Can Iberian red deer (*Cervus elaphus hispanicus*) discriminate among essential minerals in their diet?

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Optimal foraging predicts that animals should be able to assess the content of important nutrients in food. Ungulates discriminate salt and P, but discrimination of other minerals is controversial even though they are also essential and often limiting. Animal scientists have explained this taste through palatability, which predicts the same pattern of discrimination for calves and hinds and greater consumption by the latter. Social learning may also be involved, predicting a correlation between mother and calf and less consumption by the latter. The present study examines the consumption behaviour of free-choice supplemented minerals by hinds and calves of Iberian red deer (*Cervus elaphus hispanicus*) to discern between these hypotheses. Behavioural indices of intake correlated with actual mineral consumption (*P*<0.001). Mother and calf behavioural indices correlated only for salt-mixed minerals. Calves showed overall behavioural indices of consumption greater than hinds (*P*<0.001 and *P*<0.001), and also for all single supplements except NaCl, as expected from growth needs and in contrast to the palatability hypothesis. Calves showed a greater consumption of CuSO₄ and lower of Na₂SeO₃ than pure salt. Hinds showed a different pattern, ingesting lower amounts of all minerals except CuSO₄ and salt. Additional analyses also showed discrimination between minerals unmixed with salt, such as CaHPO₄ and CaCO₃ (*P*=0.012 and *P*=0.002). The greater intake of growing calves and the different consumption patterns for hinds and calves suggest that deer can discriminate among minerals, and that they do not consume minerals for their palatability or driven by social learning. Therefore, deer may be selecting minerals according to nutritional requirements.

**Conditioned learning: Diet selection: Free choice: Mineral supplements: Palatability**

Optimal foraging theory¹⁻³ predicts the role of food quality in determining the diet composition and foraging tactics of animals. In the case of herbivores, this happens mainly by optimising energy intake and protein⁴⁻⁵, but also nutritional value⁶,⁷, macronutrients⁸, maximising digestion rate⁹, and even avoiding poisonous toxins and tannins that reduce the digestibility of plant material³,¹⁰. However, balanced nutrition is a very complex process which requires an adequate intake of minerals, vitamins and other nutrients¹¹. Thus, diets of free-ranging ungulates are usually much more varied than ecologists predict on the basis of this theory¹², and this implies that when animals behave as optimal foragers they should be able to assess the content of the most important nutrients in food. Among others, the most essential minerals should also be assessed on this basis, and ingested to meet threshold amounts.

All mammals have the ability to taste salt, and since Belovsky¹² explained diet selection of moose (*Alces alces*) by energy and Na balance, many behavioural studies have focused on Na intake, as this is one of the most limiting minerals for ungulates in natural habitats¹³,¹⁴. However, many other minerals are also essential and limiting in nature, and in fact they are usually supplemented in ruminant livestock¹⁵,¹⁶. McNaughton¹⁷,¹⁸ even explained the distribution and migration of African ungulates based on Na availability in pastures, but also pointed out a possible influence of other minerals such as Al, Ca, Fe, Mg and P. Thereafter, several studies have suggested that different ungulate species were actively seeking for different minerals such as Ca, Mg or P under different situations such as free-choice cafeteria-style experiments, use of soil licks or analysis of forage mineral composition¹⁹⁻²². As optimal foraging theory assumes, many of these studies¹⁷,¹⁸,²²,²³ suggested or showed that patterns found were related to diet deficiencies (‘specific hungers’ or ‘nutritional wisdom’ hypothesis²⁴).
also proposed for trace minerals and ungulates (25), but in fact a corollary of foraging theory as mentioned above. Our own previous results in red deer (Cervus elaphus hispanicus) showed specific intakes of Na and Co in relation to their content in food (26). Thus, evidence reported suggests that ungulates have evolved the ability to detect Na and the major minerals forming vertebrate bodies (Ca and P (27)). In contrast, there seems to be little evidence whether ungulates can detect and consume other minor but essential minerals.

The optimal foraging approach as a general rule has been criticised (particularly in the case of minerals) by animal scientists arguing that with such variety of nutrients (amino acids, vitamins, minerals, etc) and toxins, it seems unlikely that evolution has equipped animals with a specific appetite for each one (15,28–32). They have proposed that ‘conditioned food learning’ is the most important mechanism by which herbivores optimise food selection of some nutrients and toxins by learning about the negative and positive consequences of consuming particular plant species through a series of encounters (post-ingestive cues (33–35)). Thus, by having this mechanism, animals would not need an innate ability to assess each specific nutrient. Negative conditioning has been repeatedly shown in ruminants under experimental (36–39) and natural conditions (40), but hardly for positive conditioning as would be required to study mineral intake (41) (but see Ginane et al. (42) and Sclafani (43) for negative results), and neither for experiments with multiple foods similar to free-ranging conditions (35,44–40). Thus, conditioned learning assumptions seem unlikely to be met in the complex ruminant diets proposed by optimal foraging theory (45–49). Moreover, conditioned learning seems unlikely for minerals because they are needed from the earliest stages of life (thus, there should be some ‘innate predispositions’ (35,50)), and the remarkable effect they have on growth (16,51) suggests that mammals are unlikely to afford the amount of time required for such learning. In addition, conditioned learning effects depend on relative deficiency, ranging from increasing positive effects with increasing intake under deficiency, to neutral effects when requirements are met, and finally, increasing negative effects with increasing intake when toxicity thresholds are exceeded. On the other hand, the nutritive value of a particular mineral content in a plant or food source depends on the amounts of the same or other minerals present in other plants or food sources consumed simultaneously, as the intake of some minerals reduces the absorption of others, causing their deficiency (16). Thus, the complex interactions between intakes of specific minerals in a food source may have positive effects on some occasions, but neutral or even negative effects on other ones depending on the rest of the food items consumed at the same time.

Another factor involved in food selection is taste, which has evolved to evaluate some parameters of food such as salinity, energy, toxins and maybe proteins (52), creating ‘innate predispositions’ widely accepted for many nutrients (53). Thus, taste is another mechanism involved in consumption of mineral supplements in such a way that ruminants may even die before consuming an unpalatable mineral source (15,53). The prediction derived from this hypothesis is a great intake of a palatable taste regardless of its beneficial effect (54,55).

Finally, the process of food selection according to the nutritive value of the diet components may be influenced by social learning. This term indicates a higher probability that an animal eats a certain food if it sees another one consuming it, or smells such food from the mouth of another (56). This may be particularly interesting in our setting, as calves may learn from the behaviour of their mothers, being more likely to taste those minerals that their mothers consume and being more reluctant to eat even necessary minerals that their mothers do not consume.

The aim of the present paper was to examine taste- and social- learning- triggered intake predicted by the optimal foraging hypothesis through the consumption behaviour of free-choice- supplemented minerals by lactating hinds of Iberian red deer and their calves, with an experimental design to assess if deer can discriminate between minerals. As positive conditioning seems unlikely to explain mineral nutrition by ruminants, free-choice consumption of salt-mixed mineral supplements can only be driven by optimal foraging or by palatability. Common salt, because of its palatability, is a valuable carrier of unpalatable minerals when mixtures contain 30–40% salt or more (15). We predicted that if deer discriminate among salt-mixed macro- and microminerals, they should show different consumption patterns. Under the palatability hypothesis they should show similar consumption patterns among all salt-mixed mineral supplements. Finally, under social learning calves should show similar patterns to their mothers, but less consumption shaped to their different weight. We also predict a greater consumption by calves if they behave as optimal foragers because they have greater requirements than hinds, whereas consumption should be greater for hinds if intake is predicted by palatability because of their larger bodies.

Materials and methods

The present study was carried out at the Experimental Farm of Universidad de Castilla-La Mancha (Albacete, Spain), under similar conditions as described by Landete-Castillejos et al. (57). The experiments were performed during the 2005 and 2006 lactation season involving adult red deer hinds aged between 2 and 12 years old. All animals used were reared in captivity. During the first year, we used thirty-six hinds and their calves, and in the second year twenty-three different hinds and their calves. None of the hinds calved twins in those years. Study animals were kept captive in 10 000 m² enclosures without pasture. Both during gestation and throughout lactation, animals were fed with diets based on suggestions by Brelurut et al. (58), using barley straw and hay from barley, lucerne, oat and sweet beetroot (16 % protein). Deer had ad libitum access to food and water. Calving took place during the months of May and June. Calves were weighed on their first 24 h of life and marked with ear tags (Allflex GTLF1, 76 × 57 mm; Allflex USA, Inc., DFW Airport, TX, USA). After 1 week, when calves started to be active all day, they were marked with ovine-livestock collars (Flexican 00 015, 655 × 59 × 12 mm; Flexican, Albacete, Spain), the same as hinds, so that all individuals could be identified from a distance. All enclosures were connected to handling premises by a 5 m wide corridor, where animals were weighed once per week on a ± 50 kg electronic balance. Calves up to 35 kg body weight were measured on a ± 5 g balance and on the same balance as their mothers thereafter.

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Diet selection of minerals by red deer

Table 1. Empirical formulas, mineral concentration and source of minerals supplemented

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>Supplement</th>
<th>Empirical formula</th>
<th>Offering format</th>
<th>Mineral concentration</th>
<th>Element content in diet*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>Calcium carbonate</td>
<td>CaCO₃</td>
<td>Pure</td>
<td>38-0 % Ca</td>
<td>0-73 %</td>
</tr>
<tr>
<td>Co</td>
<td>Cobaltous sulfate</td>
<td>CoSO₄·7H₂O</td>
<td>Mixed with NaCl at 7-5 %</td>
<td>1-8 % Co</td>
<td>0-03 ppm</td>
</tr>
<tr>
<td>Cu</td>
<td>Cupric sulfate</td>
<td>CuSO₄·5H₂O</td>
<td>Mixed with NaCl at 7-5 %</td>
<td>1-9 % Cu</td>
<td>16 ppm</td>
</tr>
<tr>
<td>Fe</td>
<td>Iron carbonate</td>
<td>FeCO₃</td>
<td>Pure</td>
<td>38-0 % Fe</td>
<td>230 ppm</td>
</tr>
<tr>
<td>I</td>
<td>Calcium iodate</td>
<td>Ca(IO₃)₂</td>
<td>Mixed with NaCl at 7-5 %</td>
<td>4-7 % I</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Potassium chloride</td>
<td>KCl</td>
<td>Pure</td>
<td>52-3 % K</td>
<td>0-99 %</td>
</tr>
<tr>
<td>Mg</td>
<td>Magnesium oxide</td>
<td>MgO</td>
<td>Pure</td>
<td>55-0 % Mg</td>
<td>0-32 %</td>
</tr>
<tr>
<td>Na</td>
<td>Sodium chloride</td>
<td>NaCl</td>
<td>Pure</td>
<td>40-0 % Na</td>
<td>484 ppm</td>
</tr>
<tr>
<td>P</td>
<td>Dicalcium phosphate</td>
<td>CaHPO₄·2H₂O</td>
<td>Pure</td>
<td>18-0 % P; 23-0 % Ca</td>
<td>0-45 %</td>
</tr>
<tr>
<td>Se</td>
<td>Sodium selenite</td>
<td>Na₂SeO₃</td>
<td>Mixed with NaCl at 7-5 %</td>
<td>0-04 % Se</td>
<td>13 ppm</td>
</tr>
<tr>
<td>Zn</td>
<td>Zinc sulfate</td>
<td>ZnSO₄·4H₂O</td>
<td>Mixed with NaCl at 20 %</td>
<td>7-2 % Zn</td>
<td>36 ppm</td>
</tr>
</tbody>
</table>

ppm, Parts per million.

* Mineral content in diet was measured by atomic absorption spectrophotometry. Iodine content in diet could not be detected.

One set of containers (30 cm wide; 50 cm long; 20 cm deep) with different minerals was offered lined up inside a shed which provided shelter from the wind and rain. Minerals were offered in chemical forms commonly used as animal supplements, and often selecting the alternative of highest bioavailability. This is defined as the proportion of the mineral which can be used by the animal to meet its bodily needs. Minerals were offered in mixtures and concentrations recommended for ruminants (16,59,60) (Table 1) and the position of the containers was randomly changed monthly to prevent confounding preference for a specific site with mineral discrimination. As trace minerals have toxic doses at low levels, and thus their presentation in pure form could risk accidental poisoning, they were offered mixed in with NaCl at concentrations trading detectability and safety. Animals could thus choose between pure Na and Na with Co, Cu, Se, I or Zn. Supplement consumption necessary to meet daily requirements of all salt-mixed minerals (Co, Cu, Se, Zn and I) implies the ingestion of just 28 % of Na daily requirements (calculated following available data on requirements (16,61)). That way, the ingestion of one mineral can be considered as independent of the ingestion of other minerals. Containers were weighed weekly with a Gram Precision AK Eagle 30 (± 5 g) portable scale (Gram Precision Scales, Inc., Mississauga, ON, Canada).

Behaviour of mineral consumption was recorded by two cameras installed inside the shed where minerals were offered. Cameras worked from 07.00 to 19.00 hours, from the first birth (middle May) up to weaning (middle September), and recording was buffered on a hard disk. Recordings showed every mineral intake event by each animal, its time length and the supplement consumed (containers were labelled both sides to be easily identified). As the exact amount of mineral swallowed by every animal could not be assessed, total consumption time (in s) and total number of intake visits were used as behavioural indices of consumption. Visits were considered only when jaw movement was observed, as animals used to sniff briefly different containers before eating. Other species (pigeons, rodents, etc) were seen to interact with the mineral containers.

As milk production requires large amounts of minerals (62), we also assessed milk yield and its influence on mineral consumption by hinds. Hinds were milked under anaesthesia on weeks 2, 4, 6, 10, 14 and 18 of lactation, after 6 h isolation. Milking frequency was reduced to prevent stress and the potential damaging effects of the anaesthesia. A low-dose combination of xylazine (0-5 mg/kg body weight) and ketamine (1 mg/kg), delivered by intravenous injection, was used. Once anaesthesia was induced, 10 IU oxytocin were injected in the right jugular vein 1 min before the start of milking, in order to induce milk let-down. Total production of milk was computed as the mean production of two milkings multiplied by the time period between them, and then adding up the results for all milking periods (63).

Ethical note

All sampling procedures and handling procedures were designed to reduce stress for the animals, according to European and Spanish laws and current guidelines for ethical use of animals in research (64). The experiment was approved by the University Ethical Committee of Universidad de Castilla-La Mancha.

Statistical analysis

Pearson correlations showed how the behavioural indices used (time and visits) correlated with total supplement consumption. Student’s t tests were used to assess differences between hinds and calves in behavioural indices of consumption (separately, mean intake visits and mean consumption time per individual; both in general and for every mineral compound). Similar Student’s t tests analysed the effect of calf sex in mean values per individual of the same variables. The same analysis showed differences between male and female calves in birth weight and gains during lactation, as well as differences between hinds rearing a male or a female in calving weight and milk production.

General linear model (GLM) analyses were performed on total intake visits and total consumption time per hind, in order to see the influence of age in overall mineral consumption relative to other physiological variables. In order to assess discrimination among different minerals, another set of GLM examined mean intake visits and time spent on each mineral per animal (coded as a categorical factor) relative to that of NaCl. These sets of GLM (examining separately hinds and calves) also examined the effect of important lactation variables such as calf sex, age, total milk production, calving weight of mothers, and birth weight and gains of calves.
during lactation. Statistical analyses were performed using SPSS (version 15.0; SPSS, Inc., Chicago, IL, USA).

To assess the effect of social learning, we correlated the consumption time or frequency of visits of each hind and her calf towards each supplement separately. Because the data did not fit a normal distribution, we used non-parametric Spearman correlations between behavioural indices of the mother and those of her calf.

**Results**

As the exact amount of mineral consumed in every visit could not be assessed, total consumption time (in s) and total intake visits were used as behavioural indices of consumption. These indices correlated significantly with total consumption (g) of every supplement during every year of the experiment (n 21; consumption time, \( R^2 0.79 \); intake visits, \( R^2 0.74 \); both \( P<0.001 \)). Thus, they can be used as indices of actual mineral consumption.

**Age-related differences in mineral consumption**

Student’s \( t \) tests revealed overall differences in behavioural indices of mineral consumption between adult hinds and suckling calves (Fig. 1). Calves had a longer consumption time (\( F(1, 117) = 7.67; P<0.01 \)) and greater frequency of intake visits (\( F(1, 117) = 17.7; P<0.001 \)) than their mothers. Mean time per visit was similar for hinds and calves. The same analysis exerted on each mineral showed differences between hinds and calves on mean consumption time for all mineral supplements, except NaCl (Fig. 2(a); parameters not shown for purposes of briefness). Similarly, there were

![Fig. 1. Overall behavioural differences in consumption-related behaviours (time and frequency of intake visits; all minerals pooled), and time per event, between hinds (□) and calves (■). Values are means, with standard deviations represented by vertical bars. Mean value was significantly different from that for the hinds: ** \( P<0.01 \), *** \( P<0.001 \) (Student’s \( t \) test).](image1)

![Fig. 2. Behavioural consumption differences between hinds (□) and calves (■) for every mineral offered in a cafeteria test. (a) Consumption time; (b) intake visits. Values are means, with standard deviations represented by vertical bars. Mean value was significantly different from that for the hinds: * \( P<0.05 \), ** \( P<0.01 \), *** \( P<0.001 \) (Student’s \( t \) test).](image2)
differences between hinds and calves on mean frequency of intake visits for all mineral supplements except NaCl and CuSO₄ (Fig. 2(b)).

A GLM examining overall mineral consumption by hinds also showed the influence of age on total consumption time and frequency of intake visits. This age effect was only observed over intake visits (model $R^2 = 0.24\%$; intercept, $-37$ (SD 32); calf sex, $15.2$ (SD 7.4), $P=0.047$; calving weight, $0.90$ (SD 0.37), $P=0.018$; total milk yield, $(10 \text{ (SD 1)}) \times 10^{-3}$, $P=0.026$; age, $-2.68$ (SD 1.31), $P=0.046$; year was NS) but not over consumption time.

Sex-related differences in mineral consumption

Male and female calves showed similar consumption behaviour (Fig. 3(a) and (b)) except for NaCl (consumption time, $F(1, 58) = 4.26$, $P=0.044$; intake visits, $F(1, 58) = 5.40$, $P=0.024$) and CaCO₃ (consumption time, $F(1, 58) = 6.19$, $P=0.016$; intake visits, $F(1, 58) = 5.14$, $P=0.027$). Even if males have greater calf birth weight ($F(1, 58) = 14.44$; $P<0.001$) and calf gains ($F(1, 58) = 47.06$; $P<0.001$), there was no effect of sex on overall behavioural indices of consumption (Table 2), although indices were always greater for males than females. GLM models also showed a greater consumption time and intake visits by hinds rearing a male calf (Table 3), but there were no differences in calving weight ($F(1, 58) = 2.38$; NS) and total milk yield ($F(1, 43) = 0.93$; NS).

**Mineral discrimination**

Two GLM tested the difference in consumption time and intake visits between minerals supplemented and the most consumed mineral (NaCl), in addition to the influence of important physiological factors (Tables 2 and 3). For calves, the analysis showed indices of consumption similar to NaCl for all minerals supplemented, both in consumption time and intake visits, except a greater consumption of CuSO₄ and a smaller consumption of Na₂SeO₃ (both mixed with salt) and CaCO₃ (Table 2), therefore suggesting discrimination at least for these minerals. It also showed increased consumption in heavier calves, as well as differences between years. There was no influence of sex on consumption time or intake visits. Because CaHPO₄, CaCO₃, FeCO₃ and MgO were offered unmixed with salt, additional models tested if hinds or calves discriminated among these pure, non-salty minerals using CaCO₃ as a reference. These models revealed a different consumption pattern between CaHPO₄ and CaCO₃ (model for calves’ consumption time: $R^2 = 0.07\%$; calf birth weight $= 12.7$ (SD 5.7), $P=0.028$; CaHPO₄ $= 29.7$ (SD 11.7), $P=0.012$; NS terms: year, sex, calf gains, FeCO₃ and MgO. Model for calves’ intake visits: $R^2 = 0.06\%$; calf birth weight $= 1.19$ (SD 0.60), $P=0.048$; CaHPO₄ $= 2.87$ (SD 1.23); $P=0.020$;

![Fig. 3. Behavioural consumption differences between male (□) and female (■) calves for every mineral offered in a cafeteria test. (a) Consumption time; (b) intake visits. * Mean value was significantly different from that for the male calves ($P<0.05$; Student’s $t$ test).](https://www.cambridge.org/core/core/9547040.1114509992091)
year, sex, calf gains, FeCO₃ and MgO were NS). This shows that calves discriminated not only between NaCl and salt-mixed minerals (CuSO₄, Na₂SeO₃), but also among minerals not mixed with salt.

The same analysis on hinds revealed that all minerals supplemented (except consumption time of CuSO₄) showed a different pattern compared with the reference mineral (NaCl). The models also showed a greater consumption by younger hinds and hinds rearing heavier calves, in addition to a greater consumption time and intake visits by hinds having a male calf and those producing less milk. Models testing discrimination among unmixed supplements showed lack of differences both in consumption time and intake visits. Thus, the only evidence of mineral discrimination by hinds relates to NaCl and CuSO₄ against all other minerals.

Social learning and mineral consumption

Table 4 shows the correlation between the time or frequency of visits of the calf and those of the mother for the fifty-nine pairs of hinds–calves (twenty-three in the case of Co). The results show that there was a social learning effect, i.e. the calf was more likely to consume the mineral if the mother consumed it, for those minerals that were mixed with salt (Co, Cu, I, Zn, Se and Na), but calves consumed those minerals not mixed with salt irrespective of the consumption behaviour of their mothers.

Discussion

Results suggest that deer seem to discriminate between minerals even if they are mixed with a palatable excipient with a strong flavour such as sodium salt, but also among palatable mineral supplements not mixed with salt. In addition, calves showed behavioural indices of consumption greater than their mothers even though both showed a similar mean time per visit. Because both visits and time correlated with the actual consumption of mineral supplements, the former differences suggest greater mineral consumption by calves compared with hinds. Consumption in response to palatability should produce greater intake by larger hinds and larger calves, as found here, but also a much greater consumption by hinds with respect to calves. Thus, differences between calves and hinds may reflect a greater consumption behaviour based on the greater physiological demands of growth (14–16), while results found within calves and hinds are also compatible with greater demands as weight increases (14–16). The effect is not independent of behavioural influences such as social learning in calves watching their mothers, but this was only found for minerals mixed with salt, whereas calves consumed minerals not mixed with salt even though their mothers did not consume them.

Several studies have shown differences in mineral consumption related to sex and age, but always within adults or yearlings (21,22,65,66). In contrast, mineral consumption by young calves has been scarcely reported. Hinds consumed mainly NaCl and CuSO₄ (mixed with salt), but not other

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Reference</th>
<th>Coefficient</th>
<th>Mean</th>
<th>SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>Reference</td>
<td>Coefficient</td>
<td>Mean</td>
<td>SD</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-29</td>
<td>12</td>
<td>0.014*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-3.3</td>
<td>1.2</td>
<td>0.009**</td>
</tr>
</tbody>
</table>

* P < 0.05, ** P < 0.01, *** P < 0.001.
† CoSO₄, CuSO₄, Ca(IO₃)₂, Na₂SeO₃ and ZnSO₄ were diluted in NaCl, whereas the rest were offered as a single compound.
‡ The coefficient for the factor ‘year’ refers to the first year.
§ Mineral was computed as a categorical variable, testing the differences in consumption time and intake visits with respect to NaCl taken as a reference. Because CaHPO₄, CaCO₃, FeCO₃ and MgO were not offered mixed with salt, an additional model tested differences in time and event among them relative to the consumption of calcium carbonate. These models showed that calves also discriminated between CaHPO₄ and CaCO₃ (see Results section).
or negative. However, minerals show decreasing positive and simple way of learning a one-way effect: always positive wild(33,44)). Conditioned learning seems to be an appropriate mixtures of different foods (as usually happens in the experimental settings include both positive and negative cues or free-ranging ruminants because learning fails when exper-
mimental. Thus, conditioned learning may be much more ineffective than innate ability to ingest minerals depending on relative requirements. One reason for this is that in the complex system of diet selection by ungulates, a quick and accurate provision of balanced nutrients should be much more important than a slow process of learning the properties of foods(46). In addition, many assumptions of the conditioned learning model do not fit to the present experiment as there is no microminerals supplemented even though they had a very similar salted flavour (KCl and salt-mixed minerals CoSO4, Ca(IO3)2, Na2SeO3 and ZnSO4). This is particularly striking for the case of KCl, which has a very similar salty flavour to the human taste. In contrast, consumption by calves was more balanced among all supplements. However, despite this, Cu, which is one of the most important trace minerals involved in growth(16,51,67), was apparently consumed in greater quantities. The suggestion that growth imposes greater needs of mineral consumption also seems to explain the consumption by calves of NaCl mixed with trace minerals which hinds did not consume. Moreover, among hinds greater behavioural indices of consumption were observed in younger ones, reflecting the additional effect of still-growing animals on the needs imposed by lactation(68). In contrast, if intake depends on palatability larger animals with larger bodies should consume more and, thus, hinds should consume greater amounts of minerals than calves. A further argument against intake driven by palatability is that preference of minerals depends on palatability larger animals with larger bodies on the needs imposed by lactation(68). In contrast, if intake is driven by palatability is that preference of minerals was different for calves and hinds, whilst the same pattern for all of them should be predicted by palatability.

As previously indicated, conditioned learning seems to be the most accepted mechanism underlying diet selection but most of the assumptions of this model seem hard to apply to free-ranging ruminants because learning fails when experimental settings include both positive and negative cues or mixtures of different foods (as usually happens in the wild33,44). Conditioned learning seems to be an appropriate and simple way of learning a one-way effect: always positive or negative. However, minerals show decreasing positive effects with increasing intake within deficiency up to a certain range when they have a neutral effect, and increasing negative effects afterwards. In cases such as Se, the range between positive effects and toxicity is a very narrow one(16). Thus, conditioned learning may be much more ineffective than innate ability to ingest minerals depending on relative requirements. One reason for this is that in the complex system of diet selection by ungulates, a quick and accurate provision of balanced nutrients should be much more important than a slow process of learning the properties of foods(46). In addition, many assumptions of the conditioned learning model do not fit to the present experiment as there is no

### Table 3. General linear models showing the influence of different mineral compounds and lactation variables on total consumption time and intake visits by Iberian red deer (Cervus elaphus hispanicus) hinds (n = 59)†

(Mean values and standard deviations)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Coefficient Mean</th>
<th>SD</th>
<th>P</th>
<th>Coefficient Mean</th>
<th>SD</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>12-8 %</td>
<td>16</td>
<td>--</td>
<td>1-6</td>
<td>9-4 %</td>
<td>--</td>
</tr>
<tr>
<td>Year</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td>7</td>
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<td>1-5</td>
<td>0-6</td>
<td>0-015*</td>
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<td>Age</td>
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<td>Total milk yield</td>
<td>-0-001</td>
<td>0-000</td>
<td>0-030*</td>
<td>-0-26</td>
<td>0-11</td>
<td>0-015*</td>
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<td>Calving weight</td>
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<td>0-086</td>
<td>0-029</td>
<td>0-003*</td>
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<tr>
<td>mineral†</td>
<td>-0-54</td>
<td>19</td>
<td>0-005**</td>
<td>-6-6</td>
<td>1-6</td>
<td>&lt;0-001***</td>
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<td>Salt + CoSO4</td>
<td>-0-54</td>
<td>19</td>
<td>0-005**</td>
<td>-6-6</td>
<td>1-6</td>
<td>&lt;0-001***</td>
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<td>--</td>
<td>-3-0</td>
<td>1-3</td>
<td>0-021*</td>
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<tr>
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<td>16</td>
<td>0-002**</td>
<td>-6-0</td>
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<td>&lt;0-001***</td>
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<tr>
<td>Salt + ZnSO4</td>
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<td>0-002**</td>
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<td>0-001**</td>
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<td>0-001**</td>
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<td>0-001**</td>
<td>-6-5</td>
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<td>CaHPO4</td>
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* P<0-05, ** P<0-01, *** P<0-001.
† CoSO4, CuSO4, Ca(IO3)2, Na2SeO3 and ZnSO4 were diluted in NaCl, whereas the rest were offered as a single compound.
‡ Mineral was computed as a categorical variable, testing the differences in consumption time and intake visits with respect to NaCl taken as a reference. Because CaHPO4, CaCO3, FeCO3 and MgO were not offered mixed with salt, an additional model tested differences in time and event among them relative to the consumption of calcium carbonate. These models showed the same results.

### Table 4. Correlation coefficients between consumption time or events by the call and those by their mothers

<table>
<thead>
<tr>
<th>Animals (n)</th>
<th>Spearman’s ρ</th>
<th>P</th>
<th>Spearman’s ρ</th>
<th>P</th>
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<tbody>
<tr>
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<td>0-203</td>
<td>NS</td>
<td>0-207</td>
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<tr>
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<td>0-167</td>
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<tr>
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<td>23</td>
<td>0-397</td>
<td>NS</td>
<td>0-467</td>
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<tr>
<td>Cu</td>
<td>59</td>
<td>0-346</td>
<td>0-007</td>
<td>0-332</td>
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<tr>
<td>Fe</td>
<td>59</td>
<td>0-126</td>
<td>NS</td>
<td>0-109</td>
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<td>I</td>
<td>59</td>
<td>0-487</td>
<td>0-000</td>
<td>0-467</td>
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<td>NS</td>
<td>0-257</td>
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previous learning, several similar flavours correspond to different mineral contents, and animals frequently ate from more than one supplement on every visit.

Thus, our evidence suggests that deer are capable of discriminating minerals beyond evidence published for Na and P\textsuperscript{15,16,31}. This also seems to be the first published evidence that animals can detect small amounts of microminerals even within a homogeneous strong flavour such as salt (for human subjects, see Epke & Lawless\textsuperscript{69}). In addition, results suggest that discriminating behaviour probably reflects physiological requirements for some of them (as also was previously published\textsuperscript{26}), especially because the pattern observed was different for calves and hinds, whilst palatability predicts the same for both. Thus, for example, hinds showed low levels of behavioural indices of consumption for all minerals supplemented except NaCl, which was the most actively sought. This may reflect the fact that milk production is constrained by Na\textsuperscript{20}. Behavioural indices of consumption for calves were similarly high for most salt-flavoured supplements (except a higher one for CuSO\textsubscript{4} and a reduced intake of Na\textsubscript{2}SeO\textsubscript{3}). In addition, consumption indices for CaHPO\textsubscript{4} were greater than those for CaCO\textsubscript{3}. Chládek & Zapletal\textsuperscript{21} showed how cows control the Ca:P ratio by choosing between different mineral blocks independently of Na content, and similar results were obtained by Villalba et al.\textsuperscript{27}. Because Ca and P are the main elements of bone but calcium carbonate also has Ca, the behaviour observed also supports the idea that animals have evolved the ability to discriminate among these minerals as an attempt to meet diet requirements. Male calves showed an intake of NaCl and CaCO\textsubscript{3} greater than that of females, and hinds’ consumption for most minerals also depended on having a male or a female calf. That is coherent with previous findings by our research group that show differences in milk mineral composition related to the sex of the calf\textsuperscript{22}, which suggests both a sex effect on calf mineral requirements and a different physiological effort for milk mineral production of mothers of males compared with mothers of females.

In conclusion, sex- and age-related differences were found in behavioural indices of mineral consumption in Iberian red deer hinds and calves. These differences show discrimination of essential minerals in a different pattern for calves and hinds. Both the greater consumption by calves and the different preference for calves and hinds suggest that deer do not discriminate and consume based on palatability. Results suggest that behavioural indices of consumption may respond to physiological needs, and thus they might support the existence of discrimination mechanisms that may make possible that deer select a balanced mineral diet. However, further experiments are needed to fully prove that red deer behave as optimal foragers of trace minerals, i.e. showing if animals respond to inflicted specific trace-mineral deficiencies by adjusting intake of them, as recently shown for Se consumption by hens\textsuperscript{73}.

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T. L.-C., A. J. G. and L. G designed the original trial; F. C., A. J. G. and J. A. E. participated in data collection; L. G. and T. L.-C. obtained funding; F. C. and T. L.-C. undertook the statistical analyses and wrote the first draft of the manuscript. All authors approved the final manuscript.

All authors declared that they had no conflict of interest.

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Diet selection of minerals by red deer

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