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Evaluating the Effects of Novel Enrichment Strategies on Dog Behaviour Using Collar-Based Accelerometers

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Abstract: Environmental enrichment is crucial to improve welfare, reduce stress, and encourage natural behaviours in dogs housed in confined environments. This study aimed to use accelerometery and machine learning to evaluate the effect of different enrichment types on dog behaviour. Three enrichments (food, olfactory, and tactile) were provided to dogs for five consecutive days, with four days between each treatment. Acceleration data were collected using a collar mounted ActiGraph®. Nine behaviours were classified using a validated machine learning model. Behaviour and activity differed significantly among the dogs. Dogs interacted most with the food enrichment, followed by the olfactory and then tactile enrichments. The dogs were least active during the olfactory enrichment, whereas activity was relatively consistent during the food and tactile enrichments. For all enrichments, dogs exhibited the most exploratory/locomotive behaviour during the first hour of each enrichment period, but this declined over the treatment period indicating habituation. For exploratory and locomotive behaviour, food enrichment was the most stimulating for the dogs with longer daily engagement than for both olfactory and tactile enrichments. These results illustrate that accelerometery and machine learning can be used to evaluate enrichment strategies in dogs, but it is important to consider variation among dogs and habituation.

Keywords: canine; machine learning; environmental enrichment; overall dynamic body acceleration

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1. Introduction

The purpose of environmental enrichment (EE) is to enhance the quality of life of animals under human care by providing additional temporary stimuli and activities to their external environment [1,2]. For EE to be considered enriching, it must enhance the overall welfare state of the animal [2]. The benefits of EE include an increase in the frequency and diversity of species-specific behavioural repertoires, as well as a reduction in stress and anxiety, abnormal behaviours, and improved cognitive abilities [2–7].

In domestic dogs (*Canis familiaris*), several food, sensory, and tactile enrichment techniques have been used. Food-based enrichments are a popular way to engage dogs, and they usually involve placing food around the animal's environment or hiding food in toys or puzzle feeders [3,8,9]. These enrichments are designed to promote 'natural' feeding behaviours that are not typically displayed in captive environments, although their effectiveness for domestic dogs has yielded mixed results [2–4,10]. Given the highly attuned senses of dogs, it is unsurprising that sensory enrichments (e.g., auditory, olfactory, and visual stimulation) are generally effective and commonly used, especially given the simplicity and low cost of such techniques [1]. Olfactory enrichment is particularly effective for anxious and excitable dogs, as it can promote calming and explorative behaviours, as well as cognitive stimulation [1]. Odours such as essential oils, prey urine, and dog-appealing pheromones have been used as effective olfactory enrichment treatments, resulting in decreased stress levels, increased overall activity, and reduced barking [7,11–13].

Tactile enrichment, such as toys and blankets, is one of the most frequently used enrichment methods for dogs, other domestic animals and exotic species [7,14]. Providing toys to both captive and domestic animals has been reported to reduce boredom, encourage play behaviours, promote exploration, and reduce abnormal (e.g., stereotypical) behaviours [7].

The variability in the efficacy of enrichment techniques can be partly attributed to the absence of objective and continuous measures for quantifying behaviour. In recent years, accelerometers have become increasingly important for behavioural assessment in enrichment studies. Triaxial accelerometers have been used to measure the success of enrichment activities in various animal species, including pigs, rats, cattle, and chickens [15–19]. In zoo settings, researchers have also used automated technologies such as accelerometers to evaluate animals' responses to their surroundings and assess their welfare [20]. There has, however, been limited research using accelerometery to determine the effects of offering dogs environmental enrichment. Nevertheless, accelerometers have been used to measure stress levels, behaviour, and welfare states of dogs [21–24].

The current study aimed to use triaxial accelerometery together with a validated random forest model to evaluate the effect of food, olfactory, and tactile enrichments on the behaviour and activity of colony-housed dogs.

2. Materials and Methods

The study was conducted at Massey University Canine Nutrition Unit (CNU), Palmerston North, New Zealand (latitude 40°230′ S, longitude 175°365′ E) from January to February 2024. The CNU is a purpose-built colony facility that housed 29 domestic dogs (10 female and 19 male) at the time of the study. All research was conducted in accordance with Massey University Animal Ethics Committee protocol number 23/63.

2.1. Animal Husbandry

Six healthy desexed domestic dogs (two females and four males) were used for this study (Table 1). The dogs were aged from 4.3 to 7.9 years (mean ± SD, 6.02 ± 1.59 years) and weighed between 21.5 and 32.1 kg (mean ± SD, 25.6 ± 4.19 kg). Dogs were managed in established pairings (Table 1) in familiar outdoor exercise paddocks during daylight hours (08:00 h to 16:00 h) and centrally heated indoor runs overnight (16:00 h–07:00 h). Once a day in the morning (~08:00 h), the dogs were fed a complete and balanced diet (Working Dog Adult formula, Black Hawk Lower Hutt, New Zealand) according to their maintenance energy requirements (MER), which were calculated as MER (kj) = 552× kg $BW^{0.75}$) [25]. The dogs had ad libitum access to water throughout the study.

Table 1. Details of study dogs including name, sex (all desexed), age, breed, weight (kg) and pair identification number.

Name	Sex	Age (Years)	Breed *	Weight (kg)	Pair
Belle	Female	7.9	Huntaway	23.4	3
Blacky	Male	4.3	Huntaway/Heading	23.6	3
Chevelle	Female	7.9	Huntaway	21.5	2
Gizmo	Male	6.1	Harrier hound	30.8	1
Gus	Male	4.4	Huntaway/Smithfield terrier	22.4	2
Monaro	Male	7.9	Huntaway	32.1	1

* New Zealand working dogs breeds.

2.2. Study Design

The study included three days of baseline data collection for each study dog between 29 August and 15 September 2023 [25], before the current 23-day experiment was conducted between 22 January and 12 February 2024. In the week prior to the experiment, there was a one-day period for dogs to habituate to wearing the accelerometer on their collar. Each pair of dogs undertook three five-day data collection periods (15 days of total data collection), which were separated by a four-day rest period during which no data were collected (Figure 1). Three observation paddocks were utilised in the study, which were maintained under the same experimental and environmental conditions. Each pair of dogs was exposed to the three different enrichment types in a randomised block design (Figure 1). After each week of data collection and a four-day rest period, dogs were rotated to the next observational paddock with a new enrichment method.

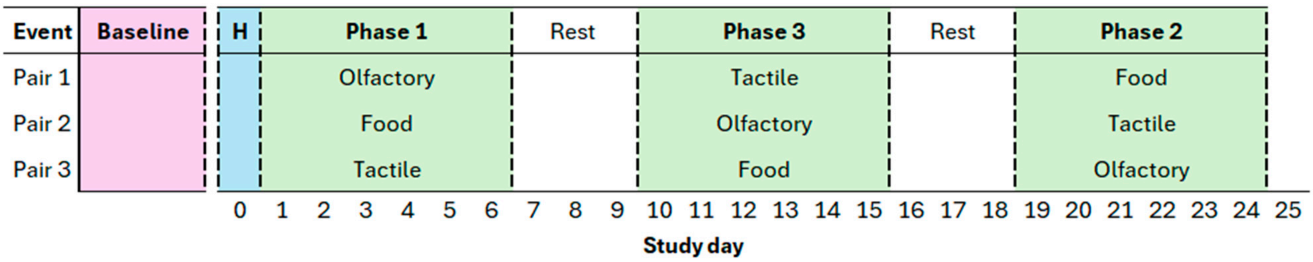

Figure 1. Experimental study design displaying the data collection phases and rest periods for each pair of dogs across different enrichment types. H = habituation phase.

During the habituation period, a triaxial accelerometer (wGT3X-BT, ActiGraph®, Pensacola, FL, USA) was attached to the existing collar of each dog for four hours, and their response to the devices was observed. No adverse responses, such as excessive scratching, shaking or attempts to remove the collar, were detected.

Six dogs participated in the experimental phase and remained in their regular pairs in one of three familiar outdoor observation paddocks (Figure 2). The food and tactile enrichment paddocks had the same dimensions (9.5 m × 12 m), whilst the olfactory enrichment paddock was smaller (6.9 m × 9.2 m; Figure 2). The olfactory enrichment paddock was selected to be the furthest away from the other paddocks to minimise potential exposure to the olfactory enrichment. Continuous triaxial acceleration data from collar-mounted triaxial accelerometers and video footage were collected while the dogs were in the observation paddocks.

During the experimental phase, each pair of dogs was offered one of three enrichment treatments for seven hours (09:30 h and 16:30 h) daily for five consecutive days (35 h total per enrichment). The olfactory enrichment was placed in the paddock approximately five minutes before the dogs entered the paddock and was removed after the dogs left the observation paddock each day. The tactile enrichment was placed in the paddock before exposure on the first day of each data collection period and remained in the paddock for each five-day test period before removal. The food enrichment was placed in the designated observation paddock approximately five minutes before exposure to the enrichment and was fully consumed each day.

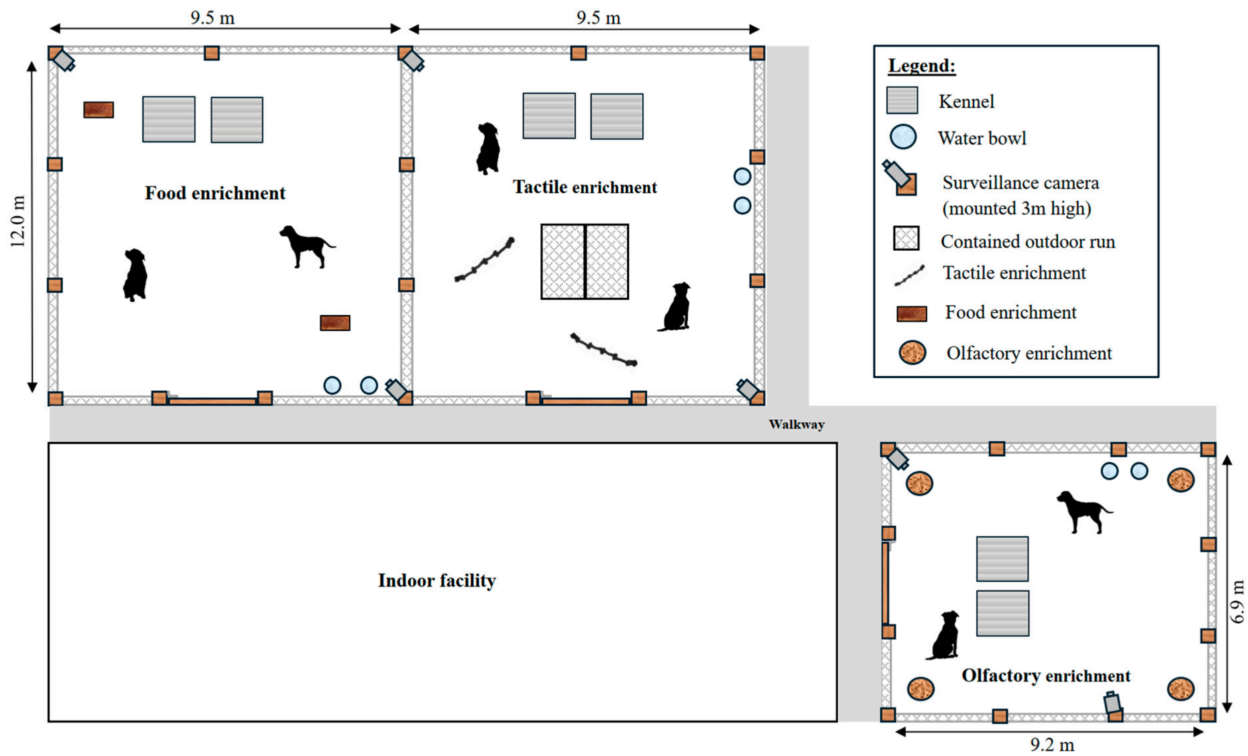

Figure 2. Diagram of the layout of the three enrichment paddocks at the Centre for Canine Nutrition showing the location of the food (12 m × 9.5 m), tactile (12 m × 9.5 m) and olfactory enrichments (9.2 m × 6.9 m).

2.3. Enrichment Treatments

Each pair of dogs was exposed to three different enrichments in a randomised block design. To prevent inter-animal aggression within the pairings, two food and tactile enrichment objects and four olfactory enrichment objects were provided in each paddock and replaced for each pair of dogs (Figure 2). The food enrichment object was an appetitive stimulation of an ice block comprised of 180 g of canned dog food (Beef and Gravy Casserole, Pedigree, MARS, Auckland, New Zealand) mixed with one litre of water. The ice blocks were frozen in silicon moulds (27.6 cm × 14.0 cm × 6.5 cm) and stored at −18 °C before being offered to the dogs. Two ice blocks were placed on opposite sides of the paddock on each day. The tactile enrichment object was a long rope tug toy with dimensions 189 cm × 8 cm × 10.5 cm (Pet Toy Knotted Mega Rope, Anko®, Kmart Australia Ltd. Mulgrave, VIC, Australia). Two rope tug toys were placed on opposite sides of the paddock each day. The olfactory enrichment was soiled chicken litter and wood shavings sourced from the indoor housing facilities at the Massey University Poultry Research Unit. On each treatment day, 400 g of soiled litter was placed in each of the four corners of the paddock (Figure 2). The litter was removed at the end of each day of data collection.

2.4. Acceleration Data

Triaxial accelerometers (wGT3X-BT, ActiGraph®, Pensacola, FL, USA) were used to record acceleration of the dogs along three independent axes (cranio–caudal, dorso–ventral and lateral) at 30 Hz and a dynamic range of ±8 g. The devices were fitted ventrally to the dog's existing collar and oriented with the lock screw located caudally as described by Redmond et al. [26]. Additionally, the accelerometers were housed in a plastic casing packed with bubble wrap to prevent any damage and residual movement (Figure 3). Collar tightness was kept as consistent as possible to minimise residual movement of the devices. Triaxial acceleration data were continuously collected throughout the day when the dogs were in the experimental paddocks. Overnight, the collars were removed to reduce the risk of the dogs damaging the device, and acceleration data were not collected.

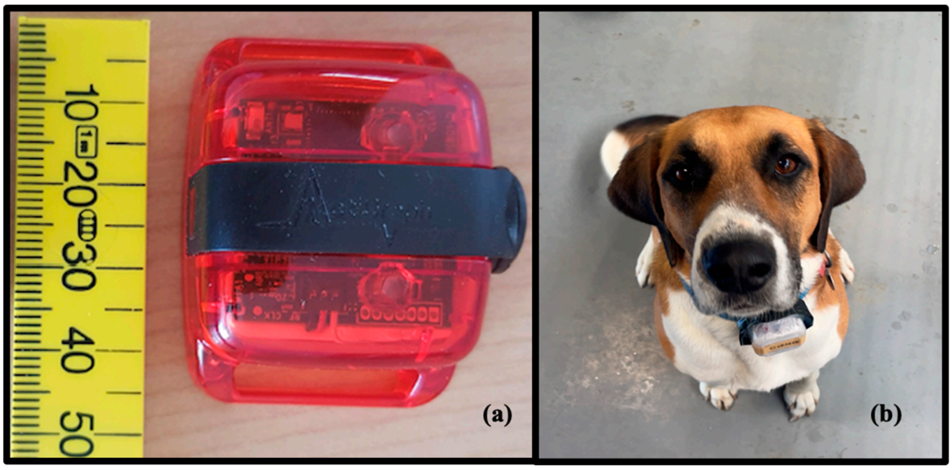

Figure 3. (**a**) The ActiGraph® wGT3X-BT device with relative measurements (weighing 19 g). (**b**) dog wearing the ActiGraph® wGT3X-BT accelerometer encased within a protective housing (the device was consistently orientated with the black band on the device representing the cranio–caudal axis) and fitted ventrally to the collar. Reproduced from Redmond et al. [26].

2.5. Video Footage

A video recording system (Professional NVR series, Swann Communications USA, Santa Fe Springs, CA, USA) included two video cameras mounted at elevated positions (2.2 m) on adjacent corners of the olfactory enrichment observation paddock, allowing for unobstructed views [27]. The remaining two observation paddocks (tactile and food) had two cameras mounted at a higher elevation (3.9 m). These cameras were placed on the diagonal corners of the two paddocks to mitigate potential blind spots in these paddocks (Figure 2). Video footage was recorded at 15 frames per second at a resolution of 1920 × 1080 (bit rate of 2048 Kbps) and used to determine the duration of interactions with the enrichment objects. Interactions included sniffing, and physical contact such as chewing, licking, and playing. Video footage was collected and assessed for each pair of dogs for seven hours each day, totalling 35 h of data per collection period and 105 h of data collected over the entire study.

2.6. Data Processing and Analysis

2.6.1. Data Cleaning and Modelling

Raw acceleration data (30 Hz) were downloaded from the accelerometers using proprietary software (ActiLife® version 6.13.4; ActiGraph, Pensacola, FL, USA) and then exported to a .csv file and processed using R version 4.3.0 (R Foundation for Statistical Computing, Vienna, Austria). The acceleration data were cleaned by removing periods when the dogs were not wearing the collars (e.g., overnight). This resulted in 25,200 data points collected daily and 378,000 data points collected for the entire study period (15 days) per dog. Due to device malfunction, data were removed for two dogs (Gus and Chevelle) on day 10 and two dogs (Belle and Blacky) on day 14. Thus, a total of 2,167,287 data points were collected for the enrichment study across all dogs.

In the final dataset, 32 identifier variables (features) were calculated according to Redmond, et al. [26] and Smit, et al. [28]. These features included the correlations between the three accelerometer axes (XY, XZ, YZ; three identifier variables), overall dynamic body acceleration (ODBA; one identifier variable), and vector magnitude (VM), as well as the mean, sum, minimum, maximum, standard deviation, skewness, and kurtosis for each axis (x, y, z) over a 1 s interval. These data were then analysed at a 1 s epoch using a validated random forest model developed by Redmond et al. [26], with an additional behaviour of sniffing added. The random forest model used for this study underwent Bayesian hyperparameter (number of trees, minimum node depth, number of identifier variables, randomly sample per tree, and sample fraction) optimisation, and was subsequently trained and tested on 90,741 s (70% of the dataset) and 38,874 s (30% of the dataset) of visually scored behaviour data, respectively [26]. The model used in this study classified nine behaviours (barking, defecating, drinking, eating, locomotion, resting-alert, resting-asleep, sniffing and standing) with an overall accuracy of 0.74, a mean balanced accuracy of 0.86, and a kappa coefficient value of 0.68. Lastly, the overall dynamic body acceleration (ODBA) and percentage of time spent exhibiting each behaviour were determined at both an hour and daily epoch. The time spent exhibiting active and inactive behaviours was also determined.

2.6.2. Statistical Analyses

All statistical analyses were conducted using R version 4.3.0 (R Foundation for Statistical Computing, Vienna, Austria) with a significance level defined as $p < 0.05$. Normality was tested using the Shapiro–Wilk normality test. The time spent interacting with each of the enrichment items was compared using Kruskal–Wallis and pairwise Wilcoxon tests. The relationship between the day of the enrichment (Days 1 to 5) and time spent interacting with each object was assessed using a Spearman correlation coefficient. To account for variation among the dogs, the effect of enrichment type on the ODBA of the dogs was compared using a repeated measures ANOVA with a Bonferroni correction. The individual behaviour data, due to their proportionality, were analysed using a Kruskal–Wallis test. Generalised linear mixed models (GLMM), with either a negative binomial or gamma log distribution, were used to evaluate the effect of enrichment type, day of the enrichment (days 1 to 5), and hour of enrichment on each behaviour, with 'dog' as the repeated measure. Total active, sniffing, barking, locomotion, standing, resting (alert), and sleeping. Eating, drinking, and defecating behaviours were excluded from the analysis due to a low frequency of occurrence. Lastly, the behavioural drivers of ODBA were explored using Spearman or Pearson's correlation coefficients, depending on the normality of the data.

3. Results

3.1. Interaction with Enrichment Objects

The time spent interacting with the enrichment objects differed ($p < 0.001$) between all three treatment groups, with the highest average duration spent interacting with an object being the food enrichment (1069.0 ± 121.3 s per day), followed by the olfactory (204.6 ± 40.4 s per day), and tactile (21.5 ± 9.2 s per day; Figure 4). The day of enrichment did not significantly affect the time spent interacting with the food or olfactory enrichment objects when 'dog' was included as a covariate (Figure 4). The time spent interacting with the tactile object, however, progressively declined over the five days of the treatment period ($p < 0.05$; Figure 4).

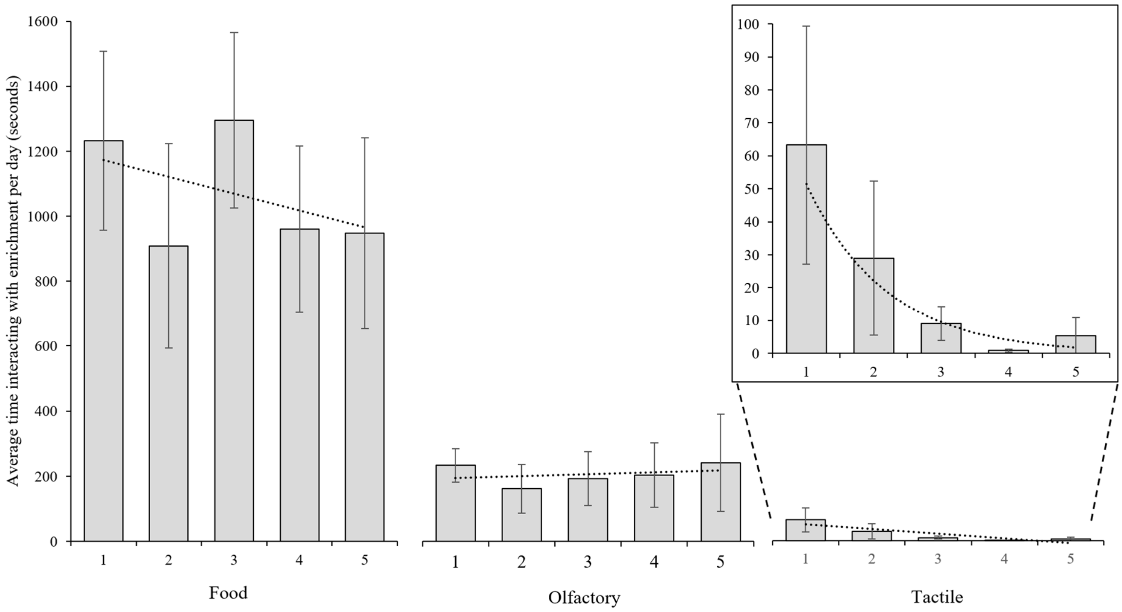

Figure 4. The mean ± SEM interaction time (seconds) for each enrichment type (food, tactile, and olfactory). The insert contains a magnified version of the tactile enrichment figure. Spearman correlation coefficients for the food, olfactory, and tactile regression lines were rho = −0.11 (p = 0.56), rho = 0.04 (p = 0.85), and rho = −0.65 (p < 0.001), respectively.

3.2. Overall Body Dynamic Acceleration

Overall dynamic body acceleration differed among the dogs (p < 0.001; Table 2). When the effect of 'dog' was accounted for, treatment had an effect on ODBA (p < 0.001), which was lower (p < 0.05) during the olfactory enrichment than either the food or tactile enrichments, which did not differ from each other (p > 0.05). The average ODBA for all dogs during all three enrichment treatments was lower than during the baseline period. When dogs were considered separately, treatment had an effect on the ODBA of all dogs; however, their response differed among the enrichment treatments (Table 2). Among the enrichment types (food, olfactory, and tactile), ODBA did not differ (p < 0.05) among Belle, Chevelle, Gizmo, and Monaro (Table 2). Blacky's ODBA was lower (p < 0.01) during the food enrichment than both the olfactory and tactile enrichments, which did not differ (p > 0.05) from one another (Table 2). In contrast, Gus was less active (p = 0.004) during the olfactory enrichment than both the food and tactile enrichments, with no difference in ODBA between the food and tactile enrichments (Table 2). Across all dogs, ODBA was greatest during the baseline period and lower during the olfactory enrichment than the tactile enrichment; ODBA during the food enrichment did not differ from either the olfactory or tactile enrichments (Table 2).

Table 2. Mean ± SEM of the total daily overall dynamic body acceleration (ODBA), representative of overall physical activity, of the dogs during each of the treatments. Different superscripted letters indicate statistical difference (p < 0.05) within a row.

Dog	Baseline	Food	Olfactory	Tactile	p Value
Belle	8713 ± 1103 ^{b}	3935 ± 721 ^{a}	3996 ± 365 ^{a}	5900 ± 1077 ^{ab}	0.005
Blacky	6068 ± 303 ^{c}	3246 ± 226 ^{a}	4483 ± 196 ^{b}	5342 ± 426 ^{bc}	<0.001
Chevelle	13,209 ± 3150 ^{b}	8471 ± 1392 ^{ab}	4467 ± 1797 ^{a}	8164 ± 1267 ^{ab}	0.045
Gizmo	3291 ± 266 ^{b}	2552 ± 187 ^{ab}	2222 ± 194 ^{a}	2062 ± 213 ^{a}	0.010
Gus	5898 ± 1510 ^{b}	5474 ± 676 ^{b}	2041 ± 511 ^{a}	5993 ± 563 ^{b}	0.004
Monaro	7489 ± 502 ^{b}	4504 ± 640 ^{a}	4594 ± 497 ^{a}	3964 ± 280 ^{a}	0.003
Average	7445 ± 1371 ^{c}	4697 ± 860 ^{ab}	3634 ± 483 ^{a}	5210 ± 842 ^{b}	<0.001

3.3. Behaviours

Time Spent Active

The percentage of time spent on active behaviours (barking, locomotion and sniffing) per day differed widely among the dogs ($p < 0.001$; Figure 5). The day of the treatment (Day 1 to 5) affected the amount of time the dogs spent being active ($p < 0.001$; Figure 6). When the random effects of 'dog' and 'day of treatment' were accounted for, the percentage of time exhibiting active behaviours was higher during the baseline period than either the food ($p < 0.001$), olfactory ($p = 0.008$), or tactile ($p < 0.001$) enrichment periods (Table 3). The amount of time that the dogs spent active, however, did not differ among the three enrichment groups (Table 3). Unsurprisingly, given the differences in active behaviour, the amount of time spent exhibiting inactive behaviours (sleeping and resting) also differed between the baseline and the three enrichment groups ($p = 0.001$, $p = 0.005$, and $p < 0.001$ for the food, olfactory, and tactile periods, respectively; Table 3).

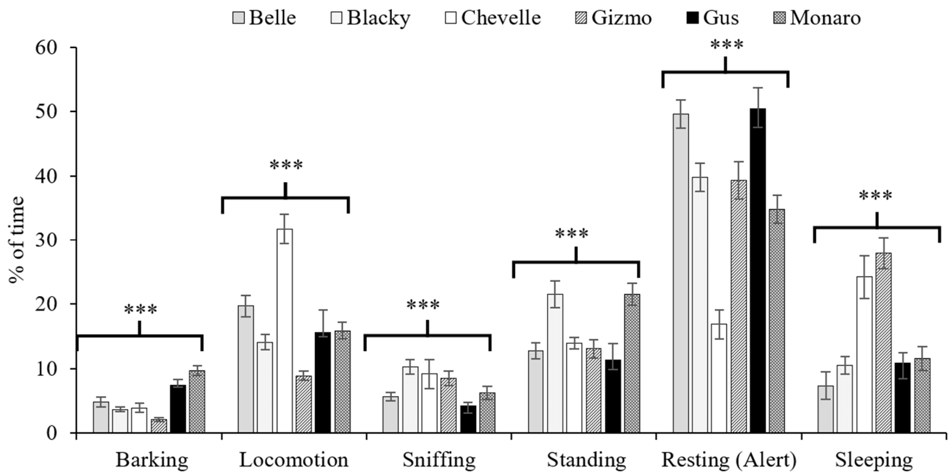

Figure 5. Mean ± SEM of the daily percentage of time that each dog spent exhibiting each behaviour. *** indicates statistical difference ($p < 0.001$) among the dogs for a given behaviour.

Table 3. Mean ± SEM percentage of time exhibiting each behaviour against treatment group (baseline and the three enrichment groups: food, olfactory, and tactile). Within a row means that the different superscripts were statistically different ($p < 0.05$).

	Baseline	Food	Olfactory	Tactile
Active (%)				
Barking	4.7 ± 0.8^{b}	5.6 ± 0.8^{bc}	4.2 ± 0.4^{a}	6.5 ± 0.8^{c}
Locomotion	22.8 ± 2.7^{b}	15.6 ± 1.6^{a}	17.3 ± 2.3^{a}	17.1 ± 1.9^{a}
Sniffing	4.8 ± 0.6^{a}	7.6 ± 0.8^{bc}	9.1 ± 1.4^{c}	6.8 ± 0.9^{b}
Standing	23.5 ± 2.4^{c}	14.7 ± 1.3^{b}	15.3 ± 1.3^{b}	12.1 ± 1.2^{a}
Total	55.8 ± 3.1^{a}	43.8 ± 2.5^{b}	45.8 ± 3.2^{b}	42.5 ± 4.5^{b}
Inactive (%)				
Resting	35.6 ± 2.8	41.0 ± 3.0	36.1 ± 3.0	35.6 ± 2.8
Sleeping	8.0 ± 1.9^{a}	15.5 ± 1.8^{b}	18.0 ± 2.6^{b}	17.8 ± 2.4^{b}
Total	43.7 ± 3.1^{a}	56.5 ± 2.5^{b}	54.0 ± 3.2^{b}	57.4 ± 5.5^{b}

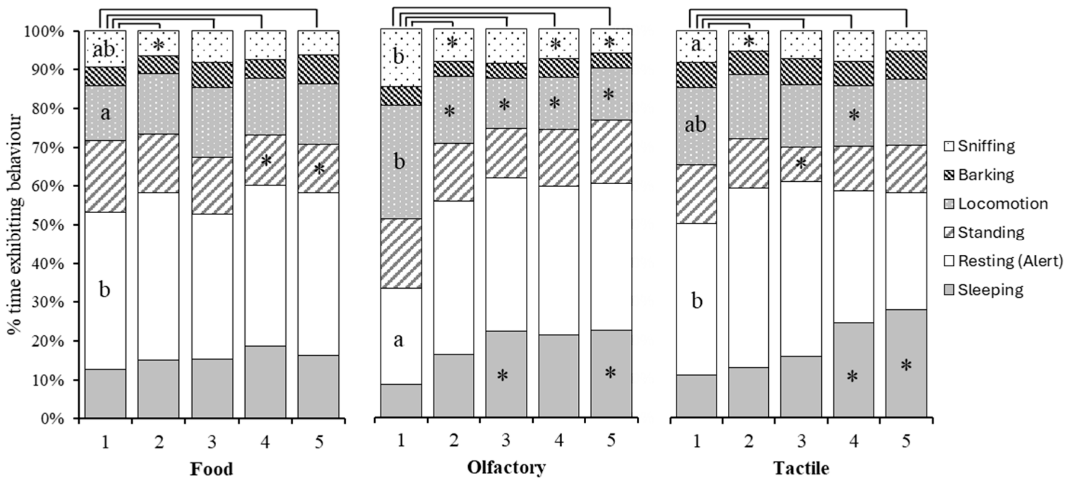

Figure 6. The average time spent exhibiting each behaviour per day during the food, olfactory, and tactile enrichment periods. Behaviours included sleeping (solid grey), resting alert (solid white), standing (wide grey diagonal stripes), locomotion (grey with white dots), barking (narrow black diagonal strips), and sniffing (white with black dots). Maintenance behaviours (eating, drinking, and defecating) were excluded due to their low frequency. * Denotes the amount of time spent exhibiting a given behaviour was statistically different ($p < 0.05$) from the first day of the enrichment period, as indicated with comparison bars at the top of the chart. Different letters within the first day of each enrichment period indicate a statistical difference ($p < 0.05$) in time spent exhibiting the behaviour between the enrichment types.

The duration that the dogs spent exhibiting active behaviours changed over time during the enrichment period ($p < 0.001$; Figure 7). The percentage of time spent active was higher ($p < 0.004$) in the first hour of being offered the enrichment compared with all other hours during the enrichment period. On average, in the first hour of each enrichment period, the percentage of time spent active was higher for the food enrichment (83.0 ± 5.21%) than the olfactory (40.2 ± 3.4%; $p < 0.001$) and tactile enrichments (40.5 ± 3.6%; $p < 0.001$), which did not differ ($p = 0.82$).

3.4. Specific Behaviours

The amount of time spent exhibiting each of the behaviours differed among the dogs (Figure 5) and the day of the treatment (days one to five; Figure 6). Treatment day affected the duration spent sniffing ($p = 0.001$) and standing ($p = 0.01$) during the food enrichment (Figure 6). During the olfactory enrichment, the percentage of time spent displaying sniffing, locomotion, and sleeping behaviour differed by treatment day ($p = 0.10$, $p = 0.002$, and $p = 0.002$, respectively; Figure 6). During the tactile enrichment, treatment day also affected time spent in locomotion ($p < 0.001$), standing ($p = 0.03$), and resting ($p < 0.001$).

To compare the effect of treatment, both 'dog' and 'treatment day' were treated as random effects. Overall, dogs spent more time each day exhibiting locomotive behaviour during the baseline period than during the food ($p = 0.005$), olfactory ($p = 0.09$), or tactile enrichment ($p = 0.02$; Table 3). Locomotive behaviour, however, did not differ among the three enrichment types (Table 3). Time spent sniffing was lower during the baseline period than either the food and olfactory treatment ($p = 0.006$ and $p < 0.001$, respectively; Table 3) but did not differ from the tactile enrichment. While sniffing behaviour did not differ ($p < 0.05$) between the tactile and food enrichments ($p > 0.05$), dogs displayed less time sniffing during the tactile than olfactory enrichment ($p = 0.01$). Time spent barking was greater during the tactile enrichment than during the baseline period ($p = 0.04$) and the olfactory enrichment ($p < 0.001$; Table 3). Dogs also spent less time barking during the olfactory enrichment than either the food or tactile enrichment treatments ($p = 0.02$

and $p < 0.001$, respectively; Table 3). Standing was greater ($p < 0.001$) during baseline than during any of the enrichment treatments. It was also lower during the tactile enrichment than either the food ($p = 0.02$) or olfactory ($p = 0.004$) treatments (Table 3). The amount of time spent resting (alert) did not differ between any of the treatment groups; however, dogs spent ($p < 0.001$) less time sleeping during the baseline period than during any of the three enrichment treatments, which did not differ ($p > 0.05$; Table 3).

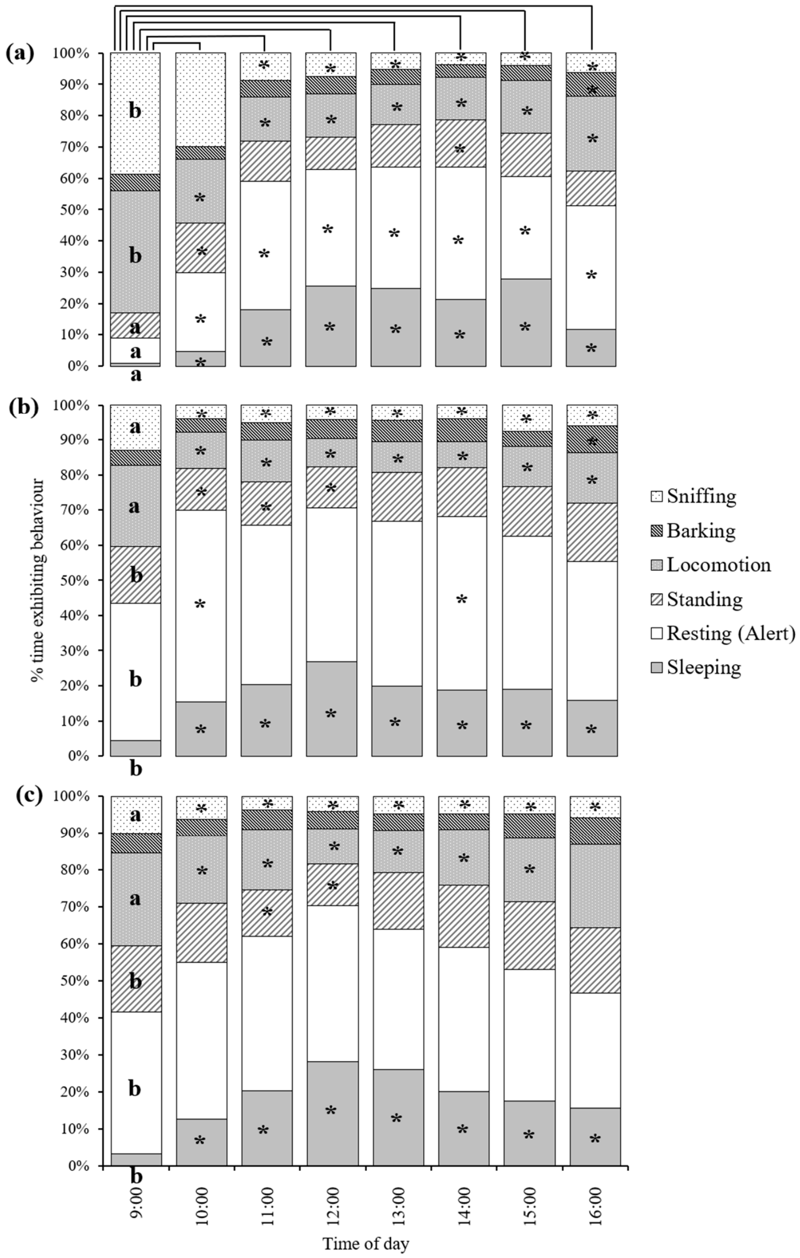

Figure 7. The average time spent exhibiting each behaviour per hour of the (**a**) food, (**b**) olfactory, and (**c**) tactile enrichment periods. Behaviours were sleeping (solid grey), resting alert (solid white), standing (wide grey diagonal stripes), locomotion (grey with white dots), barking (narrow black diagonal strips), and sniffing (white with black dots). Maintenance behaviours (eating, drinking, and defecating) were excluded due to their low frequency. * Denotes the amount of time spent exhibiting a given behaviour being statistically different ($p < 0.05$) from the first hour of the enrichment period, as indicated with comparison bars at the top of the chart. Different letters within the first day of each enrichment period indicate a statistical difference ($p < 0.05$) in time spent exhibiting the behaviour between the enrichment types.

Duration of exposure affected the behaviour of the dogs during all enrichment treatments (Figure 7). The amount of time spent exhibiting locomotive behaviour was higher during the first hour than the average of all other hours for the food ($p < 0.001$), olfactory ($p < 0.001$), and tactile ($p = 0.02$) enrichments. In fact, locomotive behaviour was significantly higher during the first hour (9:00 a.m. to 10:00 a.m.) than all other hours (10:00 a.m. to 16:00 p.m.) and treatments, with the only exception being the last hour of the tactile enrichment (Figure 7). Sniffing behaviour was higher during the first hour than all other hours for the tactile ($p = 0.01$) and olfactory ($p = 0.002$) enrichments. For the food enrichment, sniffing behaviours were higher for the first two hours (9:00 a.m.–11:00 a.m.) than all other hours (11:00 a.m.–16:00 p.m.). Resting (alert) and sleeping behaviours were more frequent during the middle of the day and afternoons than other periods during the day across all enrichments (Figure 7). Indeed, the percentage of time spent sleeping was higher for the first hour (9:00 a.m.–10 a.m.) than all other hours (10:00 a.m. to 16:00 p.m.) for the food ($p < 0.001$), olfactory ($p < 0.001$), and tactile ($p < 0.001$) enrichments.

During the first hour of the food enrichment period, dogs spent more time sniffing (38.8 ± 6.1%) than during either the olfactory (13.0 ± 1.9%; $p < 0.001$) or tactile enrichments (10.0 ± 1.4%; $p < 0.001$) which did not differ ($p > 0.05$; Figure 7). A similar pattern was observed for locomotive behaviour during the first hour of enrichment, whereby dogs exhibited more locomotive behaviour during the food enrichment (38.9 ± 5.1%) than either the olfactory (23.0 ± 2.9%; $p < 0.001$) or tactile enrichments (25.2 ± 3.3%; $p < 0.001$) which did not differ ($p > 0.05$). Standing, resting (alert), and sleep behaviours during the first hour of each enrichment period were less prevalent ($p < 0.05$) during the food enrichment (8.0 ± 1.36%, 8.3 ± 4.78%, and 0.8 ± 0.77%, respectively) than either the olfactory (16.2 ± 1.47%, 38.9 ± 3.76%, and 4.5 ± 1.04%, respectively) or tactile enrichments (17.8 ± 1.88%, 38.1 ± 3.88%, and 3.3 ± 0.78%, respectively). The time spent displaying standing, resting (alert), and sleep behaviours during the first hour of enrichment did not differ ($p > 0.05$) between the olfactory and tactile enrichments (Figure 7).

3.5. Correlation of ODBA and Behaviour

The percentage of time dogs spent exhibiting locomotion behaviour showed a strong, positive linear correlation with ODBA (rho = 0.78, $p < 0.001$; Figure 8). Barking had a weaker positive correlation with ODBA (rho = 0.38, $p = 0.001$), whereas sleeping was negatively correlated with ODBA (rho = −0.41, $p < 0.001$). No other behaviours were significantly correlated with ODBA ($p > 0.05$).

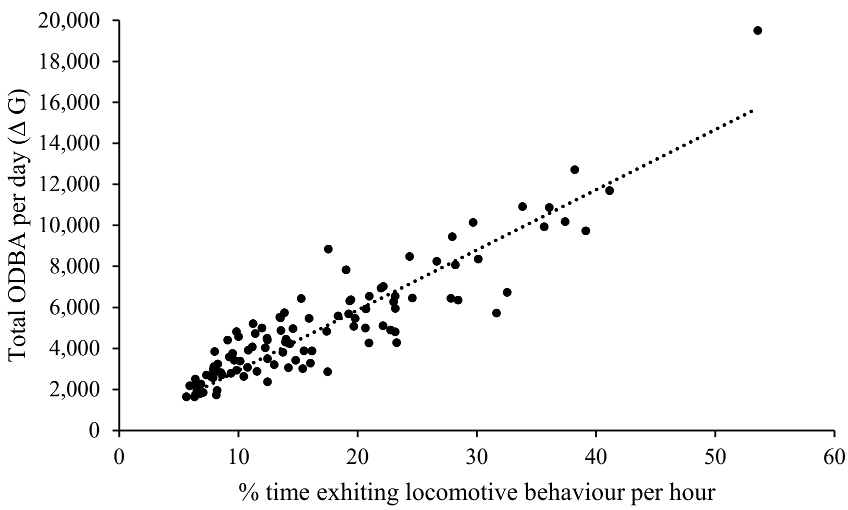

Figure 8. Correlation between the percentage of time spent active per hour and the overall dynamic body acceleration (ODBA) of the dogs.

4. Discussion

Evaluating the effectiveness of different enrichment types is crucial for optimising animal welfare, particularly for animals living in confined environments under human care. There is, however, no standardised method of assessing the efficacy of enrichment options, which has led to variable results being reported [2–4,10]. A standardised, objective method for evaluating enrichment programs is needed to tailor approaches to individual dogs and housing conditions. Therefore, this study aimed to utilise triaxial accelerometery and a validated random forest model to determine how three enrichment options affected the behaviour of colony-housed dogs.

Over the past two decades, accelerometery (often alongside gyroscope and/or magnetometer data) has increasingly been used to evaluate animal activity and behaviour [20,22,26–29]. Following the training of machine learning algorithms, accelerometer devices, such as the ActiGraph® used in the present study, can provide a continuous and objective evaluation of animal behaviour. This provides a more comprehensive analysis of behaviour than traditional methods such as focal point sampling or subjective owner- or veterinarian-based surveys. Thus, collar-mounted accelerometers can enable researchers to carry out an accurate and objective evaluation of enrichment techniques, particularly if the behavioural changes are subtle. Indeed, multiple studies have used acceleration data to evaluate the responses of animals, including dogs, to enrichment techniques [15–19,21–24].

A positive correlation was observed between ODBA and the amount of time dogs spent active. This is in agreement with previous reports in dogs [26] and dingoes (*Canis dingo*) [30]. In the present study, the amount of time spent exhibiting locomotion was also positively correlated with ODBA, which was in agreement with Tatler, Cassey and Prowse [30] who reported a clear relationship between distance travelled and ODBA. In most cases, environmental enrichment approaches are aimed at promoting active behaviours such as locomotion, scent marking, sniffing, or play [3,7,10–13,18,31]. Therefore, ODBA appears to be a useful parameter for evaluating the efficacy of enrichment approaches.

Canine behaviours were classified from triaxial acceleration data using a trained and validated machine learning algorithm [26]. A modified version of this random forest model was used in the present study. The accuracy of this model was comparable to past studies in dogs [22,24,26,27]. The main advantage of our approach is its ability to obtain continuous behavioural data over several days. Other methods, such as scan sample or subjective surveys, while enabling a broader ethogram analysis, are limited as they are non-continuous, can be impacted by observer bias, and are labour-intensive. A limitation of our approach is that behavioural classifications must be simplified to maintain model accuracy. Nevertheless, the behaviours classified using this random forest model showed that the provision of novel enrichment objects led to changes in the amount of time the dogs spent exhibiting locomotive, standing, resting-asleep, and sniffing behaviours, as well as changes in their overall activity.

In a review of the welfare of kennelled dogs, Polgár, et al. [32] reported that while overall activity can be used as a marker of animal welfare, it can be difficult to distinguish between rest, boredom, learned helplessness and depressive states. Both excessively high and excessively low activity levels can be indicative of stress [32]. During the enrichment phase of the present study, dogs were most active when given the food enrichment object, followed by the tactile enrichment and the olfactory enrichment. These changes in activity alone, however, may not necessarily imply effective environment enrichment since different strategies are targeted at eliciting different behavioural responses [7,33].

Despite an increase in ODBA, the average percentage of time dogs spent showing locomotion behaviours did not differ between the baseline period and either the food or tactile enrichments. The increase in ODBA, therefore, was likely driven by changes in other active behaviours. Dogs in the olfactory enrichment showed lower average daily locomotion than when provided either food or tactile enrichment. The olfactory enrichment paddock was chosen for its isolated position to prevent the scent from spreading to other paddocks and maintain its novelty. The paddock, however, was 44% smaller than those used for the food and tactile enrichment treatments. This difference in size likely contributed to the lower daily ODBA and locomotion behaviour observed. This is in agreement with Siwak, et al. [34] who reported that smaller housing areas limited the movement of laboratory dogs. Interpreting changes in ODBA and locomotion can be challenging, as increased and decreased levels can indicate stress in dogs [35]. It is vital, therefore, to consider each dog's 'normal' behaviour to understand their response to enrichment [36]. The lower daily locomotion during periods of enrichment compared with the baseline period suggests that other factors, such as the smaller paddock size and individual differences between dogs, need to be considered when evaluating enrichment success.

Olfactory and food enrichments are typically designed to promote exploratory and/or puzzle-solving behaviours [1,3,8,9]. Behaviours such as sniffing have been reported to directly reflect cognitive stimulation and improved welfare in dogs [31,37]. In the present study, both the food and olfactory enrichments resulted in an increase in sniffing. Interestingly, the food enrichment elicited more than twice the amount of sniffing behaviour than the olfactory enrichment. While some sniffing was expected in response to the food enrichment, it was considerably higher than when the olfactory enrichment was offered. It was likely, therefore, that other behaviours were misclassified as sniffing by the model. Behaviours with similar postures and subtle head movements are often misclassified by machine learning models when analysing triaxial acceleration data [22,24,26,28,30]. The action of licking the ice block may have exhibited a similar motion and head placement as sniffing, thus potentially causing the misclassification. The random forest model used in the current study had an accuracy of 93% for sniffing behaviour; however, licking was not a behavioural classification in the model, thus potentially resulting in the behaviour being incorrectly classified as sniffing due to their similarity [26]. Therefore, when using acceleration data and machine learning to evaluate enrichment strategies, it is important to consider the effect that unique enrichment-specific behaviours could have on model accuracy and reliability. While future studies should consider incorporating licking, chewing, and sniffing into the behavioural algorithms, it is worth noting that these behaviours are not mutually exclusive and all reflect engagement with the enrichment objects.

Each enrichment object was provided for five consecutive days to determine how quickly the dogs habituated to the objects. When provided with the olfactory and food enrichments, dogs spent a similar amount of time per day engaging with the objects across the period, suggesting that they did not lose their novelty. It was evident that the dogs were most interested in the objects during the first hour. Introducing novel objects typically encourages animals to attend to these objects quickly [38]; thus, it was not surprising that interaction with the object declined over time. Explorative behaviours such as sniffing (or licking) during the olfactory and food enrichments also declined; however, there was also a reduction in these behaviours between day 1 and day 5. The reduction in sniffing behaviour during the food enrichment period indicated that, despite there being no reduction in ODBA, the dogs habituated to the enrichment over time [39,40], although the dogs ate all of the food object each day.

Engagement with the tactile enrichment object was lower than with either the food or olfactory enrichment objects. Furthermore, dogs' interest in the tactile object showed an exponential decrease over the five days. The lack of interest in the toy may have been due to the lack of interactive engagement. Many dog toys are designed for human facilitation, such as pulling or throwing. It was likely that, given the dogs had not experienced the rope toys previously, they did not know what to do with the toy without human facilitation. Indeed, a lack of prior exposure to tactile enrichment objects has been reported to impact the ability of dogs to engage effectively with these objects [33]. In future studies, human facilitation is recommended to initially train dogs to interact with this type of enrichment. It is also recommended that non-interactive tactile toys are not provided continuously to dogs due to the loss of interest over time.

There were considerable differences in behavioural responses and activity among dogs when provided with each enrichment object. The novelty of the olfactory enrichment was likely impacted by the facility design that made it impossible to fully isolate the paddocks. Caution is needed, therefore, when comparing the responses of dogs to enrichment strategies. Both Andrews et al. [41] and Hansen et al. [28] recommended that each dog should act as its own control when evaluating the effectiveness of different enrichment techniques, particularly when using ODBA. Among dogs, behaviour and temperament differ between breeds and even between individuals within a breed [22]. The development of a personalised enrichment plan for individual dogs is likely required to optimise their welfare. Close monitoring of behaviours typically associated with negative welfare or distress (e.g., stereotypical behaviours) is essential to ensure that the welfare of animals in human care is improved [42].

In the current study, none of the dogs were observed to display stereotypical behaviours which are generally associated with stress and anxiety, such as excessive barking, pacing, destructive behaviour, digging, circling, paw lifting, tail chasing, or self-mutilation [43,44]. Of these behaviours, only barking was classified by the random forest model with a high balanced accuracy of 90 [26]. Based on the model classifications, the amount of barking in the current study did not differ between the baseline period and any of the treatment periods. Thus, this suggests that the welfare needs of the dogs at this facility were met through the day-to-day husbandry activities, although to confirm this, a study focusing on the occurrence of stereotypical behaviours would be required.

The baseline data in the current study were collected in spring (August and September 2023), while the enrichment treatment data were collected four months later (January and February 2024). Thus, seasonal variation between these periods could have influenced dog behaviour. We did observe that resting behaviour was greater in both the tactile and olfactory enrichments when compared to baseline. Studies suggest that dogs exhibit seasonal differences in activity [45,46]. These fluctuations could be due to changes in environmental conditions, such as temperature and daylight hours, which could affect dogs physiological responses and behaviour. Future research should consider the timing of enrichment interventions and how seasonal changes might influence their effectiveness, ensuring that dogs receive optimal care throughout the year.

5. Conclusions

The three enrichment treatments used in the current study resulted in changes in active and inactive behaviours, ODBA levels, and the duration during which the dogs interacted with the enrichment objects. The food enrichment treatment appeared to result in the greatest changes in behaviour, with increased active and locomotion behaviours and ODBA. Additionally, dogs spent longer periods interacting with the food enrichment object than with any other. This suggests that exposure to the food enrichment treatment promoted greater activity in these dogs. While there was a slight decrease in the duration of interaction with the food enrichment object, the dogs consumed all the food offered each day.

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writing—original draft preparation, C.R.; writing—review and editing, R.C.-T., D.T., C.A. and I.D.; visualization, R.C.-T., D.T., C.A., I.D. and C.R.; supervision, R.C.-T., D.T., C.A. and I.D.; project administration, C.R.; funding acquisition, R.C.-T. and D.T. All authors have read and agreed to the published version of the manuscript.

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