was thus necessary to weigh one individual. Time investment in voluntary weighing can be reduced by incorporating automated systems for identification and weighing in the home enclosure of NHPs, which are already available for livestock and birds (Turner *et al* 1984; Peiper *et al* 1993; Vézina *et al* 2001). These automated systems enable regular weighing of animals without human intervention. This may have the additional advantage of increasing participation in voluntary weighing, as human presence can impact animal behaviour, even when animals are properly habituated (cf Caine 1990). We therefore conclude that optimising and further developing the method will greatly enhance the utility of voluntary weighing as a means of monitoring health and welfare of captive, group-housed NHPs.

Recommendations for practical use

Based on the results of this study, we have several recommendations for the use of voluntary weighing in other institutions and/or other species of NHPs. Firstly, make sure that the monkeys cannot break the scale or injure themselves when exploring it. Use a 'monkey-proof' scale (ie no wires, screws, buttons, etc) and make sure that the monkeys cannot move it or lift it (either by weighing down the scale or fixing it to a surface). Second, apply small amounts of likeable, preferably sticky, food items to the scale and its immediate surroundings to attract individuals. Note that food preferences can differ per group and species. Third, perform voluntary weighing in the morning when individuals are yet to eat. This limits the effect of individual variation in food intake on bodyweight.

Animal welfare implications

Voluntary weighing is an animal welfare-friendly method of obtaining regular bodyweight measurements from NHPs. Regular bodyweight measurements allow the quick detection of bodyweight changes, which may signal underlying welfare issues. Voluntary weighing does not require animals to be caught and/or sedated, which minimises stress and prevents side-effects from anaesthesia. Furthermore, the animals are free to choose to participate or not.

Conclusion

Voluntary weighing is a reliable method of weighing captive socially housed NHPs. This study shows that the majority of individuals (68%) step onto the scale, but voluntary weighing is still relatively time-consuming, and efficiency of the method varies per group. When optimising and further developing the method, voluntary weighing can form a valuable tool in the captive management of NHPs.

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