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## The effect of four different feeding regimes on rabbit behaviour

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1 The effect of four different feeding regimes on rabbit behaviour

2

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15 **Keywords**

16 **Rabbit; Feeding; Behaviour; Abnormal behaviour; Hay.**

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17 Abstract

18 Dietary composition and presentation impacts on the behaviour of animals, and failure to provide a  
19 suitable diet can lead to reduced welfare through the development of poor health, the inability to  
20 express normal behaviours and the development of abnormal behaviours. This study assessed the  
21 effects of two commonly fed pet rabbit diets (extruded nuggets with hay (EH) and muesli with hay  
22 (MH)) alongside hay only (HO) and muesli only (MO) on the behaviour of 32 Dutch rabbits observed  
23 over 17 months. Increased time spent feeding was observed in the groups fed ad libitum hay (HO,  
24 EH, MH) compared to the MO group ( $P<0.05$ ). A corresponding high level of inactivity was observed  
25 in the MO group compared to rabbits receiving hay ( $P<0.05$ ). In the groups provided with hay a  
26 preference to consume hay in a natural grazing posture was observed. The higher activity levels and  
27 absence of abnormal behaviours when hay was fed support recommendations that forage should  
28 form a significant portion of the diet for domestic rabbits.

## 29 Introduction

30 As herbivores, wild rabbits consume relatively large amounts of a high fibre diet of low nutritional  
31 quality (Williams and Wells, 1974). This requires them to apportion a large amount of their time  
32 budget to grazing. Rabbits spend 30-70% of time outside the burrow grazing, pausing occasionally to  
33 groom (Mykytowycz, 1958; Myers and Poole, 1961; Myers and Mykytowycz, 1958; Lockley, 1961).  
34 Time spent eating varies with age, sex and social status within the group and has also been shown  
35 to increase when food availability falls during drought (Myers and Mykytowycz, 1958; Mykytowycz,  
36 1958). Grazing occurs mainly during late afternoon and throughout the night and daylight hours are  
37 spent underground in warrens (Myers and Mykytowycz, 1958; Mykytowycz, 1958; Lockley, 1961;  
38 Lockley, 1962). Caecotrophy is performed while underground (Southern, 1942). Domestic rabbits  
39 kept in free range conditions exhibit a similar feeding pattern to their wild counterparts (Vastrade,  
40 1987; Lehmann, 1991). In contrast, many pet rabbits are housed in small hutches with limited  
41 exercise opportunities (Mullan and Main, 2006; PDSA, 2011) and a diet consisting largely of  
42 concentrates (mono-component nugget or muesli mixes) (PDSA 2011) which can be consumed  
43 rapidly (Lidfors, 1997), with limited or no access to hay or grass (Mullan and Main, 2006; PDSA,  
44 2011).

45 Stereotypic behaviours are described as behaviours that are relatively invariant, regularly repeated  
46 and without an obvious function (Mason, 1991). Stereotypic behaviours reported to occur in  
47 laboratory rabbits include excessive grooming, sham chewing (chewing with nothing in mouth), bar  
48 biting, licking parts of cage, digging against cage, biting water nipple, sliding nose against bars, head  
49 pressing and running repeatedly in a defined pattern (Gunn and Morton, 1995; Lidfors, 1997). An  
50 apathetic state of inactivity and boredom has also been reported by Gunn and Morton (1995).  
51 Stereotypic behaviours occur most frequently during the night (Gunn and Morton, 1995) when  
52 rabbits are naturally at their most active (Mykytowycz 1958).

53 Whilst not studied in pet rabbits, the beneficial impact of providing hay to laboratory rabbits has  
54 been demonstrated (Lidfors, 1997; Berthelsen and Hansen, 1999) . The provision of hay to  
55 individually housed laboratory rabbits has proved effective at reducing the expression of abnormal  
56 behaviours (Lidfors, 1997; Berthelsen and Hansen, 1999).

57 Rabbits can consume pelleted feeds rapidly (Lidfors, 1997) and, whilst they may provide adequate  
58 nutrition for the maintenance of the rabbit, foraging behaviour is limited. If fed in limited amounts  
59 the rapid consumption of the daily ration may leave the rabbit in a state of hunger for a considerable  
60 portion of the day (Lidfors, 1997). It has been suggested that stereotypies in pigs and broiler  
61 breeder chickens develop through hunger and frustration at an inability to forage (Lawrence and  
62 Terlouw, 1993; de Jong et al., 2003; de Jong et al., 2005) when a restricted diet is fed. Rabbits  
63 provided with hay spend considerably more time interacting with it than with other forms of  
64 environmental enrichment, suggesting its importance to this species (Lidfors, 1997).

65 Despite recommendations that the ideal diet for pet rabbits is one of grasses, herbs, and leaves  
66 mimicking that of their wild counterparts (Clauss, 2012), the benefits of hay for meeting behavioural  
67 needs of rabbits , and that rabbits are able to maintain weight gain on forage only diets ([Lebas,  
68 2004](#); [Leiber et al., 2008](#)), studies suggest that at least 15-17% of pet rabbits do not have access to  
69 hay (Mullan and Main 2006; Schepers et al. 2009) and 36-42% are not fed recommended amounts  
70 (PDSA 2011; 2012). Veterinary surgeons frequently recommend feeding rabbits concentrates in  
71 limited amounts, as it is recognised that owners may often feed what may be considered excessive  
72 amounts of concentrate diets ([Harcourt-Brown, 2002a](#); [Meredith, 2006](#); [PDSA, 2011](#)) but it is unclear  
73 as to whether ad libitum (*ad lib*) access to hay is routinely recommended.

74 This study aimed to assess the effect of two commonly fed/recommended diet regimes (extruded  
75 nugget with *ad lib* hay and a mixed muesli type diet with *ad lib* hay), alongside a forage based diet  
76 and a muesli only diet, on the feeding behaviour and time budget of pet rabbits.

77 Materials and methods

78 Study animals

79 This study was conducted as part of a long term study to assess the effect of diet on the health and  
80 welfare of pet rabbits, as previously described by Prebble and Meredith (2014). Thirty two Dutch  
81 rabbits from five mixed litters (20 male and 12 female) were purchased at 8-9 weeks old from a  
82 single breeder. They were weighed on arrival (mean weight 0.84 kg±0.084). The rabbits were housed  
83 in 12 male-female neutered pairs and four male-male neutered pairs in wooden floor pens (0.96m<sup>2</sup>)  
84 with 12mm thick rubber matting, with shavings provided as bedding. The pens were split between  
85 two rooms with a 12hr light (0600-1800): 12 hour dark cycle, a temperature of 18°C (±2°C) and  
86 relative humidity between 40 and 70%. Rabbits were randomly allocated in pairs to four diet  
87 treatment groups and day 0 was designated as the day when the rabbits had been transitioned  
88 completely onto the treatment diet after an acclimatisation period. Detailed consideration of the  
89 experimental setup of the study with regard to the design and housing was undertaken and  
90 approved by the Ethical Review Committees of the Royal (Dick) School of Veterinary Studies and the  
91 Food and Environment Research Agency (FERA). The rabbits were housed in a facility licensed by the  
92 Home Office, however a project licence under the Animals (Scientific Procedures) Act 1986 (ASPA)  
93 was not required for this study. The study was continually monitored by the FERA Ethics Committee  
94 and Home Office inspector throughout its duration.

95 In the week following arrival six rabbits displayed signs of digestive disease, subsequently diagnosed  
96 as an outbreak of coccidiosis and clostridial enterotoxaemia. Supportive treatment was provided.  
97 Despite this, three rabbits died, but three recovered over the following 2 weeks. All remaining  
98 rabbits then received prophylactic treatment with a two day course of toltrazuril (Baycox 50 mg/ml  
99 Oral Suspension for Piglets, Calves and Lambs, Bayer plc, Newbury, Berkshire, UK) at a dose rate of  
100 2.5mg/kg ([Redrobe et al., 2010](#)) on day -43 and -42 and repeated five days later on day -37 and -36  
101 and metronidazole (Flagyl S 200mg/5ml Oral Suspension, Winthrop Pharmaceuticals UK Limited,

102 Guildford, Surrey, UK) at a dose rate of 20mg/kg twice daily for five days. Three 8 week old Dutch  
103 rabbits arrived on day -23 to replace those that died.

104

105 Diets

106 On arrival, rabbits were acclimatised over a period of 40 days (days -54 to -14) by maintaining their  
107 weaning diet and were fed 50g per rabbit of an extruded diet (Burgess® Excel-Junior and Dwarf  
108 Rabbit; Burgess Pet Care, Thornton Le Dale, North Yorkshire, UK) once a day plus *ad lib* Timothy Hay.  
109 Hay was provided in wall mounted hayracks to enable intake to be monitored and to prevent faecal  
110 and urinary contamination which may reduce intake of hay. Water was provided *ad lib* in 700ml  
111 bottles. At day-14 the paired rabbits were allocated to one of four diet treatment groups:

112 1 - Hay Only (HO) - *ad lib* supply of Timothy Hay (n=8);

113 2 – Extruded diet and Hay (EH) - 50g per rabbit Burgess Excel- Adult Rabbit (Burgess Pet Care,  
114 Thornton Le Dale, North Yorkshire, UK) with *ad lib* supply of hay (n=8);

115 3 - Muesli and Hay (MH) - 60g per rabbit Russell Rabbit Complete Muesli (Supreme Petfoods Limited,  
116 Ipswich, Suffolk, UK) with *ad lib* hay (n=8);

117 4 - Muesli Only (MO) - *ad lib* supply (125g per rabbit) of Russell Rabbit Complete Muesli (Supreme  
118 Petfoods Limited, Ipswich, Suffolk, UK) (n=8).

119 Rabbits were gradually transitioned on to their respective new diets over a two week period (day -14  
120 to day 0) to prevent digestive conditions associated with sudden dietary changes (Tzika et al. 2004).

121 From day 0 to the end of the study, (day 510; 17 months), rabbits were only fed the diet of that  
122 group.

123 The nutritional compositions of diets are shown in Table 1. The EH and MH diets represent two  
124 commonly fed diets fed according to the manufacturer's guidelines. The muesli consisted of 11

125 components: extrudates (4 types), pellets (2 types), grains (3 types), rolled peas and alfalfa stalks.  
126 Quantities of concentrates offered in the EH and MH groups were based on the lower end of the  
127 range of the manufacturer's stated guidelines to replicate dietary advice given by veterinary  
128 surgeons (Harcourt-Brown 2002a; Meredith 2006). The inclusion of the HO group was to provide a  
129 forage only diet similar to that of wild rabbits. The MO group was included because many  
130 commercially available muesli based diets are labelled as complete or 'nutritionally complete',  
131 leading owners to feed them alone. Muesli was provided to the MO group in sufficient quantities to  
132 ensure an ad libitum supply of food. All concentrates were weighed out and replaced daily to ensure  
133 accurate and consistent weights were offered. No measures were taken to prevent selective sorting  
134 or feeding of the different components of the muesli.

135 In the month following transition all rabbits were neutered and vaccinated against myxomatosis  
136 (Nobivac Myxo, MSD Animal Health, Milton Keynes, UK) and Viral Haemorrhagic Disease (Cylap,  
137 Pfizer Limited, Sandwich, UK) as recommended for pet rabbits at that age.

138 The rabbits continued on the four trial diets for 17 months (72 weeks). One pair of rabbits in the MO  
139 group had to be separated in week 3 following the development of aggressive behaviour and are not  
140 included in the analysis.

#### 141 Data collection

142 Behavioural observations were performed over two 24 hour periods in week 8 (timepoint 1: T1) and  
143 week 18 (timepoint 2: T2) of the trial diet period. A video recording using closed circuit television  
144 (CCTV was made for 24 hours from 0900h. Daily food rations (concentrates and/or hay) and water  
145 were provided prior to the start of recording, following which no one entered the room for the 24  
146 hour period. Red light was used during the 12h dark period which was present for 28 days prior to  
147 data collection to allow habituation. Recordings were carried out with WebCCTV NVR (Quadrox,  
148 Herent, Belgium).



149

150 Instantaneous scans of the CCTV recordings were performed every 15 minutes and the behaviour  
151 performed by each of the rabbits in the pen recorded. Data was collected by pen and  
152 measurements relating to bout duration were not recorded as rabbits were housed in pairs and  
153 could not be distinguished from each other on recordings. At both timepoints (T1 and T2) the first  
154 observations were in sequence from the lowest to the highest pen numbers. Individual behaviours  
155 were categorised into five groups (Feeding, Maintenance, Active, Inactive and Investigative) for  
156 analysis.

157 An ethogram based on Gunn and Morton (1993) was developed following prior observation of the  
158 rabbits and is detailed in Table 2. In addition, assessment of proximity was made during each  
159 instantaneous scan. Proximity was described as rabbits either separated by more than a third of the  
160 pen (apart), in the same third of the pen without touching (near to each other) , or in direct physical  
161 contact (together).

162

### 163 Statistical Analysis

164 Analysis of the data by behaviour group (Table 2) was performed on the total data set and also  
165 separately on data from light and dark periods. Behaviours in the feeding category were also  
166 analysed individually. The effects of sex on behavioural expression could not be assessed as it was  
167 not possible to distinguish between individual rabbits. Statistical analysis was performed using R  
168 software (v3.1.2 © 2014 The R Foundation for Statistical Computing and the R package *lme4* v 1.1-7).  
169 Overall percentages of time spent performing each behaviour when both time points were  
170 considered together were analysed using generalised linear mixed-effect models with binomial  
171 errors (*glmeb*) with Pen as the random effect. *Glmeb* models were also used to compare how hay  
172 was consumed, and whether rabbits differed in how much they stayed physically closer together  
173 between the 2 timepoints. When considering differences in behaviour between diet treatment

174 groups at specific time points, general linear models with binomial errors (*glmb*) were utilised.  
175 Tukey's post-hoc tests were carried out for both sets of models to assess pair-wise differences  
176 between groups where overall differences were found. Pearson's correlation was used to examine  
177 relationships between behaviours.  $P < 0.05$  was taken to indicate statistical significance and mean  $\pm$   
178 standard errors are quoted throughout.

179

## 180 **Results**

181 Figure 1 shows the percentage of time spent performing different behaviours at the two timepoints  
182 by diet treatment group. Overall, *feeding* was negatively correlated with *inactivity* at both time  
183 points (T1:  $\rho = -0.892$ , T2:  $\rho = -0.918$ ,  $P < 0.001$ ) and *maintenance* behaviours at timepoint 2 ( $\rho = -0.547$ ,  
184  $P = 0.035$ ).

### 185 Effect of dark/ light period on behaviour

186 Differences in percentage of time spent performing different behaviours were affected by the light  
187 dark cycle (Figure 2). *Feeding* (Dark: mean =  $32.44\% \pm 2.84$ , Light:  $28.54\% \pm 4.68$ ), *maintenance*  
188 (Dark:  $9.76\% \pm 1.34$ , Light:  $5.93\% \pm 1.06$ ) and *investigative* (Dark:  $3.15\% \pm 0.69$ , Light:  $1.5\% \pm 0.29$ )  
189 behaviours occurred more frequently in the dark period (Overall:  $P < 0.001$ , T1:  $P < 0.019$ , T2:  $P < 0.013$ )  
190 whilst *inactive* (Dark:  $52.31\% \pm 2.29$ , Light:  $63.20\% \pm 3.90$ ) behaviours occurred more frequently in the  
191 light period ( $P < 0.001$  for overall, T1 and T2).

192 In the light period, the HO group spent more time *feeding* (overall  $49.7\% \pm 2.4$ ) in comparison to  
193  $9.3\%$  ( $\pm 3.5$ ) of time by the MO group ( $P < 0.001$  for overall, T1 and T2), and the HO group spent less  
194 time *inactive* (overall  $45.8\% \pm 3.3$ ) than the MO group (overall  $83\% \pm 6.2$ ,  $P < 0.001$  for overall, T1 and  
195 T2). No differences between the 4 groups in percentage of time spent performing *maintenance* and  
196 *investigative* behaviours were present in the light period ( $P > 0.085$  for overall, T1 and T2). In  
197 contrast, *maintenance* behaviours were performed more frequently in the MO group than all other

198 groups in the dark period overall ( $P<0.029$ ) and T1 ( $P<0.037$ ), but only the HO group spent less in  
199 *maintenance* than MO at timepoint 2 ( $P<0.001$ ,  $P>0.120$  other groups) (Figure 2).

200

#### 201 Effect of diet group on behaviour

202 Over the total twenty four hour period (combining light and dark periods) at each timepoint, the MO  
203 group spent significantly less percentage time *feeding* (T1:11.33%  $\pm$ 4.33, T2:9.33%  $\pm$ 4.68) and more  
204 time *inactive* (T1:71%  $\pm$ 4.02, T2:74.67%  $\pm$ 3.35) than all other groups ( $P<0.006$ , Figure 1). The HO  
205 group also spent significantly more percentage time *feeding* (T1:44.25%  $\pm$ 1.60, T2:40.75%  $\pm$ 1.31)  
206 than the MH (T1:26%  $\pm$ 1.68, T2:23.5%  $\pm$ 1.44) group at both timepoints ( $P<0.001$ ). The EH group  
207 spent significantly less percentage time *feeding* (T1:26%  $\pm$ 1.68, T2:23.5%  $\pm$ 1.44) than the HO group  
208 ( $P<0.001$ ), however there was no significant difference in levels of *inactivity* between these two  
209 groups (53%  $\pm$ 2.42) at time point 1 ( $P=0.846$ ). At time point 2 the EH group spent significantly more  
210 percentage time *inactive* (59.25%  $\pm$ 1.70, than the HO group ( $P<0.002$ ). Compared to the EH group,  
211 the MH group spent significantly less percentage time *feeding* and more time *inactive* at timepoint 1  
212 ( $P<0.001$ ), but there was no significant difference spent *inactive* at timepoint 2 ( $P>0.09$ ).

213 Consumption of hay from between the bars, with the front paws placed on the hayrack (T1:16.38%  
214  $\pm$ 5.75, T2:26.45%  $\pm$ 14.9) occurred significantly less than consumption of hay whilst in a natural  
215 grazing posture from either the floor or whilst sat in the hay rack (T1:83.62%  $\pm$ 5.75, T2:73.55%  
216  $\pm$ 14.9,  $P<0.001$ , Figure 3).

217 Observations of *maintenance* behaviours were significantly higher in the MO group (T1:11.67%  
218  $\pm$ 1.47, T2:12.67%  $\pm$ 1.89) than in the HO group (T1:5%  $\pm$ 0.41, T2:6%  $\pm$ 1.35) at both timepoints  
219 ( $P<0.001$ ) and the EH group (T1:7%  $\pm$ 1.37, T2:9.75%  $\pm$ 2.14) at timepoint 1 ( $P=0.027$ ). *Maintenance*  
220 behaviours occurred significantly more frequently in the MH group (T1:9%  $\pm$ 2.86, T2:8.25%  $\pm$ 1.7)

221 than the HO group at timepoint 1 ( $P<0.02$ ) but not timepoint 2 ( $P=0.391$ ). While at timepoint 2  
222 *maintenance* behaviours were significantly greater in the MO group than the MH group ( $P=0.038$ ).  
223 *Active* behaviours were observed significantly more frequently in the MH group (T1:2.5%  $\pm$ 0.65,  
224 T2:2%  $\pm$ 0.58) than the HO group (T1:0.5%  $\pm$ 0.29, T2:1.75%  $\pm$ 0.85) only at timepoint 1 ( $P=0.018$ ).  
225 *Investigative* behaviour occurred more frequently in the MO group (T1:4.67%  $\pm$ 0.63, T2:2%  $\pm$ 0.48)  
226 than the HO group again only at timepoint 1 (T1:1.25%  $\pm$ 0.25, T2:2%  $\pm$ 0.41,  $P=0.001$ ).

227

228 In all groups, time spent in direct physical contact (together) was greater at T2 (38.73%  $\pm$ 2.37) than  
229 at T1 (10.13%  $\pm$ 1.58, Figure 4,  $P<0.001$ ). The HO group spent less time together (T1:4%  $\pm$ 1.08, T2:  
230 27.75%  $\pm$ 3.09) than the MH (T1:14.25%  $\pm$ 8.76, T2:46.5%  $\pm$ 7.44) and MO (T1:15.33%  $\pm$ 6.22, T2:58%  
231  $\pm$ 6.08) groups at both timepoints ( $P<0.015$ ). The MH and MO groups spent a greater proportion of  
232 time together than the EH (T1:8.25%  $\pm$ 2.78, T2:27.5%  $\pm$ 4.17) group only at the second timepoint  
233 ( $P<0.001$ ). In addition the MO group spent more time together than the MH group only at timepoint  
234 2 ( $P=0.019$ )

235

#### 236 Other observations

237 Throughout the study, rabbits from MH, HO and EH groups were observed pulling hay from the hay  
238 rack using a digging motion with their front paws and subsequently consuming hay from the floor.  
239 In addition, rabbits in the majority of pens also jumped into the hay rack to consume hay.

240 Over the whole study period (17 months), hair chewing was recorded in one rabbit within the MO  
241 group and occurred in the period following the removal of its pen mate from the trial. Chewing of  
242 objects in the pen was seen infrequently on the videos (0.14% of observations), however damage to  
243 wooden fixtures within the pen as a result of chewing occurred in all groups over the whole study

244 period. Chewing of the rubber matting used as flooring was observed only in the MO group. In  
245 addition to chewing the rubber matting, rabbits in the MO group were also often observed eating  
246 the shavings provided as bedding over the duration of the entire 17 month trial.

## 247 **Discussion**

248 This study has provided preliminary information on the effect of diet on the time budgets of pet  
249 rabbits. Diet affects time budgets of many herbivorous mammals including horses, sheep and pigs  
250 (Ruckebusch and Gaujoux, 1976; Robert et al., 1993; Thorne et al., 2005). Previous studies in rabbits  
251 have been limited to laboratory rabbits which focus on environmental enrichment including the use  
252 of hay and food based enrichments rather than their use as a diet (Lidfors, 1997; Berthelsen and  
253 Hansen, 1999; Harris et al., 2001), whereas this study assessed the effect of different feeding  
254 regimes on the time budgets of pet rabbits.

255 Time spent feeding was highest in the HO group which had the diet of lowest nutritional value. Wild  
256 rabbits spend between 30-70% of their time above ground eating (Myers and Mykytowycz, 1958;  
257 Mykytowycz, 1958) but this can rise to 90% when diet quality is poor (Myers and Poole, 1961). As  
258 wild rabbits are above ground between 11 and 13 hours per day (Mykytowycz, 1958) this equates to  
259 a range of approximately 14 - 38% of total time spent eating. The time spent feeding in the groups  
260 provided with hay (HO, EH and MH) groups falls within this range at both timepoints, however the  
261 average time spent feeding by the HO group was at the top end of this range and is similar to figures  
262 reported by Myers and Poole (1961) in rabbits during summer when diet quality is of low nutritional  
263 value. Conversely the MO group spent less time feeding (9-11%) than wild rabbits. Reduced  
264 opportunity for foraging in herbivores, including rabbits, has been associated with the development  
265 of abnormal and stereotypical behaviours (Robert et al., 1993; Lidfors, 1997; Berthelsen and Hansen,  
266 1999; Thorne et al., 2005). These may occur as a result of boredom, hunger or frustrated attempts  
267 to display foraging behaviours which they are motivated to perform (Newberry, 1995; D'Eath et al.,  
268 2009).

269 The reduction in time spent feeding was matched with corresponding increases in time spent  
270 inactive; a similar pattern of behaviour is also reported in sheep (Ruckebusch and Gaujoux, 1976).  
271 The increase in inactivity and reduction in active feeding behaviours may have contributed to both  
272 the development of abnormal behaviours ( see below) and high weight gain and increased body  
273 condition observed in the MO group (Prebble and Meredith, 2014).

274 Stereotypy has been reported to occur at a mean frequency of 11% over a 24 hr period in laboratory  
275 rabbits (Gunn and Morton, 1995). Stereotypical behaviours include hair chewing, chewing objects,  
276 nose sliding and licking objects (Gunn and Morton, 1995). Hair chewing along with other abnormal  
277 behaviours are suggested as indicators of stress (Podberscek et al., 1991; Gunn and Morton, 1995)  
278 and therefore in the one rabbit in which hair chewing was observed, this could have been triggered  
279 by the loss of the companion, as rabbits are highly motivated to have social contact (Seaman et al.,  
280 2008). The lack of access to hay may also have contributed to the hair chewing in this rabbit, as  
281 provision of hay has been demonstrated to prevent hair chewing in laboratory rabbits (Mulder et al.,  
282 1992). Although chewing of wood occurred in all diet groups in this study, the chewing of rubber  
283 matting and ingesting of shavings in the MO group could be indicative of abnormal behaviour. The  
284 chewing of rubber matting may be misdirected chewing as a consequence of reduced time feeding.  
285 Increased levels of abnormal behaviours have been found in pigs that do not have a suitable  
286 substrate for foraging (Spooler et al. 1995). This would indicate that the rabbits needed or craved a  
287 higher fibre food source and is a behaviour also reported in horses fed on a low forage diet (Houpt et  
288 al. 1988).

289

290 The level of potential stereotypy and abnormal behaviour is lower in this study than that reported by  
291 Gunn and Morton (1995) and this may reflect differences in the rabbit's husbandry. Rabbits in this  
292 study were housed in pairs whereas rabbits studied previously were housed in social isolation which  
293 increases expression of abnormal behaviours (Chu et al. 2004). The observations of Gunn and

294 Morton (1995) were also performed in laboratory cages which limited behaviours such as rearing,  
295 hoping and lying outstretched. Increasing the amount of space available reduces inactivity and  
296 allows expression of a fuller behavioural repertoire in rabbits (Dixon et al. 2010) and reduces  
297 abnormal behaviour (Chu et al. 2004). Therefore the social contact and increased space (allowing  
298 expression of most behaviours) provided in this study may have contributed to the low overall levels  
299 of abnormal behaviours seen. In addition, the use of instantaneous scans rather than continuous  
300 monitoring may have reduced detection of misdirected chewing behaviour as it occurs as an event  
301 rather than a state.

302

303 The higher proportion of time spent consuming hay from the floor or whilst sitting in the hayrack  
304 suggests that rabbits prefer to consume hay in a natural grazing posture with the head down rather  
305 than from a hay rack which requires elevation of the head. Similar findings have been observed in  
306 horses which have been observed actively pull hay onto the floor and spending a higher proportion  
307 of time consuming it from the floor than from troughs (Sweeting et al., 1985).

308

309 The findings of this study highlight the effect of forage on behaviour in pet rabbits. The increased  
310 inactivity and reduction in time spent eating in rabbits on the muesli only diet indicates an impact on  
311 welfare through the inability to express normal foraging behaviour (evidenced by misdirected  
312 chewing of rubber matting and consumption of bedding), in addition to the development of obesity,  
313 also reported elsewhere in the MO rabbits (Prebble et al., 2014) through reduced activity levels.

314 Provision of forage is essential to promote welfare of rabbits and should form a significant portion of  
315 the rabbit's diet.

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317

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418 **Table 1.** Nutritional composition of diets offered, with values expressed as % Dry Matter (DM)

419

420 **Table 2.** Rabbit Ethogram used in this study (based on Gunn and Morton (1993))

421

422 **Figure 1.** Time budgets of Dutch rabbits fed on four diets, hay only (HO), Extruded nugget and hay  
423 (EH), Muesli and hay (MH) and Muesli only (MO). Percentage of observations consisting of feeding,  
424 inactive, maintenance and other (made up of active and investigative behaviours) behaviours for a  
425 24 hour period at timepoint 1 (week 8) and timepoint 2 (week 18) after the start of the dietary  
426 treatments.

427

428 **Figure 2.** Time budgets of Dutch rabbits fed on four diets, hay only (HO), Extruded nugget and hay  
429 (EH), Muesli and hay (MH) and Muesli only (MO). Percentage of observations consisting of feeding,  
430 inactive, maintenance and other (made up of active and investigative behaviours) behaviours for the  
431 light and dark periods (12 hour light dark cycle) at timepoint 2 (week 18) after the start of the dietary  
432 treatments.

433

434 **Figure 3.** Feeding behaviour of Dutch rabbits fed on four diets, hay only (HO), Extruded nugget and  
435 hay (EH), Muesli and hay (MH) and Muesli only (MO). Breakdown of the feeding behaviours  
436 observed at timepoint 1 (week 8) and timepoint 2 (week 18) after the start of the dietary  
437 treatments.

438

439 **Figure 4.** Proximity of paired Dutch rabbits to each other. Rabbits fed on one of four diets, hay only  
440 (HO), Extruded nugget and hay (EH), Muesli and hay (MH) and muesli only (MO). Percentage of time  
441 spent separated by more than a third of the pen, in the same third of the pen without touching, or in  
442 direct physical contact over a 24hour period at timepoint 1 (week 8) and timepoint 2 (week 18) after  
443 the start of the dietary treatments.