Animal Cognition
https://doi.org/10.1007/s10071-020-01460-6

ORIGINAL PAPER

Does stress run through the leash? An examination of stress transmission between owners and dogs during a walk

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Received: 20 October 2020 / Revised: 1 December 2020 / Accepted: 12 December 2020

Abstract
Humans and dogs have co-evolved for over 10,000 years. Recent research suggests that, through the domestication process, dogs have become proficient at responding to human commands, attention and emotional states. However, the extent to which a companion dog responds to human emotions, such as stress, remains to be understood. This study examines whether a companion dog's stress, as measured by cortisol levels and heart rate, increases during a familiar outdoor walk in response to its owner's experience of stress. Sixty-eight owner/dog dyads participated in this study. The dyads were randomly assigned to an *Experimental* or *Control* group. Owners in the *Experimental* group were informed the walk would be digitally recorded for subsequent evaluation of their handling skills, whereas those in the *Control* group were informed the walk would be digitally recorded for archival purposes (no evaluation). This manipulation was implemented to induce a mild stress response in the owners. Salivary cortisol samples were collected from the owner and their dog before and after the walk. The dyad was also fitted with monitoring devices to record heart rate throughout the walk. Finally, personality information regarding the owner and their dog was collected. We found that cortisol production within the dyad showed a marginal inverse correlation. We also found that owners' *Openness to Experience* and dogs' *Fearfulness* influenced the heart rate of the other during the first minute of a walk. These results support that although stress may be detected within a dyad, this does not result in an associated significant change in cortisol or heart rate.

Keywords Stress · Cortisol · Heart rate · Dog · Human

Introduction

The mutualistic relationship that humankind has developed with companion dogs (*Canis lupus familiaris*) over a millennium of co-evolution, is an unmatched feat in the process of domestication (Udell et al. 2010). Dogs have solidified their role as an integral member of modern society by providing a myriad of benefits to their human partners. These range from practical, hands- (paws?) on work, to emotional enrichment and companionship. In return, dogs are typically provided with the nutrition, housing and care that allows them to live long and comfortable lives. The consequence of the close interactions with humans has resulted in dogs becoming adept at responding to human attention, gestures and emotions. For example, several studies have shown dogs to be responsive to human gestures and attentiveness (Gácsi et al. 2004; Kaminski et al. 2017), perhaps even more so than primates or wolves (Hare and Tomasello 2005; Miklósi et al. 2003; Topál et al. 2009). Research has supported that dogs can use humans as demonstrators when learning new tasks from gestures (Pongrácz et al. 2001) and even favour human gestures over previously reinforced choices (Kis et al. 2012). Tomasello and Kaminski (2009) have also reported that dogs may be as adept as human infants in responding to and processing cues from human adults. Overall, research supports that dogs show strong proficiencies in socio-cognitive tasks that require them to attend to or learn from humans.

Dogs are not only proficient at detecting and understanding the meaning of humans' physical gestures, but have also been argued to respond to human emotion. For example, dogs have been shown to gaze longer at pictures of human

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10071-020-01460-6.

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Published online: 03 January 2021

facial expressions that are congruent with prerecorded, emotionally expressive human voices (Albuquerque et al. 2016). With the ability to detect and process information from a variety of human states, it may not be surprising that dogs have also been shown susceptible to emotional contagion. Emotional contagion is the ability to mirror the expressions, vocalizations, postures and movements of another individual (Hatfield et al. 1993), and typically a similar emotional response is thought to be triggered by perceiving the state of another individual. This phenomenon is not limited to human-to-human interactions, but may also occur among dogs. For example, Dreschel and Granger (2005) found that thunderstorm-phobic dogs were better able to buffer their stress response to a simulated thunderstorm when other non-phobic dogs where in the household. Furthermore, research has supported that dogs may experience emotional contagion from humans. Human physical contact with dogs has been shown to result in lower stress levels in dogs, regardless of age, breed or sex (Coppola et al. 2006), and human contact has been shown to improve a dog's ability to buffer stress before a brief separation from its owner (D'Aniello et al. 2018). Furthermore, dogs have been shown to display behavioural changes in response to human stress, as they have been reported to display a marked improvement in bomb detection after their handler experienced a stressor (Zubedat et al. 2014), and experience a stress response when hearing a human infant cry, as compared to infant babbling or white noise (Yong and Ruffman 2014).

Although considerable research supports that dogs are able to respond to human stress and show emotional contagion, less is known regarding the mechanisms supporting these abilities. Considering the physiological response to stress, when an organism experiences a stressful situation there is an activation of the hypothalamic–pituitary–adrenal (HPA) axis. One aspect of this activation includes an increase in the hormone *cortisol* (Allen et al. 2017). A wealth of knowledge is known regarding the HPA axis response to stress in humans (e.g. Kogler et al. 2015). More recently, research has begun to examine similar physiological responses by dogs. Much of this research has examined fluctuations in salivary, plasma and serum cortisol production (Beerda et al. 1996). For example, Beerda et al. (1998) reported that dogs produce significantly elevated levels of salivary cortisol after being exposed to aversive stimuli. Salivary cortisol is of particular relevance, as this measure of short-term or acute stress has been established to be a non-invasive, accurate measure of cortisol production (Beerda et al. 1997). Moreover, salivary cortisol samples from dogs have been shown resilient against potential confounding variables such as age (if the dog is older than six months), breed, weight and assay type (Cobb et al. 2016).

A limitation of using only cortisol concentrations as a measurement for stress is the duration required for it to circulate throughout the body. This delay can influence the type of sampling technique required. Thus, a secondary measure of stress response is often used. Cardiac activity is an expression of the sympathetic nervous system. Heart rate (HR) and heart rate variability (HRV) have provided an accurate means for evaluating stress-related behavioural changes and have shown to parallel cortisol responses for humans (e.g. Polheber and Matchock 2014) and dogs (Beerda et al. 1998; Zupan et al. 2016). HR responses in dogs for example, have been linked to emotional arousal (Zupan et al. 2016) and an increase in cortisol and HR has been shown to co-occur after a dog experiences aversive stimuli (Beerda et al. 1998). With continued improvements in heart rate monitoring technology the accuracy of wireless HR monitors has allowed this approach to be a feasible means of examining stress responses by humans and dogs on a second-by-second basis (Brugarolas et al. 2016; Essner et al. 2013; Gilgen-Ammann et al. 2019).

Many intrinsic characteristics may also influence the stress response of humans and dogs. One of these factors is personality type. Human personality is commonly assessed using the "Big Five Inventory" (BFI; John and Srivastava 1999; McCrae and Costa 1986), in which scores among the five dimensions of personality have been shown to influence how an individual perceives and copes with stressful events (Penley and Tomaka 2002; Soliemanifar et al. 2018). A similar personality index has been created in an attempt to quantify dog personality, the Dog Personality Questionnaire (DPQ; Jones 2008). Although, such owner-assessed dog personality scores have been shown to accurately predict some behavioural traits of dogs, whether these measures can be used as valid predictors of physiological responses to stress is less clear (Ottenheimer-Carrier et al. 2013). Further research is needed to evaluate whether these measures can be used to gain insight into whether these owner-reported temperament or disposition traits of dogs may be used to accurately predict the stress reactivity of owners, analogous to how personality inventories have been used to examine the affect of owner disposition on dog reactivity (Schöberl et al. 2017).

The daily walk is a commonly shared experience between dogs and owners. Although many studies have focused on laboratory or other controlled-settings to carefully monitor whether intrinsic and extrinsic factors influence the stress responses of owners and dogs (Coppola et al. 2006; D'Aniello et al. 2018; Powell et al. 2019), the current study focused on how these factors are expressed in the naturalistic setting of a walk. We evaluated the salivary cortisol and HR of human–dog dyads over the course of a walk in their familiar neighbourhood. To evaluate experimentally whether an owner's stress affected their dog, half of the owners were subjected to a mild stressor before the walk to elevate their stress levels. To maintain the naturalistic applicability of this study, this stressor was intentionally mild to reflect levels similar to what a dog owner may experience during their daily walk. As such, we predicted that the owners who experienced the stressor may have significantly elevated salivary cortisol and HR compared to the non-stressed owners. Regardless of our manipulation, we predicted an overall correlation between these measures in the owners and their dogs because of emotional contagion. Our stress induction was included to determine whether a mild stressor would effectively highlight this contagion. Finally, we predicted that some aspects of the owner's personality would have an influence on a dog's stress response and vice versa with the dog's temperament affecting the owner's stress responses. Overall, we expected owners and dogs would show reciprocity in the influence of stress when on a walk.

Methods

Subjects

Sixty-eight owner/dog dyads participated in this study (female owner/male dog: $n=28$; female owner/female dog: $n=25$; male owner/male dog: $n=7$; male owner/female dog: $n=8$). Participants were recruited using posters placed in pet stores, veterinary offices, online forums, as well as the University of Manitoba SONA participant recruitment system available to students enrolled in the course *Introduction to Psychology*. Participants recruited through the public were not compensated, whereas students received a credit towards their Introduction to Psychology grade. All potential owner/dog dyads were pre-screened to assess their eligibility to participate. Pre-screening consisted of an online self-report to collect information regarding the participant and their dog. Included was the participant's contact information and availability, as well as their dog's medical history and temperament (found in Supplemental Information, Appendix A). Only the participants who met the eligibility criteria completed the study. These criteria included: (1) owner's availability from 14:00 to 18:00 Central time, (2) up-to-date vaccinations for the dog (e.g. Rabies, Distemper, Hepatitis, Parvo virus and Bordetella), (3) the ability for the dog to walk on a leash and harness alongside the owner and (4) no history of aggression by the dog, including stranger aggression. Participation was voluntary and all dog owners were permitted to withdraw from the study at any time. This study was approved by the University of Manitoba's Human Research Ethic Board (HS23036) and the Local Animal Care Committee (F19-013).

General procedures

This study was conducted at the residence of the owner/dog dyads. During the home visit, saliva samples, HR information and self-report data were collected before, during (except saliva) and after a 15-min walk (see specific procedures below). Home visits took approximately 75 min and were scheduled between 14:00 and 18:00 to ensure cortisol levels were least variable, as previous research has shown greatest consistency in salivary cortisol levels during the mid-afternoon (Hucklebridge et al. 2005). Salivary cortisol levels from a sample provide information on a window of time approximately 15 min prior to the collection (Kirschbaum et al. 1993). Therefore, the first saliva sample was collected immediately upon arrival at the owner's house, to provide a baseline state of the owner and dog before the arrival of the researchers. Similarly, a sample was collected after the walk to represent cortisol levels of the owner and dog during the walk.

To cause minimal disturbance, the researchers (a team of 2–3 individuals) phoned the owners upon their arrival. Owners first completed a consent form, immediately after which the baseline saliva collection was taken (elaborated in *Saliva Collection*), followed by the securing of the HR monitors to the human and dog participants (elaborated further in *Heart Rate Collection*). Once the HR monitors were in place, owners were given instructions for the walk portion of the study. All owners were instructed to walk a regular route in close proximity to their home for approximately 15 min. They were informed that during this walk the researchers would follow behind, recording the event. Participants in the *Control* group were told that the purpose for recording the walk was simply to have a video record ("Walk your dog in your normal way, as if we (the researchers) were not present. We are only filming the walk to have documentation of highly unusual events if they occur"), whereas participants in the *Experimental* group were told that the footage would be relayed to dog obedience experts, who would then assess the owner's dog walking skills ("We want you to walk your dog as you usually do. We will be filming the entire duration of the walk, and this footage will be examined by undergraduate and graduate students who are experts in dog obedience training. They will be evaluating how you handle your dog and your dog-walking skills."). The purpose of this deception was to increase the owner's stress due to the performance aspect of the walk (Koolhaas et al. 2011; Sarason 1984). Upon conclusion of the visit, owners in the Experimental group were provided with full debriefing as to the actual purpose of the experiment. All participants were digitally recorded using a chest-mounted GoPro Hero7 Black®, worn by one of the researchers.

During the walk, the researchers followed at an estimated distance, never < 10 m, behind the owners, who were asked to ignore the researchers. The researchers departed the household approximately 30 s before the owner/dog dyad, which allowed them to wait at a distance before following behind the owner and dog. This also allowed the researchers to define precisely the beginning of the walk for all dyads. In the event that the following distance was not sufficient, as indicated by the dog stopping and/or repeatedly looking back at the researchers, the researchers increased the distance until the dog was no longer distracted. Owners were supplied with a small pouch containing two iOS cellphones to carry throughout the walk. These devices were paired with the HR monitors for the human and dog, respectively. To minimize verbal communication between the owner and the researchers, an alarm was set for nine minutes on one of the devices, at which time the owner was instructed to return home using the same route. This duration was selected in an attempt to ensure the walk would be completed in 15 min at minimum. Owners were instructed to shut off the alarm as soon as possible to avoid disturbing their dogs. After completion of the walk, saliva was collected immediately from both the owner and the dog, and the HR monitors were removed. Finally, the owner completed a questionnaire regarding the personality characteristics (i.e. Big Five Inventory and the Dog Personality Questionnaire) of themselves and their dog (see in Supplemental Information, Appendix B).

Saliva collection

Baseline saliva samples were collected first from the dog and immediately followed by saliva samples from the owner. During sampling from the dog, owners were instructed to gently restrain the dog as the researcher, wearing latex-free gloves, collected the saliva sample using a *Sarstedt*® salivette. In order to maximize comfort for the dog and to ensure researcher safety, the researchers used stainless steel forceps to hold the salivette when collecting saliva from both sides of the buccal cavity (one salivette per side). The researchers then collected the owner's baseline saliva. The owner was instructed to wear one latex-free glove, to handle their salivette with only their gloved hand, and to collect saliva from both the left and right side of the buccal cavity (one salivette per side). The salivettes for both samples remained in the owner and dogs' mouths for 60 s, as per *Sarstedt*® saliva collection guidelines to obtain a suitable volume of saliva. Upon collection, each sample salivette was immediately placed in an Eppendorf tube, labelled and stored in a portable ice-filled cooler. The final samples taken from the owners and dogs reflected their post-walk salivary cortisol concentrations and followed the same collection procedures as the baseline samples. Samples remained in the cooler for one to four hours. Upon return to the research facility, saliva samples were permanently stored in a freezer (– 24 °C) until processing.

Heart rate collection

Both the owner and the dog wore a heartrate monitor for the duration of the walk. Polar® HR monitors were used, as previous literature has established their validity and reliability for humans and dogs (Dogs: Essner et al. 2013; Humans: Gilgen-Ammann et al. 2019; Hettiarachchi et al. 2019; Schubert et al. 2018). The dog's HR monitor (Polar® H10) was attached first. To correctly fit the Polar® H10 around the dog, the monitor was placed against the skin adjacent to the dog's left axilla and the chest strap was tightened around the torso until it was comfortably snug. To improve the monitor's ability to detect HR through fur, saline electrode gel (Spectra Electrode Gel) was applied to the dog's fur and skin and to the electrode band on the chest strap. Once the dog's HR monitor was attached, the owner was fitted with his/her HR monitor (Polar® OH1). Adhering to the Polar® user guidelines, this HR monitor was positioned on either the forearm or upper arm of the participant. As the OH1 collected HR via EMF radiation, application of electrode gel was not necessary. The H10 and the OH1 devices monitored HR at one-second intervals. Once the researchers established that both HR monitors were fully functioning, *Baseline* HR recordings were collected with the owner sitting in a neutral position and the dog unrestrained for approximately 75 s (for consistency the first 60 s were used for *Baseline* comparisons, see "Methods" section). During this period, the verbal instructions for the walk were provided. The HR monitors were continuously worn by the owner and dog for the duration of the walk; upon returning to the start location both monitors were removed.

Questionnaire data collection

The final step of the home visit was the completion of a self-report questionnaire. This questionnaire collected information regarding the owner's experience during the walk, the training and background of the dog (e.g. presence of other dogs in the home, etc.) and both the owner's and dog's personality traits (BFI: John and Srivastava 1999; DPQ: Jones 2008; see Supplemental Information, Appendix B). The BFI is an empirically-validated questionnaire designed to gather information regarding the owner's extraversion, neuroticism, agreeableness, conscientiousness, and openness to experience (e.g. Costa and McCrae 1995). For this questionnaire, *Extraversion* is defined as the extent to which an individual is gregarious, assertive, excitement seeking, and active. *Neuroticism* is defined as the extent to which an individual is anxious, hostile, self-conscious, vulnerable to stress and depression, and impulsive. *Agreeableness* is defined as the extent to which an individual is trusting, straightforward, altruistic, modest, and compliant. *Conscientiousness* is defined as the extent of which an individual is orderly, competent, achievement striving, self-disciplined, and dutiful. *Openness* to experience is defined as the extent to which an individual values fantasy, aesthetics, feelings, actions, and ideas. Scores for each of these facets indicate the strength of their presence in the participant—with higher scores indicating that this facet presents strongly in the individual (John and Srivastava 1999).

The DPQ provided information regarding the general disposition of the dogs, such as general fearfulness, aggression towards people, activity/excitability, responsiveness to training, and aggression towards animals. *Fearfulness* is defined by fear of people, nonsocial fear, fear of dogs, and fear of handling. *Aggression Towards People* is defined by general aggression and situation aggression. *Activity/Excitability* is defined by general excitability, playfulness, active engagement, and companionability. *Responsiveness to Training* defined by general trainability and controllability. *Aggression Towards Animals* defined by aggression towards dogs, prey drive, and dominance over other dogs. Similar to the BFI, scores for these facets are indicative of the strength of presentation of these traits in dogs, with higher scores indicating that this facet presents strongly in the individual (Jones 2008).

Upon the completion of the questionnaire, the researchers debriefed the participant as to the purpose of the study, including the rationale for the use of deception for participants in the Experimental group and provided a detailed explanation of the purpose for collecting physiological and personality information. Before the researchers concluded the session, participants were given an opportunity to ask any further questions regarding the study and were provided with the contact information of the researchers.

Salivary cortisol processing

All saliva samples were allowed to defrost at room temperature (~22 °C) on the day of processing. Saliva was extracted from the salivettes using two methods. The first was manual compression using a syringe. If this method was unsuccessful, the second was to centrifuge samples at $1500 \times g$ for 15 min. Cortisol was extracted from the saliva using enzyme-linked immunosorbent assay (ELISA®) purchased from Salimetrics ELISA®. All procedures for processing cortisol followed as per instructions from the Salimetrics ELISA® kits. The software package GraphPad Prism was used to interpolate the final ELISA® values (obtained by plate reader) into cortisol concentrations.

Data analysis

The *difference score* was calculated by subtracting the baseline cortisol values from the post-walk cortisol values for each participant. These difference scores (calculated for both the owner and the dog) were used for further analyses.

HRs (defined as beats per minute, BPM) were collected every second for the duration of the walk (separately for the owner and dog). However, to evaluate changes in HR during the walk, four representative time points were evaluated: (1) the *Baseline* HR was collected from 60 s before the start of the walk, (2) first 60 s of the walk (0:00–0:59), (3) the mid-point of the walk (6:30–7:29) and, (4) the conclusion of the walk (13:00–13:59). The average HR was calculated for each dog and human within each of these time points. To evaluate successive changes in HR, we calculated three *difference scores* by subtracting the average Baseline from the average of the first 60s (*Timepoint One*), the average of the first 60 s from the average of the mid-point of the walk (*Timepoint Two*), and the average of the mid-point from the average of the conclusion of the walk (*Timepoint Three*). These difference scores were used for further analyses.

Generalized Linear Mixed Models (GLMM) were used to assess which factors accounted for the most variance in the cortisol and HR data. A separate GLMM was used to analyze owner's HR, dog's HR, owner's cortisol, and dog's cortisol. The difference scores for HR and salivary cortisol were used as dependent variables.

All HR models were analyzed to determine if *Timepoint* (*One, Two or Three*) had any interaction with following factors: *Group* (*Control or Experimental*), *Sex* (*female or male*) and *Personality Information* (variables for dogs were: *Fearfulness, Aggression Towards People, Activity/Excitability, Responsiveness to Training and Aggression Towards Animals*, whereas variables for owner's were: *Extraversion, Neuroticism, Agreeableness, Conscientiousness and Openness to Experience*). In addition, for the models of dogs' HR the factors *Reproductive Status* (*Sterilized or Intact*) and *Weight* (continuous variable) were included.

Cortisol models were analyzed to determine if the difference score had any interaction with following factors: *Sex* (*female or male*) and *Personality Information* (variables for dogs were: *Fearfulness, Aggression Towards People, Activity/Excitability, Responsiveness to Training, and Aggression Towards Animals*, whereas variables for owner's were: *Extraversion, Neuroticism, Agreeableness, Conscientiousness, and Openness to Experience*). In addition, for the models of dogs' cortisol the factors *Reproductive Status* (*Sterilized* or *Intact*) and *Weight* (continuous variable) were included. These factors were considered as they allowed us to evaluate whether aspects of the owners or the dogs had an influence on each other's physiology. Furthermore, including these factors allowed us to evaluate which personality type, of either the owners or dogs, were more susceptible to the stress of the walk or our experimental manipulation.

In order to determine the most representative model within the analyses described above, all models were compared against the closest, simplest model. Specifically, single factor models were compared against the null model (e.g. *Group* vs *Null*). As models became more complex, the significance of the interaction effect of factors was established by comparing the model to the identical model lacking the newly added factor (e.g. *Group* × *Walk Timepoint* vs *Group*). To estimate the fit of each model, we used Akaike's Information Criterion (*AIC*). Models were considered equivalent when $\Delta AIC < 2.0$. We obtained p values for each fixed factor through likelihood ratio tests that compared the model with the target fixed factor against the model without the target fixed factor. Parameter estimation was achieved using residual maximum likelihood. For GLMM, the parameter estimates for the best models are presented in (Supplemental Information, Tables 1 to 4) and final models are presented in (Supplemental Information, Tables 5 to 8). Significant effects were followed by Tukey's post hoc analyses. Alpha was set at 0.05 for all statistical analyses.

Analyses and plots were conducted using R version 4.0.2 with the *rstatix, lme4*, *MuMIn, dplyr, tidyverse, ggpubr, ggpmisc, GGally, data.table, lsmeans* packages (Aphalo 2020; Barton 2020; Bates et al. 2015; Dowle and Srinivasan 2020; Kassambara 2020a, b; Lenth 2016; Schloerke et al. 2020; Wickham et al. 2019, 2020).

Results

As complete data sets were required for both the owner and their dog, out of a total of 68 owners/dog dyads, we used 20 dyads for the correlation analysis, 42 dyads for the HR analysis (*Control*: $n = 24$, *Experimental*: $n = 18$) and 37 dyads for the salivary cortisol analysis (*Control*: $n = 16$, *Experimental*: $n = 21$). Loss of HR data resulted from failure to acquire signals from the monitors. Failures causing greater than 10% data loss during either *Baseline* or *Timepoint One, Two* or *Three* resulted in the dyad being excluded. The loss of cortisol data resulted from insufficient saliva volumes during either initial collection and/or loss of saliva due to the extraction techniques during the ELISA® processing stage. Thus, the 20 dyads used in the correlation analysis represented successful collection of cortisol and HR from both members of the dyads.

Initial descriptive analyses showed that the range in difference scores for salivary cortisol concentrations in owners was from − 0.394 to 0.252 µl/dL and − 0.082 to 0.206 µl/dL for dogs. The range of scores for the owners' BFI were: 26–44 for *Agreeableness*, 15–39 for *Extraversion,* 24–45 for *Conscientiousness,* 8–33 for *Neuroticism,* 24–49 for *Openness to Experience.* The range of the dogs' scores in the DPQ were: 24–45 for *Activity/Excitability,* 15–39 for *Fearfulness,* 26–44 for *Aggression Towards People,* 24–49 for *Aggression Towards Animals* and 8–33 for *Responsiveness to Training.*

Do the physiological markers of stress for one species affect the physiological levels of stress of the other?

Linear regressions were performed to predict whether changes in an owner's HR influenced their dog's HR. This linear regression examined the BPM difference score (the difference from *Baseline* to *Timepoint One,* the BPM difference from *Timepoint One* to *Timepoint Two* and the BPM difference from *Timepoint Two* to *Timepoint Three*). The owner's HR did not significantly influence their dog's HR for either the *Control* or the *Experimental* groups during *Timepoint One* (*Control*: $F_{(1,7)} = 0.322$, $p = 0.588$; *Experimental*: $F_{(1,9)} = 0.626$, $p = 0.449$), *Timepoint Two* (*Control*: $F_{(1,7)} = 0.0897$, $p = 0.773$; *Experimental*: $F_{(1,9)} = 0.0513$, $p = 0.826$) or *Timepoint Three* (*Control*: $F_{(1,7)} = 1.88$, $p = 0.212$; *Experimental*: $F_{(1,9)} = 1.34$, $p = 0.276$). As there were no significant differences between groups, we ran an additional linear regression on the HR data, which included all dyads. The analysis showed that the owner's HR did not significantly influence their dog's HR during Timepoint One ($F_{(1,18)} = 1.14$, $p = 0.3$), Timepoint Two ($F_{(1,18)} = 0.274$, $p = 0.607$) or Timepoint Three ($F_{(1,18)} = 0.006$, $p = 0.935$) (see Fig. 1).

We performed two separate linear regressions on the salivary cortisol difference scores between owners and their dogs for both the *Control* and *Experimental* groups. The analysis did not show a significant regression for the dog/owner dyads in the *Experimental* group ($F_{(1,31)} = 1.96$, $p = 0.171$, $R^2 = 0.06$) or the *Control* group ($F_{(1,25)} = 1.84$, $p = 0.188$, $R^2 = 0.068$). As there were no significant differences between groups, we ran an additional linear regression on the salivary cortisol data, which included all dyads. The analysis showed that owner's cortisol levels have a marginally significant influence dog's cortisol levels ($F_{(1,58)} = 3.37$, $p = 0.071$; see Fig. 2).

Which variables account for changes in a species' physiological responses during the walk?

Dogs' heart rate

According to *AIC*, the model that best explained changes in a dog's HR during the walk included the interaction effects of *Timepoint* × *(Owner's) Openness to Experience* ($\chi^2_{(1)} = 9.444$, $\Delta AIC = 0.000$) (Supplemental Information, Table 1). The best model showed that a dogs' HR tended to be higher when their owner's *Openness to Experience* was higher during the first portion of the walk (from *Baseline* to *Timepoint One*) (Estimate based on best model: 1.99 ± 0.37 BPM, but stabilised over the course of the walk, see Fig. 3). A post hoc Tukey test showed that Dogs' HR was significantly higher during *Timepoint One* than *Timepoint Two*

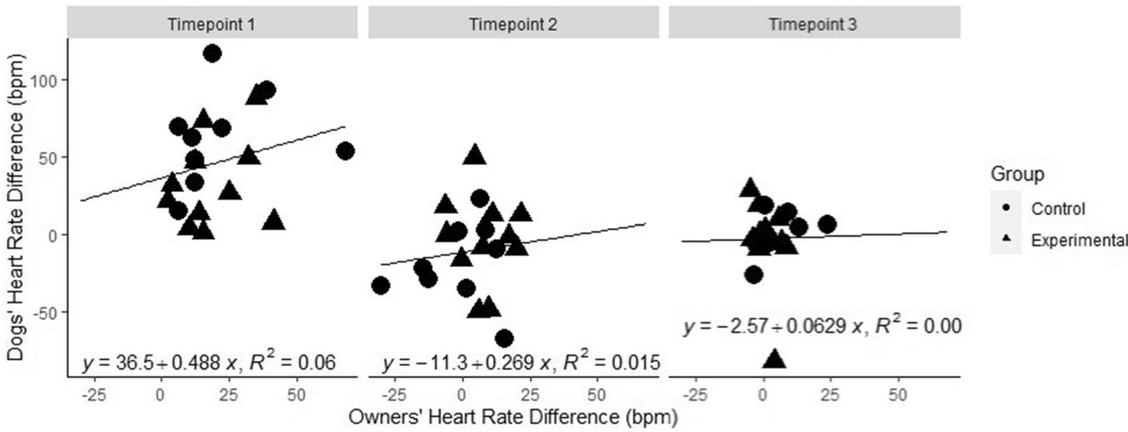

Fig. 1 Linear regression of dogs' and owners' difference scores for heart rates showing Control (circles) and Experimental (triangles) groups across three Timepoints of the walk. Although the groups did not differ significantly, they are shown separately here for comparative purposes

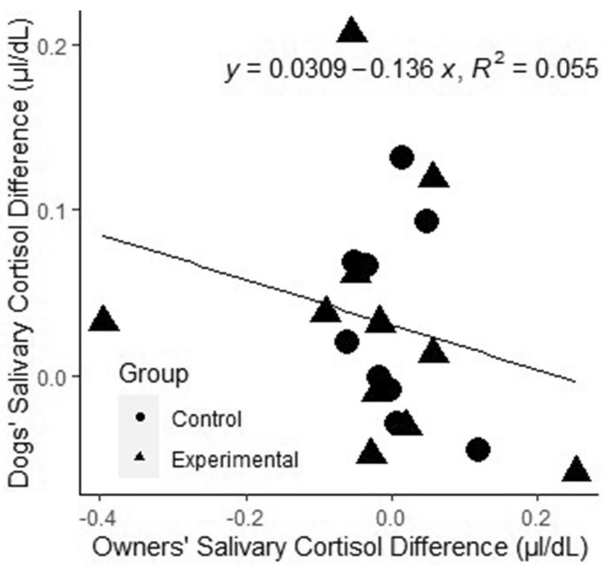

Fig. 2 Linear regression of dogs' and owners' difference scores for salivary cortisol showing Control (circles) and Experimental (triangles) groups. Although the groups were only differed marginally, they are shown separately here for comparative purposes

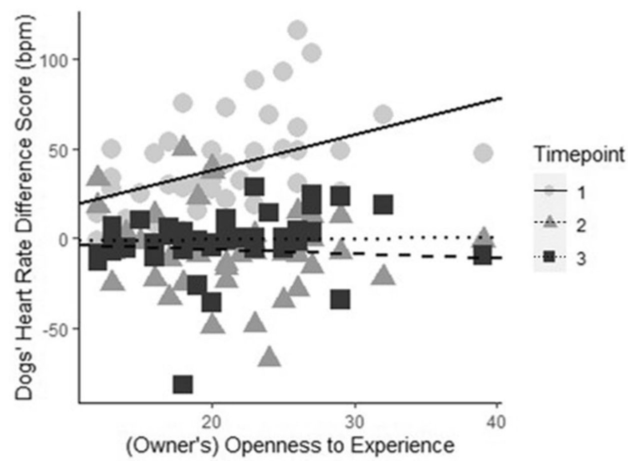

Fig. 3 Dogs' heart rate difference score during the three Timepoints of the walk as a function of the owner's *Openness to Experience*

($t_{(105)} = 9.865$, $p < 0.001$) and *Timepoint Three* ($t_{(105)} = 8.613$, $p < 0.001$); there was no differences between *Timepoint 2* and *Timepoint 3* ($t_{(105)} = -1.251$, $p = 0.4259$).

Dogs' cortisol

According to *AIC*, the four models that best explained the change in a dog's cortisol level from the start of a walk to its conclusion were: (1) *(Dog's) Activity/Excitability* ($\chi^2_{(1)} = 2.769$, $\Delta AIC = 0.000$), (2) the null model ($\Delta AIC = 0.246$), (3) *(Dog's) Neutering* ($\chi^2_{(1)} = 1.887$, $\Delta AIC = 0.881$) and (4) *(Dog's) Aggression towards animals* ($\chi^2_{(1)} = 0.909$, $\Delta AIC = 1.859$). Although the model *(Dog's) Activity/Excitability* was the best model (weight = 0.166, $\Delta AIC = 0.000$), *(Dog's) Activity/Excitability* only marginally influenced a dog's cortisol level ($p = 0.064$, Supplemental Information, Appendix Table 2; Fig. 4). Dog's salivary cortisol decreased by an average of 0.04 µl/dL with each increase in dogs' *Activity/Excitability* score. Although the models *(Dog's) Aggression towards animals* (weight = 0.065, $\Delta AIC = 1.859$, $p = 0.340$) and *(Dog's) Neutering* (weight = 0.106, $\Delta AIC = 0.881$, $p = 0.169$) also fit the data, they did not significantly influence a dog's cortisol level. Finally, the dogs' salivary cortisol difference scores were not influenced by any of the owners' personality traits.

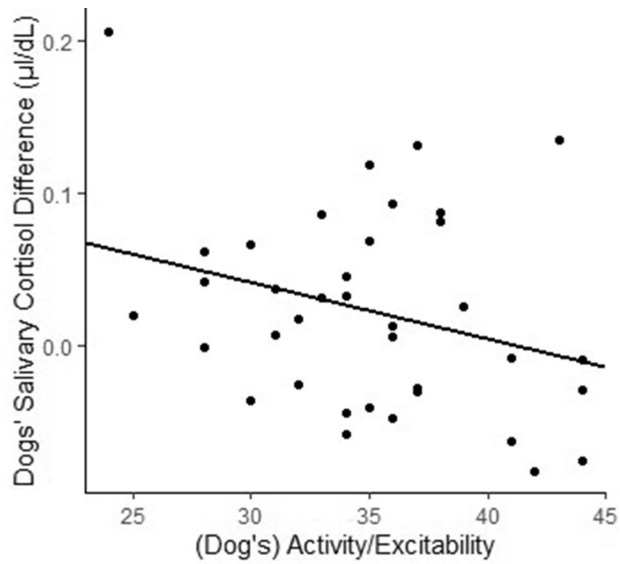

Fig. 4 Dogs' salivary cortisol difference score shown as a function of the dog's *Activity/Excitability*

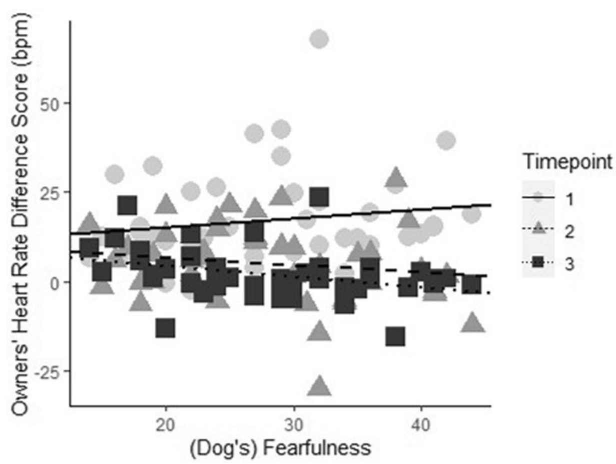

Fig. 5 Owners' heart rate difference score during the three Timepoints of the walk as a function of the dog's factor *Fearfulness*

Owners' heart rate

According to *AIC*, the model that best explained changes in an owner's HR during the walk was the interaction effects of *Timepoint* × *(Dog's) Fearfulness* ($\chi^2_{(1)}=6.187$, $\Delta AIC=0.000$) (see Supplemental Information, Table 3). The best model showed that owner's HR tended to be higher when their *(Dog's) Fearfulness Score* was higher during the first portion of the walk and lower during the reminder of the walk (Fig. 5). A post hoc Tukey test showed that Owners' HR was significantly higher during *Timepoint One* than *Timepoint Two* ($t_{(105)}=5.280$, $p<0.001$) and *Timepoint Three* ($t_{(105)}=6.635$, $p<0.001$); there was no differences between *Timepoint 2* and *Timepoint 3* ($t_{(105)}=1.354$, $p=0.3687$).

Owners' cortisol

According to *AIC*, the five models that best explained the change in an owner's cortisol level from the start of a walk to its conclusion were: (1) the null model ($\Delta AIC=0.000$), (2) *(Owner's) Sex* ($\chi^2_{(1)}=1.406$, $\Delta AIC=1.116$), (3) *Group* ($\chi^2_{(1)}=1.194$, $\Delta AIC=1.327$), (4) *(Owner's) Extraversion* ($\chi^2_{(1)}=1.153$, $\Delta AIC=1.368$) and (5) *(Owner's) Conscientiousness* ($\chi^2_{(1)}=0.459$, $\Delta AIC=1.974$). (Supplemental Information, Table 4). Although the models *(Owner's) Sex* (weight = 0.105, $p=0.235$), *Group* (weight = 0.094, $p=0.274$, *(Owner's) Extraversion* (weight = 0.092, $p=0.282$) and *(Owner's) Conscientiousness* (weight = 0.068, $p=0.459$) fit the data, they did not significantly influence owner's cortisol levels. The change in owners' salivary cortisol was not influenced by any of the dogs' personality traits.

Discussion

During the present study, we attempted to examine empirically whether the commonly held believe that an owner's emotional state "runs down the leash", affecting the emotional state of the dog. To evaluate this claim, as well as a possible reciprocity, we asked owners to take their dogs on a short walk through their familiar neighborhood. To manipulate the owner's emotional state or *stress* as we define it here, one group was informed the walk would be digitally recorded in order for experts to evaluate the owner's ability to handle their dog, whereas the other group was told the recording was only to be used for data archiving. We measured both the change in the owner's and the dog's HRs (at three equal time points along the walk) and cortisol levels (before and after the walk) as objective measures of physiological change. Our results showed a marginally significant inverse correlation of salivary cortisol difference scores within owner/dog dyads. Although this relationship was in the opposite direction of our prediction, it supports an ability of dogs to interpret and react to their owner's stress. Our results showed some support for reciprocity, specifically that some personality factors of the dogs and the owners influenced each other's HR. However, the only variables influencing cortisol levels were factors related to the individual themselves.

Do the physiological markers of stress in one species affect the physiological levels of stress of the other?

Contrary to what was initially predicted, HR difference scores within the dyads were not shown to be significantly correlated to one another. This finding supports that owner's stress, as measured by HR, did not influence their dog's HR and vice versa. However, changes in salivary cortisol levels was shown to have a marginally negative correlation for owners and dogs. Specifically, the greater the difference score for salivary cortisol of the owners, the lower the difference score for salivary cortisol for dogs. A relationship opposite to our prediction and contrary to other existing literature. For example, Yong and Ruffman (2014) found that a dog's salivary cortisol levels increased after hearing an infant crying, suggesting that dogs may experience emotional contagion. However, Zubedat et al. (2014) reported that detection dogs showed *improved* detection performance (increase speed and accuracy) when their handler had experienced an external stressor. Parallels may be drawn between the methodology and results of the Zubedat et al. (2014) study and our current study, as they suggested dogs may be sensitive to their handler/owner's stress and reacting by mediating their own stress responses. The researchers reported that during an explosive detection task, conditions that increased handler stress and anxiety caused a decrease in handler's attention, but also resulted in superior performance by the detection dogs. This was unexpected, but the researchers interpreted the result to suggest that the impairment in handler attention allowed the dogs to "take control" over the task outcome. Although only marginally significant, we also found a similar opposing relationship between owner stress and dog stress, as measured by cortisol; an increase in owner's salivary cortisol concentrations correlated with a decrease in the dog's salivary cortisol concentrations.

Which variables account for changes in a species' physiological responses during a walk?

The current study predicted that the personality of an owner and their dog would show reciprocal affects on the physiological responses of each other. However, examining changes in cortisol levels, neither the owner's nor the dog's salivary cortisol concentrations were significantly influenced by the other species' personality scores. Sundman et al. (2019) examined whether a dog's personality scores affected their owner's stress by examining cortisol concentration in hair samples to gain a long-term measure of owner stress. The researchers reported that the dog's personality type had no effect on their owner's chronic stress levels. However, several of the owner's personality traits (i.e. *Neuroticism, Openness to Experience* and *Conscientiousness*) influenced their dog's hair cortisol concentrations. Although the current study examined acute stress, we found a similar lack of support that dogs' personality traits influence their owner's cortisol levels. However, we also did not find support for owner's traits influencing cortisol levels of the dogs.

Focusing on the relationship between a dog and its owner, Dreschel and Granger (2005) examined whether owner behavior or quality of the dog–owner relationship could buffer the severe stress response, measured by salivary cortisol levels, of a thunderstorm-phobic dog during a simulated thunderstorm. Although this study did not examine the influence of human personality per se on dogs' stress physiology, their results showed that neither the owners' behaviours (i.e. petting or talking to the dog), nor the owners' bond with their dogs (measured by the *Companion Animal Bonding scale*) influenced the dogs' stress response. Yet, Coppola et al. (2006) reported that interactions with humans lowered the salivary cortisol concentrations in shelter dogs. Perhaps the apparent contradictory results from the Coppola et al. study and those (including ours) with companion dogs, may be due to the absence of a stable owner–dog relationship for the shelter dogs. The presence of this relationship may lessen the overall cortisol response, such that the stress or emotion expected to "run through the leash" is dampened compared to situations in which a stable, positive dog–owner relationship is not present, as in shelter dogs. Whether presence of a stable owner–dog relationship is acting in a way to reduce stress as measured by cortisol levels, warrants further examination.

The results from the current study show that intrinsic variables accounted most for the changes in both owner's and dog's salivary cortisol levels. For dogs, the owner-reported *Activity/Excitability* scores showed a marginally negative relationship with salivary cortisol concentrations. This finding is somewhat novel, as exercise has been shown to increase cortisol production in sled dogs with similar fitness levels (Fergestad et al. 2016). Although speculative, this finding may be a function of a dog's physical fitness, as a dog scoring higher on the *Activity/Excitability* trait may have found the walk less physically stressful. For instance, Ramos and Castillo (2020) reported that, similar to humans, obese dogs tend to have higher cortisol levels compared to leaner dogs. As we would expect dogs scoring high in *Activity/Excitability* would tend to be lean, this may be a plausible explanation for this result. Although we did not find that weight was an influencing factor, using a variable that more accurately represents a dog's fitness may be more informative.

The results from the current study support a reciprocity in the influence of personality traits on HR over the course of the walk. Our results support that dogs' HR was marginally influenced by owners' *Openness to Experience* score. Specifically, as an owner's tendency to be open to new experiences increased, dogs showed a greater change from *Baseline* HR during the first minute of the walk. This result is similar to that reported by Sundman et al. (2019) who found that owners' *Openness to Experience* scores were correlated with their dog's increase in hair cortisol concentration. Beerda et al. (1998) reported that unpredictable stressors administered to a dog (i.e. shocks, loud noises, etc.) produced greater stress responses than stressors that were more visibly predictable (i.e. a researcher approaching the dog in order to apply restraints). Perhaps these results shed light on why an owner's *Openness to Experience* may have affect HR levels in their dogs. Owners who are open to new experiences may be more likely to place their dogs in unpredictable situations or novel environments. This may account for why the dogs in our study showed an increased change of HR during the first portion of the walk when their owner's scored high on *Openness to Experience*. Unfortunately, we did not inquire as to how many walking routes or novel experiences owners provided for their dogs in our questionnaire to be able to evaluate this possibility.

Owners were also affected by the personality traits of their dogs, specifically their dog's *Fearfulness*. This finding supports that owners with dogs scoring high on *Fearfulness* scale showed a greater increase in HR during the first minute of the walk. Many animals are known to show a physiological response as a consequence of witnessing fear in another individual. For example, Sanders et al. (2013) reported that mice showed behavioural empathetic fear responses when witnessing another mouse being subjected to shocks, if they had previous experience themselves with shock. Humans certainly are known to have empathetic responses to fear. Decety et al. (2012) argue that as a highly social species, humans have evolved to be adept at understanding and reacting to emotional cues from other humans. Thus, it may not be surprising that owners would anticipate a walk as a potentially adverse experience if they report experiencing their dog as typically fearful and thus experience an increased HR during the start of a walk. However, this finding does not result in a subsequent salivary cortisol trend that would allow us to further conclude it is a stress response and not simply due to activity.

Our stress manipulation was intentionally designed to be mild to reflect a level of stress that an owner may experience on a daily walk and not representative of a high anxiety-provoking situation. However, this mild stress did not result in cortisol differences between the *Experimental* and *Control* groups. Thus, we are not able to determine whether mild stress does not result in emotional contagion between owner's and their dogs or if the experimental situation was not interpreted as sufficiently stressful. Alternatively, we may not have not seen a significant change in cortisol due to the timing of our post-walk saliva sample. Our salivary collection post-walk provided a measure of cortisol levels 15 min earlier—the start of the walk. This period was chosen as likely representing the most stressful period for the participants in the *Experimental* group, as this would be the initial onset of the "evaluation". However, including additional post-walk collections would be informative to better evaluate the timeline of salivary cortisol responses over the entire walk.

In conclusion, the current study examined whether owners and their dogs showed reciprocity in physiological responses to stress during a walk. Although our mild stress manipulation did not produce a significant difference between the groups, the current study provides insight to the interactions between an owner/dog dyad in their familiar daily environment. Our results presented a more complicated picture than expected, particularly in the finding that cortisol production within the dyad was *inversely* correlated. The initial component of the walk was most reveling, with the owners' Openness to Experience and dogs' Fearfulness influenced the HR of the other. However, these factors did not continue to evoke an influence as the walk progressed. Thus, we found limited support for the adage that *emotion runs through the leash*.

Acknowledgements The study reported here was in partial fulfillment of the requirements for Bachelor's of Science Honors degrees to Candace Briggs and Shane Thiessen. Research support was provided by a Natural Science and Engineering Research Council Discovery grant (RGPIN/4944-2017) and Canada Research Chair to Debbie M. Kelly. We thank Kevin Leonard and Parisa Sepehri for assistance with data collection and Alizée Vernouillet for statistical advice.

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