Applied Animal Behaviour Science 160 (2014) 106–115

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Emotional contagion in dogs as measured by change in cognitive task performance

Zsófia Sümegi[a,*], Katalin Oláh[b,c], József Topál[b]

[a] Department of Ethology, Eötvös University, Budapest, Hungary
[b] Institute of Cognitive Neuroscience and Psychology, Hungarian Academy of Sciences, Budapest, Hungary
[c] Department of Cognitive Psychology, Eötvös University, Budapest, Hungary

ARTICLE INFO

Article history:
Accepted 12 September 2014
Available online 20 September 2014

Keywords:
Emotional contagion
Dog–owner relationship
Stress
Memory

ABSTRACT

Domestic dogs are living with humans in a very special inter-species relationship. Previous studies have shown physiological and hormonal synchronisation between dogs and their owners during positive interaction. Dogs are also known to be able to discriminate human emotions and they were also presupposed to have the capacity to empathise with humans. Based on these results we hypothesize that the owner's emotions can be contagious to the dog and stress-related emotional changes in dogs can be tracked by memory tasks because both human and nonhuman studies indicate a significant effect of perceived stress on subjects' cognitive performance. In the present study the owners, after having completed State Anxiety Inventory and having participated in a memory task, were manipulated with either negative (*Stressed owner* condition) or positive (*Non-stressed owner* condition) verbal feedback in an additional task. Results indicate that the owners' self-reported anxiety significantly increased in the *Stressed owner* condition due to the manipulation. We also measured the effect of the different manipulations on the owners' and also on their dogs' memory performance and found that in line with earlier studies the stress-evoking intervention had an improving effect on the owners' memory performance. After separation from their owner (*Stressed dog* condition) dogs also showed better performance in a spatial working memory task and, more interestingly, task completion was also affected by the manipulation of their owners stress level. These findings provide further support for the emotional contagion between dogs and their owners, and suggest that measuring changes in the memory performance can be used as an indicator of contagion-induced changes in dogs' stress level.

1. Introduction

Emotional contagion, a concept coined by Hatfield et al. (1992) can be described as an automatic response to perceiving another's emotional state through which a similar emotional response is triggered in the observer. The phenomenon can be seen as a primitive form of empathy which appears to be widespread amongst mammals. However it is widely accepted that the contagion of emotional responses does not require the ability to differentiate between own and other's emotions or any conscious control over emotional reactivity (Preston and de Waal, 2002).

Emotional contagion has been extensively examined in rodents (for a review see Edgar et al., 2012). For example

* Corresponding author at: Department of Ethology, Eötvös University, Pázmány Péter sétány 1/C, H-1117 Budapest, Hungary.
Tel.: +36 1 381 2179; fax: +36 1 381 2180.
E-mail addresses: zsofisumegi@gmail.com, s.zsozso@freemail.hu (Z. Sümegi).

http://dx.doi.org/10.1016/j.applanim.2014.09.001
0168-1591/

social transmission of fear response has been reported in rats (Knapska et al., 2010) and pain sensitivity in mice also seems to be influenced by a conspecific's pain response (Langford et al., 2006; Jeon et al., 2010). Birds may also show evidence of emotional contagion, greylag geese (Wascher et al., 2008) as well as chickens (Edgar et al., 2011) show physiological responses while observing distressed conspecifics. Regarding the empathic abilities of nonhuman primates there is evidence for contagious yawning in both apes (chimpanzees – Anderson et al., 2004) and monkeys (macaques – Paukner and Anderson, 2006) and rapid facial reactions to the partner's emotional facial expression during play has been described in orangutans (facial mimicry – Ross et al., 2008).

There is ample evidence that empathic-like responding is usually more pronounced between familiar conspecifics than unfamiliar peers (e.g. Langford et al., 2006; Ben-Ami Bartal et al., 2011; Ma et al., 2011), importantly, however, contagious behaviour can occur also in heterospecific contexts. A recent study provides support for the notion of cross-species contagious yawning in chimpanzees (Madsen et al., 2013) and there is ample evidence suggesting emotionally connected heterospecific yawn contagion in dogs (Joly-Maschroni et al., 2008; Silva et al., 2012; Romero et al., 2013).

Human-dog cross-species contagious yawning has a potential link with the specific social-cognitive capacities of the domestic dog (Yoon and Tennie, 2010). In fact, many assume that dogs are socially tuned-in to humans because as a result of their unique domestication process, they have developed an evolutionary novel, inter-specific type of social competence which, among others, allowed for the establishment of a wide range of affiliative social relationships with humans (Miklósi and Topál, 2013). The relationship between the dog and its owner is functionally similar to the mother–infant attachment (see Topál and Gácsi, 2012 for a review) which is considered essential for the development of dogs' emotional responsiveness (Plutchik, 1987). Moreover, a recent study has found a correlation between the owner's attachment profile and the quality of the dog–owner attachment bond (Siniscalchi et al., 2013). In addition to providing further support for the notion that the dog–owner relationship resembles the connection between a mother and her child, these results also support the idea that dogs tend to assimilate the characteristics of their owners and this is manifested in their affective stance.

Moreover dogs and children tend to correspond in the degree to which they are able to react to the challenges of human communication (see Topál et al., 2014, for a review). They possess enhanced skills in reading human visual attention (e.g. Kaminski et al., 2009) and show special responsiveness to human gestural communication (e.g. Lakatos et al., 2012). Dogs can also learn to discriminate between different human emotional expressions (Deputte and Doll, 2011; Nagasawa et al., 2011; Racca et al., 2012) and respond differently to commands given with emotionally different tones of voice (Ruffman and Morris-Trainor, 2011). They are not only sensitive to the emotional state of their owners (Morisaki et al., 2009), but their behaviour can even be influenced by the owner's emotional expression (Merola et al., 2012).

Dogs' interspecific social- and emotional responsiveness is further supported by recent investigations (Silva and Sousa, 2011; Romero et al., 2013) that raised the possibility that dogs have the ability to feel humans' emotional experiences ('affective empathy'). It is worth mentioning, that unlike the *cognitive empathy system* which entails representing another's emotional experience (de Waal 2008), *affective empathy*, is often described as an 'automatic' process (Hatfield et al., 1993) stemming from an unconscious social contagion system. That is, instead of being able to represent another's emotional experience (cognitive empathy) dogs may have affective responses to the observed emotion of the human (i.e. feel what the human feels).

Social contagion can be seen as the rudimentary mechanism that serves to synchronize partners at different levels (physiological, emotional and behavioural synchronization). There is some experimental evidence suggesting hormonal and physiological synchronisation between owners and their pet dogs. Affiliative interactions between dogs and humans can have stress relieving effects; lower cortisol level as well as increased oxytocin and dopamine levels in both species (Odendaal and Meintjes, 2003; Miller et al., 2009; Handlin et al., 2012). Hormonal interactions between people and dogs may also occur under conditions of psychological stress (e.g. after losing a competition – Wirth et al., 2006). For example, Jones and Josephs (2006) investigated the hormonal changes in dog–human teams during agility competition and found that in losing teams, unlike in winning ones, the owners' pre-competition basal testosterone levels and their pre-to post-competition changes in testosterone are significant predictors of dogs' changes in cortisol level.

In addition to direct measurement of hormonal changes, the effects of stress on subjects' internal state can also be assessed indirectly; either by using questionnaires (e.g. Frankenhaeuser et al., 1978) or by measuring changes in subjects' cognitive performance. Some studies suggest that stress hormones can have an inverted-U shape effect on learning and memory in both humans and nonhuman animals (McEwen and Sapolsky, 1995; Belanoff et al., 2001). While moderate stress has been shown to positively impact memory retention, high stress levels can lead to impaired cognitive performance.

Although findings suggest that dogs show high responsiveness to changes in their human caregiver's stress status, and there is also evidence that stress-related emotional changes can be tracked by memory tasks, investigation of the association between stress-induced changes in owners and their dogs as measured by changes in their memory performance is lacking in the literature.

In the current study we investigated whether pet dogs can take over the emotional state of their owners in the context of experimentally induced anxiety and whether changes in their owners' affective states have an effect on dogs' memory performance. Owners' anxiety levels were experimentally manipulated: they were told that they were participating in a task designed to measure one aspect of their cognitive performance, a 'word list memory task'

(WMT). Owners were assigned either to the *Non-stressed* or the *Stressed* condition in which the difficulty of the task and the amount of experimenter-delivered positive/negative verbal feedback were surreptitiously manipulated. We predicted that (I) our procedure should be sufficient to increase the owners' self-reported stress/anxiety in the 'stressed' condition; (II) these changes should have an effect on owners' memory performance in the WMT and (III) the changes in owners' affective states should be contagious to dogs and the emotional contagion should be manifested in changes in the dogs' memory performance. As a control, we also ran a condition in which the dog's stress level was directly manipulated (*Stressed dog* condition) as opposed to being indirectly affected through the emotional state of the owner. This allowed us to test whether the potential change in cognitive performance following an indirect manipulation is comparable to that in case of more direct effects. We used the 'separation paradigm' because ample evidence suggests that separation from the owner in unfamiliar environments evokes moderate stress and anxiety in dogs (see Topál and Gácsi, 2012 for a review).

2. Materials and methods

2.1. Subjects

Fifty-two dogs (mean age ±SD: 3.81 ± 1.82 years, 26 males and 26 females) participated in the study on a voluntary basis. Out of the 52 dogs, 37 were tested together with their owners (experimental conditions; owners' mean age ±SD: 30.5 ± 8.4 years, 34 women and 3 men) Subjects were randomly assigned to one of the following three conditions: *Stressed owner* ($n = 19$), *Non-stressed owner* ($n = 18$), *Stressed dog* ($n = 15$). In the subsequent sections, we refer to the first two conditions as "experimental" and to the third one as "control". The dogs were from 18 different breeds (8 Golden retrievers, 5 Border collies, 3–3 Fox terriers, Hungarian vizslas, Labrador retrievers, 2–2 Collies, West highland terriers, 1–1 Boxer, Chihuahua, Dalmatian, Havanese, Jack Russel terrier, German shepherd, Schipperke, Yorkshire terrier, Poodle, Rottweiler, Shiba Inu) and 15 mongrels. Dogs' previous training experience was also assessed. Out of all the participants, 33 dogs had received some sort of obedience training, while 19 had never participated in any formal training. However, the distribution of "trained" and "untrained" dogs did not differ significantly across conditions, with 13, 12 and 8 trained dogs in the Stressed-owner, Non-stressed owner and Stressed dog conditions, respectively ($\chi^2(2) = 1.25$; $p = 0.53$)

2.2. Experimental arrangement

The experiment took place in a room (3.9 m × 4.1 m) at the Dept. of Ethology, Eötvös University, Budapest. Only a chair and some toys (a tennis ball and a rope) for the dog were placed in the room. These toys were present during the whole experiment, except for the dog memory tasks (see below) when only one ball as target object and 7 plastic flowerpots as hiding places were used. However in the ball-carrying task (Phase 2 – see below) and during the second dog memory task (Phase 3 – see below) additional balls (2–3) and containers (2) were also present.

2.3. Overview of the experimental procedure

The procedure consisted of three phases for both the experimental and the control conditions. In the experimental conditions the pre-manipulation phase (Phase 1) started by assessing the owners' baseline anxiety level (using a state anxiety questionnaire) and their memory performance (in a word list memory task) and we also measured the dogs' ability to retain the location of a ball in their working memory (in an object hiding and finding task). In the control condition, only the dog memory task was administered in Phase 1. This was followed by the manipulation (Phase 2) during which the owners in the experimental conditions had to answer questions about an article they had read before and they were also asked to complete collaborative tasks together with their dogs. The latter part was added to the procedure to enable the transfer of stress/anxiety between the human and his/her dog. Importantly, owners in the *Stressed owner* condition received mostly negative feedback, while owners in the *Non-stressed owner* condition were given only positive feedback. In the *Stressed dog* condition, the dog's anxiety level was manipulated by introducing a short period of separation from the owner. Finally, in the test phase (Phase 3), the owners' and their dogs' memory performances as well as the owners' state anxiety were re-tested using the same methods as used in Phase 1. In the control condition, only dogs' memory performance was assessed.

2.4. Procedure of the experimental conditions (stressed owner and non-stressed owner)

2.4.1. Phase 1 – baseline measures

Right after their arrival, the owners filled out the Hungarian version of the State- and Trait Anxiety Inventory (STAI; Sipos and Sipos, 1983) which is widely used by psychologists to measure anxiety both at a particular point in time (state) and in general (trait).

After this the owner and his/her dog were led into the experimental room by the experimenter (E) and were allowed to explore the room for a few minutes. Then the owner made the dog sit at a predetermined starting point and the E placed seven identical brown plastic flowerpots (11 cm high, 14 cm in diameter) on the floor in a semicircle (Fig. 1). The dog was sitting equidistant from the bowls (3 m away) while being held by the owner. The E then took the target object (a tennis ball), showed it to the dog, walked straight towards one hiding location, and placed the ball into the pot clearly visibly to the dog. After the hiding event the dog was led out of the room by the owner, the E also left the room and they waited outside for 30 s before re-entering the room. On re-entering the room, the dog was led to the starting point by the owner and then it was released and allowed to search for the object until finding it. During this the owner was allowed to encourage his/her dog, but was instructed not to give any specific instructions and not to direct the dog toward any of the containers. All dogs received 5 trials in a predetermined order. Two

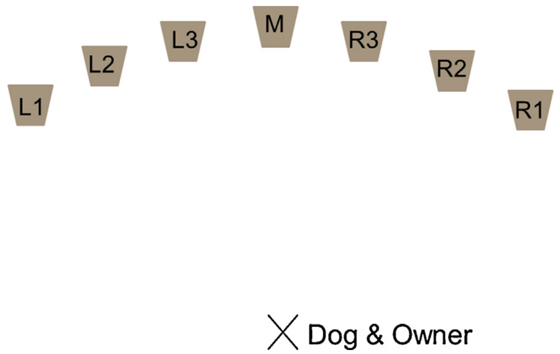

Fig. 1. Experimental arrangement of the dog Spatial Working Memory task. The owner made the dog sit equidistant from the 7 plastic containers serving as hiding places. The positions of the containers are labelled as L(left) 1–3, R(right) 1–3 and M(middle).

different hiding orders (L3, R2, M, R3, L2 and R3, L2, M, L3, R2 respectively) were used and the order of the 5-trial blocks was counterbalanced across subjects in each group. The 2 terminal pots (R1 and L1 – see Fig. 1) were never baited. Dogs had as much time as they needed to find the object.

After this the owners' memory performance was measured by Kirschbaum et al.'s declarative memory task (Kirschbaum et al., 1996). In the learning phase of the task the owners were given a list of 24 words for 5 min to read and memorize. This was followed by a 5 min long distraction phase, during which they had to read a scientific paper about dog behaviour. Finally, owners were asked to recall those words ($N = 10$) from the 24-words-list that begin with "mo" or "ko" (depending on the list) within 2 min. We used two different lists of words (word set A and B) and these were counterbalanced across conditions. Subjects in the *Non-stressed owner* condition were provided with a reading matter in the distraction phase which was easy to read and understand while subjects assigned to the *Stressed owner* condition were given a more challenging text. Dogs were together with their owners in the experimental room throughout the declarative memory task while the E was absent during the learning and distraction phases. Dogs were allowed to explore the environment, play and interact with their owners freely.

2.4.2. Phase 2 – manipulation

After this the E asked the owners several questions about the scientific article they had read during the distraction phase of the declarative memory task. This phase lasted for approximately 5 min. In the *Stressed owner* condition E gave mostly negative feedback and sometimes pointed out that the other participants were able to tell the right answer. However, in the *Non-stressed owner* condition the E gave only positive feedback and sometimes praised their performance by adding that the other participants were *not* able to tell the right answer.

This was followed by interactive situations, when owners were asked to complete different kinds of collaborative tasks together with their dogs. First a ball-carrying task, during which the dog had to carry balls under the direction of its owner from a container into another one for 5 min. The containers were placed in two corners of the room and only one of the containers was baited with the balls. In the next 2 min they had to perform basic obedience tasks (sitting, laying and staying) and they also had the opportunity to show other tricks. The ball-carrying and obedience tasks were also accompanied by the experimenter's negative or positive feedback. In the *Non-stressed owner* condition the E praised the dyads for performing the task well and did not comment the wrong performance. In the Stressed owner condition the E expressed her disapproval of the dyad's bad performance (in neutral speaking style) and did not comment on the instances where the dyad was successful. In the last 3–4 min of the manipulation the experimenter gave the text back to the owner for an additional 2 and a half minutes and in the next minute she asked further questions. Owners' responses received either positive (*Non-stressed* condition) or negative (*Stressed* condition) reinforcement.

Importantly, both praise and disapproval were given by the E in a neutral tone of voice and she behaved in a neutral manner throughout Phase 2.

2.4.3. Phase 3 – measuring subjects' performance after the manipulation

Owners were asked to fill out the same questionnaire (State- and Trait Anxiety Inventory) as in Phase 1.

Then we repeated the object hiding and finding tasks in order to measure the dogs' ability to retain the location of a ball in their working memory. We used the exact same procedure as in Phase 1: first, dogs participated in the same memory task, however, they were provided with the other 5-trial block than in Phase 1 (as described above in the section about Phase 1). Then owners completed the same memory task as in Phase 1 with the only exception that they were provided with the other set of words (A or B) and the reading material in the distraction task was also different.

2.5. Procedure in the control condition (Stressed dog)

2.5.1. Phase 1–baseline measure

First, dogs participated in the same memory task as was described above in Phase 1 for the other two conditions. This was followed by a 15 min break, thus the time elapsed between the first and the second memory task was the same as in the other two conditions. During the break the owners and the dogs were sitting in the waiting room of the department.

2.5.2. Phase 2 – manipulation

After the break elapsed, the E introduced the dog and the owner to the experimental room, then the owner left the scene and the dog was allowed to explore the room freely in the presence of the E for 2.5 min. If the dog showed distress behaviours (see below) less than 20 s long during this period the separation was continued for additional 2.5 min. If the dog showed signs of distress for at least 20 s, it was reunited with the owner and phase 3 was administered. The E played with the dog or petted it depending on its willingness.

2.5.3. Phase 3: measuring dogs' performance after the manipulation

Using the same procedure as in Phase 1, we repeated the object hiding and finding tasks, however, dogs were provided with a different order of object hiding trials.

2.6. Data collection

Owners anxiety levels were measured by STAI scores consisting of two separate 20-item (rated from 1 to 4) self-report scales; one scale measures state anxiety (s-STAI) and the other measures trait anxiety (t-STAI, Sipos and Sipos, 1983). Higher scores indicate increased level of anxiety. Based on the STAI scores measured repeatedly in Phase 1 (pre-manipulation) and Phase 3 (post-manipulation) we also calculated the change which indicates the effect of the manipulation on owners' anxiety levels in the different conditions.

Owner's memory performance was measured by the number of words they could recall correctly. The change in their performance was also calculated as the difference between pre- and post-manipulation task performance.

Dog's working memory performance was calculated on the basis of the number of erroneous choices (looking into an empty pot). The number of empty containers visited by the dog during trials 1–5 was added up and this was used as an indicator of task performance (higher scores indicates poorer memory abilities). The change in dogs' working memory performance was also calculated as the difference between pre- and post-manipulation measures.

It was also measured how intensely the dogs were encouraged by their owners during the memory task. We coded the number of any kind of verbal encouragements (e.g.: Search! You can go! Where is the ball? Fetch the ball!) given by the owner during the trials.

The owner's behaviour while interacting with his/her dog (in Phase 2 of the two experimental conditions) was also analysed using the following variables: relative duration of time spent with playing (i.e. any vigorous, toy-related behaviour between the dog and the owner); relative duration of time spent with physical contact (i.e. any form of bodily contact); number of positive (encouragement, praise etc.) and negative (prohibiting, scolding) verbal feedback provided by the owner.

In Phase 2, the number of positive (praise, telling it is a right answer) and negative (scolding, telling it is a wrong answer) verbal feedback provided by the experimenter in response to the owners' answers were also recorded.

In Phase 2 of the *Stressed dog* condition (control), while separated from their owners, dogs' behaviour was recorded and the following five mutually exclusive behaviour categories were coded:

Passive behaviours: standing, sitting or lying down.

Exploration: activity directed toward non-movable aspects of the environment, including sniffing, distal visual inspection (staring or scanning), close visual inspection, or oral examination.

Physical contact: any form of bodily contact with the experimenter

Play: any vigorous, toy- or social partner-related behaviour, including running, jumping, or any physical contact with toys (chewing, biting)

Distress behaviours: active behaviours resulting in physical contact with the door (scratching, jumping at, etc.) and/or vocalising (i.e. barking, growling, howling, whining).

In order to exclude the possibility that dogs' affective states were directly influenced by the experimenter during the manipulation phase in the two experimental conditions, a coder blind to both the condition and the purpose of the study coded the perceived stress level of the situation on a one-to-ten scale. Crucially, the coder did not speak the language that was used throughout the experiment; therefore he could not understand the content of the communication. He had to base his judgments on non-verbal gestures, tone of the voice and other non-linguistic cues, which resemble the information dogs may pick up on during the interaction between the experimenter and the owner.

2.7. Data analysis

First we employed a Generalized Estimating Equation for the analysis of the effect of the trial (performance before vs. after the manipulation) as within-subject factor and the effect of the type of the manipulation (*Stressed owner* vs. *Non-stressed owner*) as a between-subjects factor on the STAI scores and the memory performance of the owners. We performed the same analysis on the memory performance of the dogs with the modification that we included the *Stressed dog* condition in the type of manipulation variable and the previous training experience as covariate. For within-group comparisons Wilcoxon Matched-Pairs Ranks tests were used for discrete variables and paired *t*-tests for continuous variables (play and physical contact). For between-groups comparisons Mann-Whitney tests were used for discrete variables and unpaired *t*-tests for continuous variables. In the case of STAI scores and memory performances the changes due to the manipulation were calculated by subtracting the 'before-manipulation' values from the 'after-manipulation' values. The relationships between the variables were examined by Spearman correlation.

SPSS version 20 software was used for statistical analyses, all tests were two-tailed and the α value was set at 0.05.

3. Results

3.1. Changes in the owners' trait and state anxiety levels (pre- vs. post manipulation periods)

The owners' trait-anxiety seemed to be stable throughout the experiment; it was not influenced either by the trial (GEE, $\chi^2 = 1.166$, $p = 0.280$) or by the type of manipulation ($\chi^2 = 1.239$, $p = 0.266$) and the interaction was also not significant ($\chi^2 = 0.517$, $p = 0.472$). In contrast, there was a significant interaction of the two main factors for the owners' state anxiety (GEE, $\chi^2 = 27.747$, $p < 0.001$) without

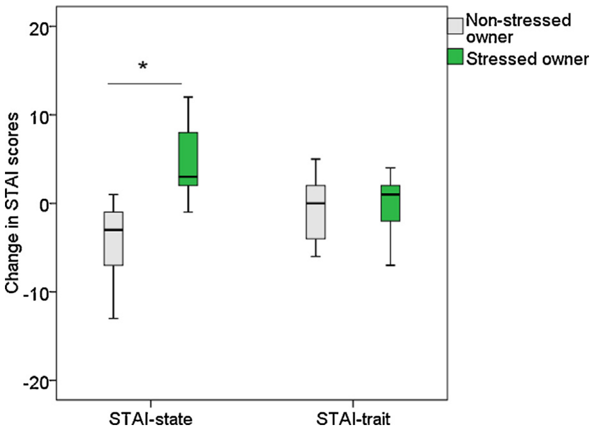

Fig. 2. Comparison of the owners' state-anxiety scores obtained from pre- and post-manipulation phases (median, quartiles and extreme values) in the non-stressed- and stressed owner conditions (*$p < 0.001$).

any significant main effects (trial: $\chi^2 = 0.009$, $p = 0.923$ type of manipulation: $\chi^2 = 1.508$, $p = 0.219$).

Owners in the *Stressed* condition received significantly more negative ($p < 0.001$) and less positive ($p < 0.001$) feedback than owners in the *Non-stressed* condition (Mann–Whitney tests, $U_{(35)} = 0.00$ for both) and these different types of manipulations affected their affective status differently. Namely, owners after having received negative feedback from the experimenter (*Stressed owner* condition) reported significantly greater increase in their state anxiety in comparison with those who received only positive feedbacks (*Non-stressed owner* condition) during the manipulation phase (Mann–Whitney test, $U_{(35)} = 12.5$, $p < 0.001$) (Fig. 2).

3.2. Owners' memory performance (pre- vs. post manipulation periods – comparison between the two experimental conditions)

There was a significant trial X type of manipulation interaction on the owners' memory performance (GEE, $\chi^2 = 8.248$ $p = 0.004$) without any main effects (trial: $\chi^2 = 0.268$ $p = 0.605$ type of manipulation: $\chi^2 = 0.008$, $p = 0.931$). Although the initial performance did not differ between the two experimental conditions (Mann–Whitney test, $U_{(35)} = 125$, $p = 0.169$; Fig. 3), the change in the number of recalled words was higher in the *Stressed owner* condition compared to the *Non-stressed owner* condition (Mann–Whitney test, $U_{(35)} = 91$, $p = 0.014$; Fig. 4). This suggests that moderately increased anxiety improved the participants' memory performance. Moreover the owners' memory performance changed according to the change in their state anxiety (s-STAI) scores as was indicated by a positive correlation between them (Spearman's rank correlation test, $r_{(35)} = 0.39$, $p = 0.017$).

3.3. Factors potentially influencing emotional contagion between dogs and their owners

In order to determine whether negative feedback given by the experimenter during the *Stressed* condition have

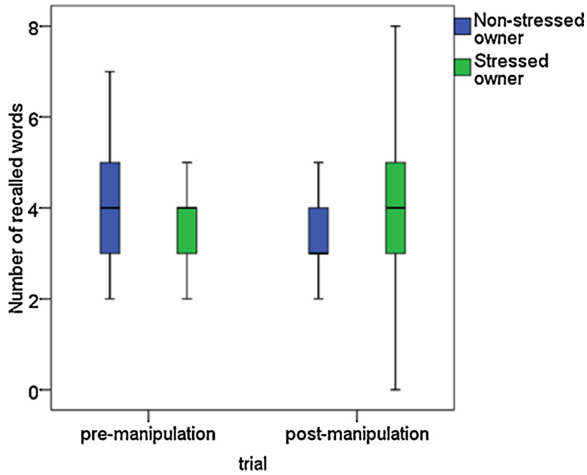

Fig. 3. Number of words recalled by the owners in the declarative memory task before and after the manipulation.

the potential to become a direct stressor for the dogs, we have analysed the non-Hungarian coder's ratings of perceived level of stressfulness in the manipulation phase (Phase 2). Our analysis showed that based on the experimenter's non-verbal gestures, tone of the voice and other non-linguistic cues a human coder cannot discriminate between the *Stressed owner* and the *Non-stressed owner* conditions (Mann–Whitney test, $U_{(35)} = 130.5$; $p = 0.175$). This finding provides indirect evidence that stressing the owner by the E was not directly perceptible by the dogs.

We next investigated the possibility whether dogs' stress level could be influenced through their owners' different behaviour in the manipulation phase of the Stressed vs. Non-stressed condition. In fact, dogs got the opportunity to freely interact with their owners in Phase 2 and thus we may assume that during this period the perception of expressive behaviours of the owner can transfer emotional states from the owner to his/her dog. In line with this assumption we coded and analysed the owners' behaviour while interacting with their dogs. Although

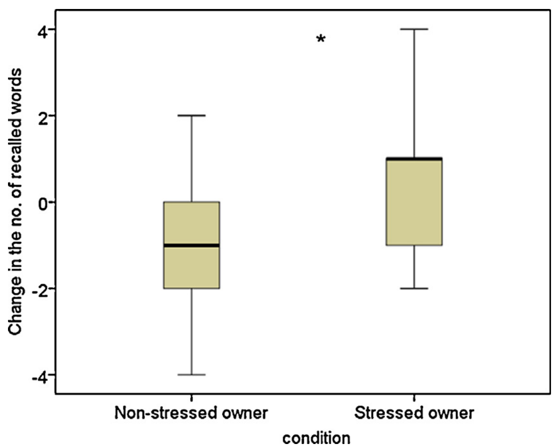

Fig. 4. Changes in the number of words (pre- vs. post-manipulation phases; median, quartiles and extreme values) recalled by the owners in the declarative memory task (*$p = 0.014$).

there was no difference between the groups regarding the time spent with physical contact (two sample *t*-test, $t_{(35)} = 0.011$, $p = 0.768$), dog–owner pairs in the *Stressed owner* condition played less than in the *Non-stressed owner* condition ($t_{(35)} = 2.069$ $p = 0.01$). Playing seems to be a good behavioural indicator of the owners' distress, because it correlates with the change in s-STAI (Spearman's rank correlation test, $r_{(35)} = -0.453$, $p = 0.005$) and with the change in the owners' memory performance as well ($r_{(35)} = -0.37$, $p = 0.024$). Further analyses showed that owners in both conditions gave more positive than negative reinforcements (Wilcoxon Matched-Pairs Ranks tests, *Stressed owner* condition: $Z_{(18)} = -2.201$, $p = 0.028$ *Non-stressed owner* condition: $Z_{(17)} = -3.726$, $p \leq 0.001$) and the number of negative reinforcements were not significantly different between conditions (Mann–Whitney test, $U_{(35)} = 165$, $p = 0.854$). At the same time dogs in the *Non-stressed owner* condition were reinforced positively significantly more frequently than in the *Stressed owner* condition ($U_{(35)} = 86$, $p = 0.01$). These characteristic changes of the owners' behaviour in the Stressed condition could potentially contribute to the contagion of stress in dog–human relationships.

3.4. Dogs' behaviour during the separation phase (Stressed dog condition, Phase 2)

All but two dogs showed active sign of distress for less than 20 s (0–6.6 s) during the 2.5 min separation thus for these subjects ($N = 13$) the duration of this episode was prolonged (+2.5 min.). The analysis of the relative percentage of the time spent with the different behaviours shows that dogs interacted with the experimenter 29.7% (range 1.2–89.9%) of the time on average. This was either physical contact (9.6 ± 14.1%) or playing (20.1 ± 26.7%) with the experimenter. They also explored the room (22.3 ± 7.9%, range 11.1–34.5%) and behaved passively (30.2 ± 19.2, range: 4.8–60.4%). Dogs spent 17.7 ± 15.6% of time in close proximity (<1 m) of the door but showed distress behaviours on average only 5.46 ± 13.1% (range: 0–50%) of the total duration.

3.5. Dogs' memory performance (pre- vs. post manipulation periods – comparison between all three conditions)

Analysing the dogs' memory performance we found a significant main effect of trial (pre- vs. post manipulation periods: GEE, $\chi^2 = 7.89$; $p = 0.005$), without a main effect of type of manipulation ($\chi^2 = 1.227$; $p = 0.541$) or previous training experience ($\chi^2 = 0.887$; $p = 0.346$). More importantly there was an interaction between manipulation type and trial ($\chi^2 = 12.464$, $p = 0.002$) (Fig. 5). In comparison with their 'baseline' performance (Phase 1) dogs in both the *Stressed owner* and the *Stressed dog* conditions showed a significant improvement in the post-manipulation (Phase 3) working memory test (Wilcoxon Matched-Pairs Ranks tests, *Stressed owner* condition: $Z_{(18)} = 2.682$, $p = 0.007$, *Stressed dog* condition: $Z_{(13)} = 2.253$, $p = 0.024$). In the *Non-stressed owner* condition, however, there was no change ($Z_{(17)} = 1.261$, $p = 0.207$).

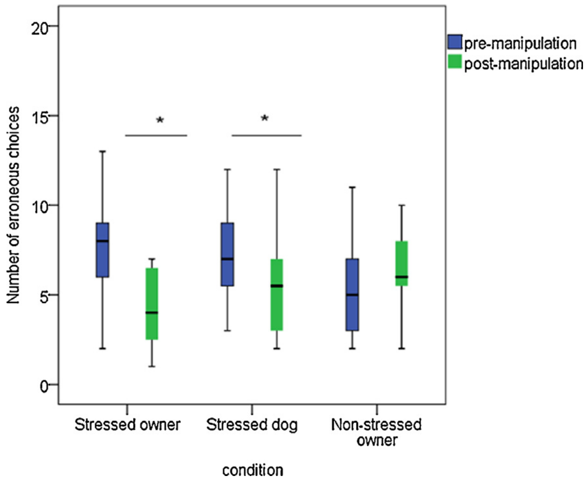

Fig. 5. Number of erroneous choices (pre- vs. post-manipulation phases; median, quartiles and extreme values) by the dogs in the memory task (*$p < 0.05$).

The finding that dogs' working memory performance varied as a function of the manipulation in Phase 2 was further supported by the analysis of the difference between pre- and post-manipulation measures. That is, the number of errors changed differently in the three conditions (Kruskal Wallis test $\chi^2_{(2)} = 10.641$, $p = 0.0049$; pairwise comparisons with Bonferroni correction: *Stressed owner* vs. *Non-stressed owner: p < 0.05; Stressed dog* vs. *Non-stressed owner: p < 0.05*). Dogs in the *Stressed* conditions showed an improved memory performance (Fig. 6).

There is a negative correlation between the change in number of errors and the change in the owners' stress level (Spearman's rank correlation test, $r_{(35)} = -0.483$, $p = 0.002$) which suggest that dogs' performance was affected by their owners' affective states. It is also worth mentioning that dogs' change in memory performance also correlated with the relative time spent with playing ($r_{(35)} = 0.439$, $p = 0.007$), dogs whose owners tended to play more with

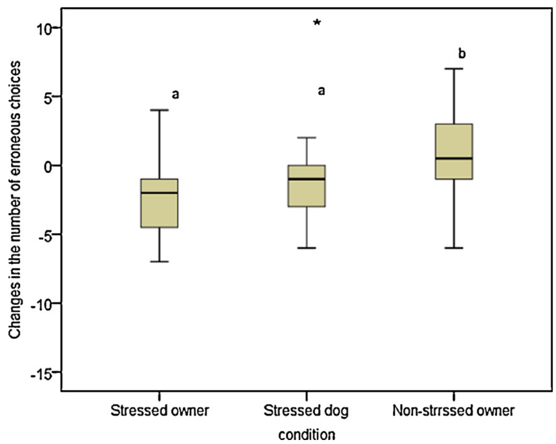

Fig. 6. Changes in the number of dogs' erroneous choices in the Spatial Working Memory task (pre- vs. post-manipulation phases; median quartiles and extreme values (*$p = 0.0049$).

them during the manipulation phase committed more errors when re-tested in the memory task (Phase 3).

Dogs' better performance in the two *Stressed* conditions cannot be explained by the owners' more explicit encouragement, because the number of (verbal) encouragements did not differ between the pre- and post-manipulation phases (Phase 1 vs. Phase 3, Wilcoxon Matched-Pairs Ranks tests, *Stressed dog* condition: $Z_{(14)} = 29$, $p = 0.21$;*Stressed owner* condition: $Z_{(18)} = -1.122$, $p = 0.262$; *Non-stressed owner* condition: $Z_{(17)} = -0.855$, $p = 0.393$). Moreover there is no significant differences between the three groups (Kruskall Wallis test, before the manipulation: $\chi^2_{(2)} = 1.56$, $p = 0.46$after the manipulation: $\chi^2_{(2)} = 3.08$, $p = 0.21$).

In addition, we analyzed whether previous training experience influenced dogs' memory performance. We compared the performance of dogs that had received some sort of official training (33) with those that had not (19), and found no difference either before (Mann-Whitney test $U_{(51)} = 259.5$, $p = 0.302$) or after ($U_{(51)} = 285.5$, $p = 0.592$) the manipulation. The change in performance was not affected by previous training either ($U_{(51)} = 268.5$, $p = 0.389$).

4. Discussion

In the current study we aimed to investigate the emotional contagion between dogs and owners and examined whether dogs show some sign of taking over their owners' affective state in a case where only the owner's affective state was manipulated. We also investigated whether the effects of this kind of contagion of an emotional state (increased level of stress) transfer to a different domain by affecting an aspect of cognitive performance as well. It has been shown that stress and stress hormones influence cognitive performance following an inverse U shape dose–response relationship in both humans (Belanoff et al., 2001) and nonhuman animals (Roozendaal, 2000; Salehi et al., 2010), so low to moderate levels of distress have an improving effect on cognitive functions (Shors et al., 1989). Psychological stress can also cause physiological changes (Chida and Hamer, 2008) and it mainly affects the hippocampus, the area of the declarative memory (Diamond et al., 1994). Our results are in line with this notion. The analyses of our data allow us to conclude that the owners' state anxiety was effectively manipulated by the experimenter (i.e. after having received negative feedback, owners achieved higher state anxiety scores). The owners' performance in the declarative memory task also seems to be affected by their anxiety level, leading to a better performance in the *Stressed owner* condition and findings from the *Stressed dog* condition indicate a similar effect of anxiety on dogs' spatial working memory. Moreover, dogs' working memory performance significantly correlated with the change in the owners' self-reported stress level and changed in the same direction as the owners' memory performance. This raises the possibility that their owners' state anxiety is contagious to dogs and the emotional contagion can be tracked by measuring changes in dogs' memory performance.

It is important to note that owners' improved performance in a stressful situation could not only be generated by the moderately increased stress level; but could also be facilitated by the procedure, by the method of the manipulation. Namely, negative verbal feedback in a skill performance situation can be regarded as a kind of failure, and this can inspire people to perform better in the next task independent of the increased level of stress that negative feedback supposedly elicits. However, the literature also provides evidence suggesting that feelings of failure, when losing a competition, can cause stress hormone release (Bhatnagar and Vining, 2003), therefore it may not be possible to disentangle these two seemingly different effects. Moreover, perceiving a situation more or less stressful depends on personality as well (Wirth et al., 2006).

One possible alternative explanation of our results could be based on the discrepancy in the difficulty of the initial task. That is, owners performed more poorly in the baseline phase of the *Stressed owner* condition because they had a more difficult text to read and therefore they had more room for improvement by the end of the experiment. However, this is not likely since there was no main effect of condition on the memory performance of owners and pairwise analyses also confirm the notion that initial performance did not differ between the two experimental conditions. The declining memory performance in the *Non-stressed owner condition* can be best explained by fatigue, because participants had to read and learn a lot and solve several tasks during the long time of the experiment. On the other hand they probably did not feel any motivation to perform better at the end of the experiment.

Another factor that could have influenced the success of the manipulation is the dogs' level of training. It could be argued that since we expected the transmission of affective state to happen – at least partly – during an obedience task, dogs that had gone through obedience training might respond differently and may not experience that much stress (or alternatively may be more attuned to the owner and therefore be more sensitive to their signals). However, we have shown that the change in memory performance did not depend on the level of training, therefore this explanation can be ruled out.

A key finding of the present study is that the anxiety experienced by the owner influences their dog's behaviour and that these effects are manifested in the cognitive domain. We propose that this phenomenon can be best explained by emotion contagion as the dogs' performance was not directly reliant on the owner's affective state or behaviour. Dogs had to solve the task on their own, therefore any change in performance had to be the result of previous interactions. Since very similar effects were observed in the memory performance of the owners, it is plausible to assume that the change of affective state was also similar.

The improvement of spatial working memory performance of dogs in the *Stressed owner* condition was similar to that of the *Stressed dog* condition. Since there were significant differences in the owners' play behaviour and the use of positive reinforcement while interacting with their dogs, we may assume that the owners' affective state was transmitted at least partly through these behaviour signals. Of course dogs could be influenced by other sources of information, for example the owners' body language (Merola et al., 2012), facial expression (Nagasawa et al., 2011; Racca et al., 2012), emotional valence of the commands (Ruffman and Morris-Trainor, 2011), or other unobservable behavioural signals or odour cues (Prehn-Kristensen et al., 2009).

One of the most important questions in the literature on emotional contagion concerns the problem of how these behavioural cues contribute to the transmission of emotions. Taking an interspecies approach to the question can shed some further light on the matter. Non-conscious mimicry of expressions has been suggested to play a key role in intraspecies cases (e.g. Hatfield et al., 1993) during which the emotional expression of one individual is imitated by the observer, generating a similar feeling in him/her too. However, non-conscious mimicry is unlikely to work properly between individuals of a different species. Therefore it seems a plausible explanation that a more sophisticated perception of the social context contributes to the phenomenon and that it cannot be accounted for by such direct physiological changes. The importance of a higher level of social sensitivity is also in line with findings that show that less social species, such as the red-footed tortoise, are not susceptible to a related phenomenon, contagious yawning (Wilkinson et al., 2011). The dog's special sensitivity to human behavioural cues, however, can lead to the appearance of emotional contagion between different species and may also serve similar functions as in a human-to-human interaction.

In sum, we showed similar effects in dogs as in their owners with direct manipulation of the owners only, supporting the existence of emotional contagion between two different species. Recent experimental data suggest that dogs' behaviour can be influenced by the pretended emotion of a human. For example they show an empathic-like response toward a crying human (Custance and Mayer, 2012), and react to an unfamiliar object according to the owner's attitude (Merola et al., 2012). The current study extends our understanding of these results since the change in the memory performance observed in dogs is unlikely to be attributed to any conditioned response to the behavioural cues of the human. Furthermore, this study gives further support for the idea that the real emotions of the owner can influence the dog; and our results suggest that the underlying mechanism may be emotion contagion. This points to the conclusion that it is possible to influence the dog's stress level via the owner even in an artificial situation. We suggest that these effects are due to the special domestication history of the dog that has endowed this species with a unique sensitivity to the behavioural cues of humans.

Ethical standards

The experiments comply with the current Hungarian laws.

Acknowledgement

The authors are grateful to Mouslim Cherkaoui for his assistance in data collection and to dog owners for participating in the experiment. Financial support was provided by the Hungarian Scientific Research Fund (OTKA K-100695).

References

Anderson, J.R., Myowa-Yamakoshi, M., Matsuzawa, T., 2004. Contagious yawning in chimpanzees. Proc. R. Soc. B 271, 468–470.

Belanoff, J.K., Gross, K., Yager, A., Schatzberg, A.F., 2001. Corticosteroids and cognition. J. Psychiatr. Res. 35, 127–145.

Ben-Ami Bartal, I., Decety, J., Mason, P., 2011. Empathy and pro-social behavior in rats. Science 334, 1427–1430.

Bhatnagar, S., Vining, C., 2003. Facilitation of hypothalamic–pituitary–adrenal responses to novel stress following repeated social stress using the resident/intruder paradigm. Horm. Behav. 43, 158–165.

Chida, Y., Hamer, M., 2008. Chronic psychosocial factors and acute physiological responses to laboratory-induced stress in healthy populations: a quantitative review of 30 years of investigations. Psychol. Bull. 134, 829–885.

Custance, D., Mayer, J., 2012. Empathic-like responding by domestic dogs (*Canis familiaris*) to distress in humans: an exploratory study. Anim. Cogn. 15, 851–859.

Deputte, B.L., Doll, A., 2011. Do dogs understand human facial expressions? J. Vet. Behav. 6, 78–79.

de Waal, F.B.M., 2008. Putting the altruism back into altruism: The evolution of empathy. Ann. Rev. Psych 59, 279–300.

Diamond, D.M., Fleshner, M., Rose, G.M., 1994. Psychological stress repeatedly blocks hippocampal primed burst potentiation in behaving rats. Behav. Brain Res. 62, 1–9.

Edgar, J.L., Lowe, L., Paul, J.C., Paul, E.S., Nicol, C.J., 2011. Avian maternal response to chick distress. Proc. R. Soc. B, http://dx.doi.org/10.1098/rspb.2010.2701.

Edgar, J.L., Nicol, C.J., Clark, C.C.A., Paul, E.S., 2012. Measuring empathic responses in animals. Appl. Anim. Behav. Sci. 138, 182–193.

Frankenhaeuser, M., Wright, M., Collins, A., Wright, J., Edvall, G., 1978. Sex differences in psychoneuroendocrine reactions to examination stress. Psych. Med. 40, 334–343.

Handlin, L., Nilsson, A., Ejdebäck, M., Hydbring-Sandberg, E., Uvnäs-Moberg, K., 2012. Associations between the psychological characteristics of the human–dog relationship and oxytocin and cortisol levels. Anthrozoös 25, 215–228.

Hatfield, E., Cacioppo, J., Rapson, R.L., 1992. Primitive emotional contagion. Rev. Pers. Soc. Psychol. 14, 51–77.

Hatfield, E., Cacioppo, J.T., Rapson, R.L., 1993. Emotional contagion. Curr. Dir. Psych. Sci. 2, 96–100.

Jeon, D., Kim, S., Chetana, M., Jo, D., Ruley, H.E., Lin, S.Y., Rabah, D., Kinet, J.P., Shin, H.S., 2010. Observational fear learning involves affective pain system and Ca(v)1.2 Ca^{2+} channels in ACC. Nat. Neurosci. 13, 482–488.

Joly-Maschroni, R.M., Senju, A., Shepherd, A.J., 2008. Dogs catch human yawns. Biol. Lett. 4, 446–448.

Jones, A.C., Josephs, R.A., 2006. Interspecies hormonal interactions between man and the domestic dog (*Canis familiaris*). Horm. Behav. 50, 393–400.

Kaminski, J., Bräuer, J., Call, J., Tomasello, M., 2009. Domestic dogs are sensitive to a human's perspective. Behaviour 146, 979–998.

Kirschbaum, C., Wolf, O.T., May, M., Wippich, W., Hellhammer, D.H., 1996. Stress- and treatment-induced elevations of cortisol levels associated with impaired declarative memory in healthy adults. Life Sci. 58, 1475–1483.

Knapska, E., Mikosz, M., Werka, T., Maren, S., 2010. Social modulation of learning in rats. Learn. Mem. 17, 824–831.

Lakatos, G., Gácsi, M., Topál, J., Miklósi, Á., 2012. Comprehension and utilisation of pointing gestures and gazing in dog–human communication in relatively complex situations. Anim. Cogn. 15, 201–213.

Langford, D.J., Crager, S.E., Shehzad, Z., Smith, S.B., Sotocinal, S.G., Levenstadt, J.S., Chanda, M.L., Levitin, D.J., Mogil, J.S., 2006. Social modulation of pain as evidence for empathy in mice. Science 312, 1967–1970.

Ma, Q.G., Shen, Q.A., Xu, Q., Li, D.D., Shu, L.C., Weber, B., 2011. Empathic responses to others' gains and losses: an electrophysiological investigation. Neuorimage 54, 2472–2480.

Madsen, E.A., Persson, T., Sayehli, S., Lenninger, S., Sonesson, G., 2013. Chimpanzees show a developmental increase in susceptibility to contagious yawning: a test of the effect of ontogeny and emotional closeness on yawn contagion. PLOS ONE 8 (10), e76266, http://dx.doi.org/10.1371/journal.pone.0076266.

McEwen, B.S., Sapolsky, R.M., 1995. Stress and cognitive function. Curr. Opin. Neurobiol. 5, 205–216.

Merola, I., Prato-Previde, E., Marshall-Pescini, S., 2012. Social referencing in dog–owner dyads? Anim. Cogn. 15, 175–185.
Miklósi, Á., Topál, J., 2013. What does it take to become 'best friends'? Evolutionary changes in canine social competence. Trends Cogn. Sci. 17, 287–294.
Miller, S.C., Kennedy, C., DeVoe, D., Hickey, M., Nelson, T., Kogan, L., 2009. An examination of changes in oxytocin levels in men and women before and after interaction with a bonded dog. Anthrozoös 22, 31–42.
Morisaki, A., Takaoka, A., Fujita, K., 2009. Are dogs sensitive to the emotional state of humans? J. Vet. Behav. 4, 49.
Nagasawa, M., Murai, K., Mogi, K., Kikusui, T., 2011. Dogs can discriminate smiling faces from blank expression. Anim. Cogn. 14, 525–533.
Odendaal, J.S., Meintjes, R.A., 2003. Neurophysiological correlates of affiliative behaviour between humans and dogs. Vet. J. 165 (3), 296–301.
Paukner, A., Anderson, J.R., 2006. Video-induced yawning in stumptail macaques (*Macaca arctoides*). Biol. Lett. 2, 36–38.
Plutchik, R., 1987. Evolutionary bases of empathy. In: Eisenberg, N., Strayer, J. (Eds.), Empathy and Its Development. Cambridge University Press, Cambridge.
Prehn-Kristensen, A., Wiesner, C., Bergmann, T.O., Wolff, S., Jansen, O., Mehdorn, H.M., Ferstl, R., Pause, B.M., 2009. Induction of empathy by the smell of anxiety. PLoS ONE 4 (6), e5987, http://dx.doi.org/10.1371/journal.pone.0005987.
Preston, S.D., de Waal, F.B.M., 2002. Empathy: its ultimate and proximate bases. Behav. Brain Sci. 25, 1–72.
Racca, A., Guo, K., Meints, K., Mills, D.M., 2012. Reading faces: differential lateral gaze bias in processing canine and human facial expressions in dogs and 4-year-old children. PLoS ONE 7 (4), e36076, http://dx.doi.org/10.1371/journal.pone.0036076.
Romero, T., Konno, A., Hasegawa, T., 2013. Familiarity bias and physiological responses in contagious yawning by dogs support link to empathy. PLOS ONE 8 (8), E71365, http://dx.doi.org/10.1371/journal.pone.0071365.
Roozendaal, B., 2000. Glucocorticoids and the regulation of memory consolidation. Psychoneuroendocrino 25, 213–238.
Ross, M.D., Menzier, S., Zimmermann, E., 2008. Rapid facial mimicry in orangutan play. Biol. Lett. 4, 27–30.
Ruffman, T., Morris-Trainor, Z., 2011. Do dogs understand human emotional expressions? J. Vet. Behav. 6, 97–98.
Salehi, B., Cordero, M.I., Sandi, C., 2010. Learning under stress: the inverted-U-shape function revisited. Learn. Mem. 17, 522–530.
Shors, T.J., Seib, T.B., Levine, S., Thompson, R.F., 1989. Inescapable versus escapable shock modulates long-term potentiation in the rat hippocampus. Science 244, 224–226.
Silva, K., Sousa, L., 2011. 'Canisempathicus'? A proposal on dogs' capacity to empathize with humans. Biol. Lett., http://dx.doi.org/10.1098/rsbl.2011.0083.
Silva, K., Bessa, J., Sousa, L., 2012. Auditory contagious yawning in domestic dogs (*Canis familiaris*): first evidence for social modulation. Anim. Cogn. 15, 721–724.
Siniscalchi, M., Stipo, C., Quaranta, A., 2013. "Like owner like dog": correlation between the owner's attachment profile and the owner–dog bond. PLOS ONE 8 (10), e78455, http://dx.doi.org/10.1371/journal.pone.0078455.
Sipos, K., Sipos, M., 1983. The development and validation of the Hungarian form of the State-Trait Anxiety Inventory. In: Spielberger, C.D., Diaz-Guerrero, R. (Eds.), Cross-Cultural Anxiety. Hemisphere, Washington, DC, pp. 27–39.
Topál, J., Gácsi, M., 2012. Lessons we should learn from our unique relationship with dogs: an ethological approach. In: Birke, L., Hockenhull, J. (Eds.), Crossing Boundaries. Brill Academic Press, Leiden, The Netherlands, pp. 163–187.
Topál, J., Kis, A., Oláh, K., 2014. Dogs' sensitivity to human ostensive cues: a unique adaptation? In: Kaminski, J., Marshall-Pescini, S. (Eds.), The Social Dog: Behavior and Cognition. Elsevier Academic Press, San Diego, CA, pp. 319–436.
Wascher, C.A.F., Scheiber, I.B.R., Kotrschal, K., 2008. Heart rate modulation in by standing geese watching social and non-social events. Proc. R. Soc. B 275, 1653–1659.
Wilkinson, A., Sebanz, N., Mandl, I., Huber, L., 2011. No evidence of contagious yawning in the red-footed tortoise *Geochelone carbonaria*. Curr. Zool. 57, 477–484.
Wirth, M.M., Welsh, K.M., Schultheiss, O.C., 2006. Salivary cortisol changes in humans after winning or losing a dominance contest depend on implicit power motivation. Horm. Behav. 49, 346–352.
Yoon, J.M.D., Tennie, C., 2010. Contagious yawning: a reflection of empathy, mimicry, or contagion? Anim. Behav. 79, e1–e3.