Can't see the forest for the trees? Investigating attentional scope as a novel indicator of emotional state in animals

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Abstract

In humans, contrasting emotional states can lead to a broadening or narrowing of attentional scope. Whether this is also the case in animals has yet to be investigated. If confirmed, measurement of attentional scope has potential as a novel cognitive method of welfare assessment. In this study, we therefore aimed to validate a test of attentional scope as a measure of emotional state in animals. We did this by inducing four putatively different emotional states in dogs (N = 10), varying in valence (positive, negative) and arousal (high, low), in two different reward contexts (food rewards in Experiment 1, social rewards in Experiment 2) and then assessing dogs' behavioural responses in a test of attentional scope. We also recorded heart rate variability (HRV) parameters as additional confirmatory affective indicators. In Experiment 1, the dogs showed a narrowing of attentional scope after the induction of both positively valenced emotional states. That dogs were in a positive state was supported by the reduced Standard Deviation of normal-to-normal R-R intervals (SDNN) and the reduced Low Frequency (LF) and Very Low Frequency (VLF) HRV. In Experiment 2, when responses to social rewards were examined, the dogs showed attentional narrowing only in the low arousal negative treatment, while the LF and VLF were reduced in the high arousal positive treatment. In conclusion, our study provides the first indication that emotional states can also alter attentional scope in animals. The results justify further investigation of this approach for use in animal welfare assessment, although further studies are needed to refine predictions.

Introduction

In humans, and more recently also in animals, it has been shown that there is a strong bi-directional link between cognition and emotion ¹. Emotions are defined as brief sensations, elicited by a specific external cause, and are associated with distinct physiological, behavioural and cognitive reactions ²⁻⁴. Particular emotional states can lead to either a narrowing or a broadening of attention in humans ⁵. A narrowing of attention can be described as 'not seeing the forest for the trees', while a broadening of attention describes 'seeing the whole forest'. However, it has not yet been investigated if a similar broadening and narrowing of attentional scope also occurs in animals when they experience different emotional states and, if so, whether it could provide a novel cognitive indicator of animal welfare.

Attentional scope can be measured with a global-local preference test, which uses visual stimuli consisting of one large element, called a global element, which is constructed from several smaller elements, called local elements. Anxious people are quicker to detect the local elements in a global-local preference test (i.e. they have a narrow attentional focus) compared to non-anxious people ^{6,7}. Whereas people in a positive emotional state generally show a broadening of attentional scope ^{8,9}. A narrow attentional scope ensures that irrelevant stimuli and perceptions can be ignored as individuals attempt to achieve a goal (e.g., get access to a resource or escape from danger) ^{5,9,10}. However, a constantly narrowed attention towards one type of stimulus can make it harder to shift attention to other stimuli that may be needed more, or when new unforeseen stimuli become available ¹¹. On the other hand, the broad

attentional scope that arises when experiencing positive emotions is associated with more open and holistic processing, which may facilitate detection of new information and the exploration of new opportunities¹². The ability to narrow and widen attentional scope depending on current emotional state is therefore essential in order to respond to different situations appropriately.

Beyond the valence of the emotion, attentional scope in humans has been shown to be influenced by motivational intensity⁵: positive emotions arise when people are motivated to approach rewarding stimuli (e.g., excitement) but also when they are successful in avoiding negative stimuli (e.g., relief). Negative emotions occur when people experience and/or anticipating harmful stimuli (e.g., fear) and when positive stimuli are removed (e.g., frustration)¹³. In the animal welfare literature, emotions are often described by a two dimensional model consisting of a valence (positive to negative) and arousal (high to low) axis¹⁴. The concept of motivational intensity and arousal are closely linked: emotions that are highly motivating are often also highly arousing (e.g., anticipation of a food reward) although there are suggestions in the human literature that this is not always the case^{5,15}. Nevertheless, for simplicity, and since in this paper we are presenting a study with animals, we have chosen to use the term 'arousal' instead of the term motivational intensity.

In summary, attentional scope reflects an interaction between the valence of the emotion and the level of arousal associated with it, so nuancing the response in a particular situation. In humans, it has been shown that while the experience of having achieved monetary gains (low arousal positive emotion) is associated with a broad attentional scope, anticipating monetary gains (high arousal positive emotion) led to a narrowing of attentional scope¹⁶. Furthermore, even if individuals' attentional scope narrowed when they had been shown a picture of an appetizing dessert, it became even more narrow when arousal increased because they were led to believe that they would eat the dessert¹⁷. Regarding negative emotions, high arousal emotions such as disgust¹⁸ and anxiety¹⁹ led to a more narrow attentional scope than low arousal emotions such as sadness¹⁸.

A local/global preference test has already been adapted for animals in order to compare cognitive processing across species (e.g.^{20,21}), however, these have been carried out without manipulation of the emotional state. Most non-human primates tend to have a narrow attentional scope²²⁻²⁴. However, other animal species such as honeybees²¹, fish²⁵ and birds^{26,27} have a local preference, although see²⁸. Dogs preferences for local or global information varied across individuals, which suggest a large wide individual variation in dogs²⁰.

In order to obtain additional measures of emotional state that can aid in interpreting the behavioural data and validate the induction of the different emotional states, we also recorded heart rate (HR) and heart rate variability (HRV) parameters²⁹. An increase in HR is generally interpreted as an increase in arousal in both humans³⁰ and in dogs³¹, although HR may also indicate valence in humans^{32,33}. HRV indexes are often interpreted as indicative of the valence component of emotional states. For example, decreases in Standard Deviation of Normal-to-Normal R-R intervals (SDNN), Root Mean Square of Successive

Differences (RMSSD), High Frequency (HF) and Low Frequency (LF) HRV have all been shown to indicate positive valence in dogs^{31,34}, while an increase in RMSSD indicated negative valence³⁴, although see³⁵.

The aim of this study was to investigate the attentional scope methodology as a novel indicator of emotional state in animals. We used dogs, as they have previously been shown to be a suitable model to investigate cognitive and emotional processes (e.g., see^{20,36}). We aimed to induce different emotional states varying in valence (positive, negative) and arousal (high, low) in two contexts that are known to be rewarding for dogs; food rewards and social interaction^{31,37–39}. We hypothesized that positive emotions in general would lead to a more broad attentional scope compared to negative emotions. Furthermore, we hypothesized that arousal would also influence attentional scope, with high arousal states leading to a more narrow attentional scope while low arousal states will broaden dogs' attentional scope. What is less clear is how these interact. Thus, we only make two specific predictions. These are that dogs in a positive, low arousal state will be most broad in their attentional scope and dogs in a negative, high arousal state will be most narrow. We hypothesize that dogs in a positive high arousal state, or a negative low arousal state should be intermediate, but this will depend on how relative contribution of emotion and valence (Fig. 1). In this study we also measure HRV indexes, predicting that heart rate should be higher in our high arousal states and that the valence of the emotion is also be associated with different HRV indexes, thus validating our inductions of emotional states.

Materials And Methods

All methods were carried out in accordance with relevant guidelines and regulations. The study was approved by Uppsala animal ethics committee (document number 5.8.18–01758/2020) and complied with the ARRIVE guidelines⁴⁰.

1. Subjects

This study started with 21 laboratory beagle dogs. Dogs that did not succeed in learning the task were excluded (see criteria in the section below). Consequently, five males and five female dogs between 2 to 10 years of age completed the whole experiment. All dogs were kept in kennels at the University Animal Hospital in Uppsala, Sweden, in groups of 3 to 6 individuals. They were kept in indoor enclosures of 24.3 m² (9 m × 2.7 m) from 16:00 h until 8:00 h and in outdoor enclosures varying between 145 and 200 m² (around 6 m × 25 m) the rest of the time. They were fed twice a day with Hill's Science plan Mature Adult Chicken between 4 and 8 dl per day depending on the dogs' weight and water was available *ad libitum*. Twice a week they were walked by a caretaker.

2. Global-local preference test stimuli

The global-local preference test used to assess attentional scope involved training dogs to discriminate between different visual stimuli characterized by a two-level hierarchy pattern. A stimulus was made of a global shape composed of smaller local shapes, which lead to two possible levels of discrimination: local

or global. The stimuli we used were similar to Navon-type stimuli ⁴¹. The local shapes were 4 cm high and wide, the global shapes were 22.9 cm high and wide. The stimuli were created in PowerPoint (Windows 10), using black opaque symbols on a white background. Two different sets of stimuli were made in order to avoid any bias coming from a specific aspect of the pattern of the stimuli ⁴². The training stimuli are shown in Fig. 2a, and half of the dogs were randomly assigned to set A and the other half to set B. We used the random number generator function in Microsoft Excel (function = Rand()) to assign the dogs to the different symbol sets. The conflict stimuli are shown in Fig. 2b, and these were used to assess local and global preferences.

3. Experimental setting

The test apparatus consisted of a TV screen NEC Edition of 125 cm long and 72 cm high, the bottom edge of the screen was 10 cm above the floor level. The speaker (Extron) was placed directly above the screen (aligning to the middle of the screen). A divider of 70cm long was placed in front of the TV screen to separate it in two halves to help the dog go to one side or another and touch only one symbol with its nose. A chair was placed 2.15 m away from the screen for the researcher to sit on while training and testing the dogs (Fig. 3). The visual angle ($\text{visual angle} = 2 \cdot \arctan(0,5 \cdot \text{object size} / \text{distance})$) from the starting position was 5.58 and the visual angle from the beginning of the divider (70 cm in front of the screen) was 28.6., with the object size being 22.9 cm).

4. Training

Habituation

Dogs were first habituated to the researchers in their home pens, and later to the test room. They were then taught to associate a click on a standard clicker device with a food reward. Following this, the dogs were trained to touch with their nose a single rewarded stimulus (see Fig. 1a) printed on an A4 paper on the floor first and later on the wall, using clicker training.

Training for the global-local preference test

Dogs were trained to either set A or B in sessions of 20 trials for a maximum of three times per day for five days a week. Within each session, the rewarded symbol was displayed 10 times on the left side and 10 times on the right side of the screen in pseudo-random order (no more than three times in a row on the same side). Dogs had to give 16 out of 20 correct responses on two consecutive days to proceed to the next training phase.

The training for the global-local preference test was divided into four different phases in order to gradually teach the dogs to discriminate between the different symbols. In phase 1, the rewarded symbol was displayed on one side of the TV screen while the other side was left blank. In phase 2, the rewarded symbol was displayed on one side of screen and the other side simultaneously displayed one local element of the unrewarded symbol. In phase 3, the rewarded symbol was displayed versus the

unrewarded symbol, which was reduced to 50 percent of its total size. In training phase 4, both rewarded and unrewarded symbols were displayed at full size (Fig. 1a).

At the beginning of each trial, the dog was held by its collar by the experimenter sitting on the chair. Each trial started with the display of a plus sign (1.7 cm wide and 2.1 cm high) in the middle of the screen combined with a 'pling' sound to draw the dogs' attention to the screen. Once the dog was looking at the screen, the experimenter closed her eyes, and then the rewarded and unrewarded symbols were displayed simultaneously (Fig. 1a). After about 2 seconds the experimenter said 'go' and released the dog. The experimenter kept her eyes closed until the dog was released in order to avoid influencing the dog's subsequent choice. The experimenter opened her eyes again once the dog had started to move towards the screen. The dog received a clicker confirmation sound followed by a food reward given by the experimenter if it approached the screen and touched the rewarded symbol. If the dog approached and touched the unrewarded symbol, no click and reward were given, and a new trial was started immediately. This same procedure was then repeated for the other trials.

5. Global-local preference test following different treatments

All testing took place between 9:00 h and 11:00 h. Before starting the test, each dog needed to correctly respond to 4 out of 5 final training trials (80% correct). If the dog did not pass this criterion, they received another 5 training trials to pass the criterion. If the training criterion was passed, the dog experienced a treatment designed to induce a specific emotional state. Each dog completed each of the four treatments, in random order (using the random number generator in excel), once (repetition 1), before being tested for the same four emotional treatments a second time (repetition 2). The dogs performed no more than one test per day. It was not possible for the experimenters to be blind to the treatments, because these had to be administered immediately before testing.

Emotional treatments

The four emotions we aimed to induce varied according to valence (positive, negative) and arousal (high, low) in two different reward contexts, according to the four different quadrants of the animal emotion framework¹⁴ leading to specific predictions regarding attentional scope (see Fig. 1). The high arousal positive states were created by giving the dog a small amount of something it desired (food (Experiment 1) or social (human) contact (Experiment 2))³¹, but without letting the dog consume it until satiated, in order to induce (more) desire or excitement (pre-goal and high arousal). The low arousal positive states were induced by providing the dog with rewards until satiated (social context) or until nearly satiated in the food context, in order to create a post-consummatory state of satisfaction or contentment (post-goal and low arousal)⁴³. It was not possible to give food treats until the dogs stopped consuming them, because then they were no longer motivated to perform the test itself (which was identified as a potential issue in a pilot study prior to the experiment). The high arousal negative states were created by preventing the dogs to access to a desirable reward, in order to induce frustration³⁶. The low approach negative states were induced by making the dog expect a reward, but then this reward was never presented, in order to induce disappointment⁴⁴.

In experiment 1, food rewards were used to induce the emotions. We used a hidden treat toy (“Dog Smart”, Nina Ottosson, Sweden) that consisted of 9 holes containing treats that were covered with lids. The dogs had to remove the lids with their mouth in order to access the treats (Table 1). In experiment 2, the emotions were induced by social interactions with the experimenter (Table 2).

Table 1
Treatments used in experiment 1 that were designed to inducing the different emotions.

Treatment	Emotion (arousal/valence)	Description of the treatment	Duration
Initial access to treats	High arousal positive	Access to the hidden treat toy containing 9 pieces of 2–3 mm sausage.	50–60 seconds
Prolonged access to treats	Low arousal positive	Access to the hidden treat toy containing 9 pieces of dry dog biscuits. The toy was refilled every two minutes, ten times in a row.	20 minutes
Inaccessible treats	High arousal negative	Non-accessible toy with 2–3 mm pieces of sausage, without lids, covered by a wire rack so the treats were visible but not accessible.	60 seconds
No treats	Low arousal negative	Access to an empty hidden treat toy without lids. Wait until the dog stops interacting/loses interest in toy, then wait 30 seconds.	40–60 seconds

Table 2
Treatments used in experiment 2 that were designed to induce different emotions.

Treatment	Emotion (arousal/valence)	Description of the treatment	Duration
Initial access to interaction	High arousal Positive	The experimenter played and interacted with the dog.	60 seconds
Prolonged access to interaction	Low arousal positive	Experimenter petted the dog (voluntary) until the dog relaxed (head down on floor/paws without movement, eyes open or closed) or lost interest and walked away.	15–40 minutes
Inaccessible play	High arousal negative	The test dog is alone in the testing area. The experimenter played with a pen mate on the other side of the fence in front of the test dog, and invited the test dog to come to play by calling it and making eye contact with it. However, the dog was unable to cross the fence and join the play session.	60 seconds
No play	Low arousal negative	The experimenter initiated play for 10 seconds, then stopped, crossed her arms, stood still and ignored the dog. The experimenter waited until the dog stopped interacting, and then tested after 30 seconds.	40–60 seconds

Conflict test

Immediately after experiencing each emotional treatment, the dogs' preferences for local or global information were assessed in a conflict test. This involved displaying two inconsistent test stimuli (Fig. 2b): one symbol with the same global element as the rewarded symbol, but with a local element never seen before (a preference for which would indicate a global preference) and another symbol showing the same local elements as the rewarded symbol, but with a global element never seen before (a preference for which would indicate a local preference). The dogs were always rewarded regardless of their choice. Each dog was tested twice in each emotional state, and right and left presentations of global and local choices were balanced across the repetitions.

Local and global discrimination test

To confirm that dogs could discriminate at local and global levels, and ensure that the emotional treatments did not impair the dog's ability to discriminate at local and global levels, a local discrimination test and a global discrimination test²¹ was carried out directly after the conflict test. The procedure was identical to that of the conflict test but with the exception that the correct symbol differed from the rewarded symbol only at the global level for the global discrimination test (Fig. 2c) and only at the local level for the local discrimination test (Fig. 2d). Right and left presentations of correct local and global stimuli were randomized as well as the order of the local and global discrimination. Only the choice of the correct local and global symbols was rewarded.

Motivation tests

A food motivation and a social motivation test were carried out once the local-global preference tests were completed, in order to account for individual differences in motivations toward food and social stimuli^{45,46}. Motivation testing took place in a runway of 20 meters long. For the feeding motivation test, a food bowl containing 1 piece of sausage, 1 piece of ham and 2 pieces of dry treats was placed at one end of the runway. For the social motivation test, a familiar person stood at the end of the runway and called the dog's name. The time the dog took to run to the bowl or person from the opposite end of the runway was recorded. The dog was allowed to eat the treats or was petted by the familiar person for 20 seconds. This process was repeated 4 times for each stimuli. The order of food and social motivation tests was randomized but balanced across the group.

Heart rate procedure

Dogs' heart rates were recorded with Polar watches, model V800 Polar-Systems (© Polar Electro 2021), to obtain a non-invasive real-time measurement of HR and HRV. A belt with two electrodes was placed on the dog's chest and connected to a watch-like data recorder. Electro gel was used to improve the skin-to-electrode contact. For each dog, a 15-minute recording was taken (baseline) before the dogs received the emotional treatments and global-local testing. The baselines were recorded in the same room as where training and testing took place to ensure that the baselines were recorded in the same environment as the treatments. Dogs were always very excited when coming into the training and testing room, so we could

not record any baselines immediately before conducting the emotional treatments and tests. Therefore, baseline recordings were started about 5 min after the end of a training session to ensure a resting condition. The HR and HRV were then also recorded during each emotional treatment and immediately following testing for a 15-minute period (post-test), during the first repetition only. During the baseline and post-test period recordings, the experimenter sat down quietly so that the dogs would relax and rest. HRV was measured between 9:00 h and 11:00 h.

Data analysis

Initial data exploration and statistical analysis were performed with the software R (version 4.0.2, 2020-06-22, copyright © 2020, the R Foundation for Statistical Computing) and R studio (version 1.3.1073, © 2009–2020 RStudio, PCB). Means were calculated using packages dplyr⁴⁷ and plots and figures were generated using packages ggplot2⁴⁸.

Global-local preference data

The analysed variable was the choice made in the global-local preference test. Therefore, it was a binomial variable (0 = choice of global; 1 = choice of local) and the analysis was conducted on the proportion of local choices. A generalized linear mixed model (GLMM) with a logit link function was fitted using packages lme4⁴⁹ and nmle⁵⁰ with valence, arousal, repetition and their interactions, the side of presentation of the local choice (left or right), the assigned set of stimuli (set A or set B), and the sex of the dog as fixed effects, the average number of seconds to reach the end of the runway of the food and social motivation tests as covariates, and the dog identification number as a random effect. Non-significant effects were dropped in the final model. Tukey corrected post-hoc test were conducted in the package emmeans⁵¹. The data from the social test was over-dispersed, and therefore a negative binomial mixed model was fitted instead.

To compare the dogs' abilities to discriminate on a local or global level, the percentage of correct choices in the local and global tests was calculated for each dog. In the experiment 1, since the normality criteria were not reached, a Wilcoxon test was used as a non-parametric-test to determine if the percentage of correct choices in the local and global discrimination tests were different. In the experiment 2, a paired T-test was used since the data were normally distributed.

Heart rate (HR) and Heart Rate Variability (HRV)

The raw data were divided into 3 time periods for each treatment (one data point per dog and per period): a 15-minute baseline period, a treatment period (the last 45 seconds of the treatment exposure) and a post-treatment period (15 minutes post-treatment). The HRV analysis required the identification of outliers. The recordings were first checked by the algorithm AVEC (Algorithm-supported visual error correction) in R studio in order to highlight the outliers and these were afterwards manually removed in Excel 2016 (Windows 10). On average, 0.64% of the recordings were removed.

The cleaned heart rate recordings were then analysed with Artiifact (Heart rate artifact processing and heart rate variability analysis software, version 2.13 ⁵²) which associated a list of HRV indexes values to each time period of each treatment. Artiifact software analysis yields all common time and frequency domain measures of vagally mediated HRV, including standard deviation of normal-to-normal R-R intervals (SDNN), Root Mean Square of Successive Differences (RMSSD), mean RR intervals, proportion of successive R-R intervals that differ by more than 50 ms (pNN50), High-Frequency (HF) absolute power, Low-Frequency absolute power (LF), and Very Low-Frequency absolute power (VLF). The VLF band was set to be 0.06 Hz, LF to be 0.24 Hz, and HF to be 1.04 Hz based on measurements done in dogs ⁵³.

These indexes were analysed in R with a generalized linear mixed effect model, using packages lme4 ⁴⁹ and lmerTest ⁵⁴, with period (baseline; during treatments; after treatments), emotional treatments, a period x treatment interaction and sex as fixed effects, and dog ID as a random effect. Data were log-transformed and assumptions of normality and homoscedasticity were assessed by graphical analysis of the residuals (LMERConvenienceFunction package ⁵⁵). Outliers with residuals greater than 2.5 units were excluded from the dataset (containing 119 data points). In experiment 1, we excluded 4 outliers from the SDNN, 3 outliers from the LF and 3 outliers from the VLF. In experiment 2, we excluded 3 outliers from the RR, 4 outliers from the SDNN and 3 outliers from the VLF. Tukey corrected post-hoc tests were conducted using the package emmeans ⁵¹.

Results

Only 10 out of 21 dogs passed all the training criteria. These 10 dogs were on average fully trained after 364 ± 27 trials, which is equivalent to 18 ± 1 sessions of 20 trials each.

In the motivation test, the average running speed in the runway was higher for the social reward (7.5 ± 2.0 s) than for the food reward (12.3 ± 2.2 s, Kruskal-Wallis $\chi^2 = 10.3$, $P < 0.01$).

Experiment 1: Food reward stimuli

Global-local preference test

There was a significant valence by repetition interaction on the proportion of local choices ($F_{(1,7.2)} = 7.2$, $P < 0.05$, Fig. 4), with the positive conditions leading to more local choices compared to the negative conditions in the second repetition. In addition, there was a tendency for an effect of sex on the proportion of local choices, with a higher proportion of female dogs choosing the local symbol (0.78 ± 0.07) compared to males (0.5 ± 0.06 , $F_{(1,5)} = 4.9$, $P < 0.1$). The test symbol set (A or B), side of presentation (left or right), or the animal's running speed in the feeding motivation test did not affect the proportion of local choices.

We also determined whether the choice in each treatment was different from a 50–50 choice (indicating no preference for local or global elements) by calculating confidence intervals (CI). If the CI do not include

0.5, then we can conclude that there was a preference for local or global information. We found that the CI did not include 0.5 in both positive conditions in the second repetition (Fig. 4), suggesting that the positive conditions indeed induced a preference for the local elements.

In the discrimination tests to assess discrimination at the local and global levels, the dogs performed significantly better in the local discrimination test ($76 \pm 10\%$ correct choices) than in the global discrimination test ($64 \pm 11\%$ correct choices, $P < 0.01$).

Heart rate and heart rate variability

Heart rate significantly increased during the treatment period in all treatments ($F_{(2, 98)} = 86$, $P < 0.001$), but there was no effect of treatment nor a treatment x period interaction.

The SDNN was also affected by an emotional treatment by period interaction ($F_{(6, 93)} = 112$, $P < 0.001$, Fig. 5a). Post-hoc analysis showed that all treatments decreased from baseline ($P < 0.01$). During the treatment period, the SDNN was lower in the high arousal positive treatment than in the high arousal negative treatment ($P < 0.01$), and the low arousal negative treatment ($P < 0.05$), and tended to be lower than the low arousal positive treatment ($P < 0.1$, Fig. 4).

The VLF was also influenced by a treatment by period interaction ($F_{(6, 94)} = 4.2$, $P < 0.001$, Fig. 5b), and all treatments decreased significantly from baseline ($P < 0.001$). During the treatment period, the high arousal negative treatment had a higher VLF than the high arousal positive ($P < 0.001$) and low arousal positive ($P < 0.01$) conditions. The VLF was also higher in the low arousal negative treatment compared to the high arousal positive treatment ($P < 0.01$). In addition, the VLF was higher in females ($4476 \pm 466 \text{ ms}^2$) than in males ($2796 \pm 305 \text{ ms}^2$, $F_{(1, 8)} = 8.0$, $P < 0.05$).

The LF was effected by a treatment x period interaction ($F_{(6, 94)} = 2.7$, $P < 0.05$, Fig. 5c), but only the low arousal ($P < 0.05$) and high arousal positive ($P < 0.001$) conditions decreased from baseline. During the period treatment, the high arousal negative treatment was higher than the high arousal positive treatment ($P < 0.001$) and the low arousal positive treatment ($P < 0.05$). In addition, the low arousal negative treatment also had higher LF than the high arousal positive treatment ($P < 0.05$).

Experiment 2: Social stimuli

Global-local preference test

None of the factors fitted in the mixed model significantly affected the proportion of local choices (i.e., valence, arousal, repetition, sex, social motivation strength, set and side, Fig. 6). However, the CI did not include 0.5 proportion of local choice in the low arousal negative treatment, suggesting that this treatment induced a preference for local elements (Fig. 6).

When assessing discrimination at the local and global levels only, the dogs performed significantly better in the local discrimination ($84 \pm 8\%$ correct responses) than the global discrimination test ($63 \pm 11\%$

correct responses, $P < 0.034$).

Heart rate and heart rate variability

HR was influenced by a treatment x period interaction ($F_{(6, 99)} = 3.4$, $P < 0.01$, Fig. 7b), and increased in all treatments from baseline ($P < 0.001$) except for the petting treatment. During the treatment period, the dog's responses in HR were lower in the low arousal positive than the high arousal positive treatment ($P < 0.001$), high arousal negative ($P < 0.01$) and low arousal negative conditions ($P < 0.01$). In addition, males tended to have a higher HR than females (99.4 ± 2.4 vs 87.5 ± 2.1 , $F_{(1, 8)} = 4.8$, $P < 0.1$).

The RR was affected by a treatment x period interaction ($F_{(6, 99)} = 3.4$, $P < 0.01$, Fig. 7a). The post-hoc test showed that the RR decreased from baseline in all treatments ($P < 0.001$) except for the low arousal positive treatment. While undergoing the treatments, the dog's response in RR was higher in the low arousal positive treatment compared to the high arousal positive ($P < 0.001$), high arousal negative ($P < 0.01$) and low arousal negative treatments ($P < 0.01$).

The SDNN was also affected by a treatment x period interaction ($F_{(6, 99)} = 2.5$, $P < 0.01$, Fig. 7c), and decreased from baseline in all conditions (high arousal positive and negative, $P < 0.001$; low arousal negative, $P < 0.01$; and low arousal positive, $P < 0.05$). During the treatments, dogs in the low arousal positive treatment had a higher SDNN than in the high arousal positive treatment ($P < 0.001$) and high arousal negative treatment ($P < 0.05$). In addition, the low arousal negative treatment also induced a higher SDNN than the high arousal positive treatment ($P < 0.05$).

The RMSSD was affected by a treatment x period interaction ($F_{(6, 99)} = 2.1$, $P = 0.05$, Fig. 7d), and decreased from baseline in all conditions ($P < 0.001$) except the low arousal positive treatment. During the treatments, the RMSSD was higher in the low arousal positive treatment than the high arousal positive ($P < 0.01$), low arousal negative ($P < 0.05$) and high arousal negative treatments ($P < 0.01$). Furthermore, females had a higher RMSSD than males (234 ± 15 vs 154 ± 11 , $F_{(1, 8)} = 6.7$, $P < 0.05$).

The VLF absolute power was influenced by a treatment x period interaction ($F_{(6, 95)} = 3.6$, $P < 0.01$, Fig. 8a), and decreased from baseline in all treatments ($P < 0.01$). During the treatments, VLF was lowest in the high arousal positive treatment compared to the low arousal positive ($P < 0.01$), high arousal negative ($P < 0.01$) and low arousal negative ($P < 0.01$) treatments. In addition, females had a higher VLF than males ($4822 \pm 459 \text{ ms}^2$ vs $2626 \pm 240 \text{ ms}^2$, $F_{(1, 8)} = 5.3$, $P < 0.05$).

The LF was also influenced by a treatment x period interaction ($F_{(6, 96)} = 4.1$, $P < 0.01$, Fig. 8b), but only decreased from baseline in the high arousal positive treatment ($P < 0.05$). The LF tended to be higher during the after phase in the low arousal positive treatment compared to the baseline ($P = 0.06$). During the treatment phase, LF was lower in the high arousal positive treatment compared to the low arousal positive ($P < 0.01$) and low arousal negative ($P < 0.001$) treatments. Furthermore, the high arousal negative treatment also resulted in a lower LF than the low arousal negative treatment ($P < 0.01$).

Discussion

This study aimed to investigate attentional scope as a novel indicator of emotional state in animals. In experiment 1, we found that dogs in both the high and low arousal positive conditions showed a narrowing of attentional scope compared to dogs in the negative conditions, although only in the second repetition. In experiment 2, we found that dogs in the low arousal negative treatment showed a greater narrowing of attentional scope compared to the other conditions. Although the results are not all as predicted, this is the first evidence that the emotional state can alter local and global preferences in animals, as has previously been shown in humans. It is possible that the induced arousal levels in some of the treatments were not as intended (e.g., were high instead of low) and that this potentially explains why the results were not always according to the predictions. HRV indexes confirmed that the positive treatments in experiment 1 induced the intended positive emotional states, although they may have reflected a difference in physical activity in experiment 2.

Attentional scope

Experiment 1. Food reward test

In the second repetition, dogs' attention narrowed in the positively valenced conditions, irrespective of whether it was initial or prolonged access to food rewards. Therefore, it seems that the change in attentional scope mostly reflected the difference in emotional valence, regardless of arousal. A narrowing of attention when anticipating food treats (high arousal positive state) is supported by findings in humans^{5,10,56}. However, we had expected attentional scope to broaden with prolonged access to food. One possible explanation for the lack of difference between the two positively valenced conditions could be that the dogs maintained a highly aroused anticipatory state even after receiving many food treats, and we may not have been successful in inducing a low arousal positive state.

The high arousal negative treatment (frustrated approach) did not lead to the predicted narrowing of attention compared to the low arousal negative treatment, and dogs showed no clear preference for local or global information. Previous research in humans has shown that, in some cases, negative emotional states can also lead to a broadening of attention, because it is functional to look for alternative possibilities after an unsuccessful attempt to gain a reward¹⁵. Therefore, dogs may have accepted the 'loss' of a reward in the high arousal negative treatment, resulting in a broadening of attention¹⁶. The low arousal negative treatment (receiving the food tray but without food) did not lead to the predicted broadening of attention. One possible explanation is that the low arousal negative state did not have a sufficiently large impact on the emotional state of the dogs, and therefore we did not observe a clear local or global preference.

In contrast to the second repetition, the dogs had no clear preference for local or global elements in any emotional state in the first repetition. This temporal difference could be because the conflict stimuli had not been previously shown to the dogs, and the dogs may have been confused by the unfamiliar symbols,

i.e. a response to novelty that masked initial preference⁵⁷. This possibility is backed up by finding no such difference between repetitions in Experiment 2, when all the dogs had previously experienced the conflict stimuli. In future experiments, it may therefore be worthwhile to introduce dogs to the conflict stimuli as part of their training to reduce any potential influences of novelty.

Experiment 2. Social interaction test

In experiment 2, there was no overall effect of the treatment on attentional narrowing. However, the proportion of local choices in the low arousal negative conditions (no play) was higher than 50% (i.e., the CI did not overlap with 0.5), suggesting a degree of attentional narrowing in this treatment. Given the attentional narrowing following positive emotions that we observed in experiment 1, this seems rather contradictory. One possible explanation may be that we had unintentionally generated a high rather than a low arousal negative treatment. For example, it is possible that the no play treatment led to frustration – because dogs may have anticipated play, but were then ignored.

We did not observe a similar attentional narrowing in the high arousal positive treatment (play) as in the high arousal positive food test. The motivation to play is generally lower than the motivation for food, probably because obtaining food is critical for survival and has been under evolutionary selection pressure⁵⁸. In the runway, dogs ran quicker toward the person than toward the bowl of food. However, this is probably because the person could keep calling the dog until the dog reached the person, and the social motivation can therefore not directly be compared with the motivation for food in our study. On the other hand, positive social contact is perceived to be rewarding by animals^{34,59}. All dogs did engage in play with the experimenter, although it may be more rewarding for dogs to play with an individual to whom they are socially attached (e.g. an owner or another dog)⁵⁸, rather than a familiar experimenter.

In both experiments, dogs performed better in the discrimination test at the local level than the global level, and therefore seemed to have a general preference for local elements and a better ability to discriminate at the local level. This local bias can come from a genuine preference for local rather than a global stimuli, as has been found in a number of other species^{22–24}. However, we cannot rule out that this local preference was due to the small sample size in our study, and may be related to either individual preferences²⁰ or potentially the particular breed that we used (e.g., the beagle is a hunting dog and so may have been selected for a local preference).

Heart Rate and Heart Rate Variability

In order to obtain complementary data that could confirm whether or not we had induced the emotional states we intended to, we also recorded HRV parameters. The heart rate increased during the treatment phase in both experiments, except for the petting (low arousal positive) treatment in experiment 2. During the treatment phase, we did not find any differences in the HR between the treatments nor in the LF/HF ratio, suggesting that arousal levels were also similar across the treatments³¹, with the exception of petting.

In experiment 1, the SDNN, LF and VLF decreased from baseline, with the largest decrease in the positive conditions. The SDNN is a good predictor of overall HRV at the time of recording²⁹. Therefore, the decrease in SDNN in the low arousal positive conditions and the even larger decrease in the high arousal positive conditions suggest that receiving treats were indeed perceived as positive by the dogs. The LF indicates sympathetic activity and the VLF indicates sympatho-vagal balance^{29,60} and these measures are also correlated to the SDNN⁶¹. Both the LF and VLF decreased in the positive conditions compared to baseline, suggesting an activation of sympathetic neural activity and an inhibition of vagal activity^{60,62} associated with positive valence. In a previous study, the LF also decreased from baseline when dogs anticipated a meatball, a dry food treat, a familiar person and an unfamiliar person, with the largest decrease in the most positive treatment (meatball)³¹. This, together with the lack of change in LF in the negative conditions, further supports our finding that positively valenced conditions were indeed experienced as positive by the dogs.

In experiment 2, the RR and RMSSD indexes decreased during the treatment exposure compared to the baseline for all the treatments, except for the low arousal positive (petting) treatment. The lack of change from baseline in the low arousal positive treatment is probably due to the absence of physical activity involved in petting compared to the other treatments^{63–65}. But this also suggests that the petting session may have been perceived as calming and thus lower in arousal compared to the other treatments^{31,34,66}. The RMSSD represents vagal tonal regulatory activity²⁹, and has previously been shown to decrease when anticipating and consuming a food reward³¹ but increased during a negative situation in dogs³⁴. Therefore, the RR, RMSSD, SDNN seemed to mostly reflect a change in physical activity in our study, although the VLF, LF and SDNN may also have reflected valence.

We did not control the physical activity of the dogs during the treatments, in order to not influence the dogs' responses in the local/global tests. However, activity levels in the low and high arousal positive and high arousal negative conditions were roughly similar (i.e., pawing and walking around the hidden-food toy or pawing and walking around the rack covering it), but physical activity was lower in the low arousal social treatments, and possibly also in the low arousal negative food treatment. In order to account for some of the effects of physical activity, we also included a 15 period after the treatments when dogs were resting. However, no carry-over effects of the treatments were observed during this period suggesting that the emotional states induced in our study were short-term only.

Conclusion

In conclusion, this study provides the first indication that the emotional state may alter attentional scope in animals. Positive emotions originating from consuming food rewards led to a narrowing of attentional scope compared to negative emotions associated with the loss of a food reward. HRV indexes confirmed that obtaining food rewards was a positive experience compared to inaccessible food rewards, which was likely perceived as frustrating by the dogs. However, positive social interactions did not lead to attentional narrowing in a similar way as food rewards, and this difference may stem from the

evolutionary importance of food. Therefore, although attentional scope has potential as a novel cognitive measure of emotional state, and shows some promise in identifying differences in valence, further research in this area is necessary.

Declarations

Declarations of interest. The authors declare no competing interests.

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Data availability. All data is available here: https://osf.io/x2ue6/?view_only=0c8fad220dd34845baf07b047277cf61

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Figures

Figure 1

Predictions for the narrowing or broadening of attentional scope within the two-dimensional the animal emotional state framework consisting of a valence and arousal axis.

Figure 2

Sets of symbols, with panel **1a** showing the base symbols the dogs were trained to discriminate: symbols 1 and 3 were the rewarded symbols, and 2 and 4 were the non-rewarded symbols. Panel **1b** shows the conflict task symbols, symbol 5 and 7 indicate local choices and 6 and 8 indicate global choices. Panel **1c** shows symbols used to determine discrimination at the global level only (symbol 9 and 12 are correct), and **1d** shows symbols for assessing discrimination at the local level only (symbol 14 and 15 are correct).

Figure 3

Experimental set-up to assess attentional scope. Dog vector from clipartbest.com.

Figure 4

The effect of the emotional treatments (Table 1) on the proportion of local choices (predicted means $\pm$ CI) in the conflict test. HA stands for high arousal, LA stands for low arousal. Different letters indicate a difference between positive and negative valence conditions on the second repetition ($P < 0.05$).

Figure 5

Effect of emotional treatment (Table 1) on heart rate variability indexes (mean±sem), with **a.** SDNN, **b.** VLF and **c.** LF. HA stands for high arousal, LA stands for low arousal. # Indicates a significant change from baseline ($P<0.05$), bars that do not share the same letter are significantly different from each other ($P<0.05$), b* indicates a tendency for a difference ($P<0.1$).

Figure 6

The effect of emotional state on the proportion of local choices (predicted means $\pm$ CI) in the conflict test following the social emotional treatments (Table 2). HA stands for high arousal, LA stands for low arousal. The line indicates 0.5 proportion of local choices.

Figure 7

Effect of emotional treatment (Table 2) on heart rate variability indexes (mean $\pm$ sem), with **a.** RR, **b.** HR, **c.** SDNN and **d.** RMSSD. HA stands for high arousal, LA stands for low arousal. # Indicates a significant change from baseline ($P < 0.05$), bars that do not share the same letter are significantly different from each other within the treatment period ($P < 0.05$).

Figure 8

Effect of emotional treatment (Table 2) on heart rate variability indexes (mean±sem), with **a.** VLF and **b.** LF. HA stands for high arousal, LA stands for low arousal. # indicates a significant change from baseline, bars that do not share the same letter are significantly different from each other within the treatment period ($P<0.05$).