Effects of human-animal interactions on affect and cognition

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Human-animal interaction has clear positive effects on people's affect and stress. But less is know about how animal interactions influence cognition. The aim of this study is to investigate whether interacting with animals improves cognitive performance, specifically executive functioning. To test this, we conducted two experiments in which we had participants self-report their affect and complete a series of cognitive tasks (long-term memory, attentional control, and working memory) before and after either a brief interaction with a dog or a control activity. We found that interacting with a dog improved positive affect and decreased negative affect, stress, and anxiety compared to the control condition. However, we did not find effects of animal interaction on long-term memory, attentional control, or working memory. Thus, we replicated existing findings providing evidence that interacting with animals can improve affect, but we did not find similar improvements in cognitive performance. These results suggest that either our interaction was not of sufficient dose to elicit effects on cognition or the mechanisms underlying effects of human-animal interaction on cognition differ from effects generated by other cognition-enhancing interventions such as exposure to nature. Future research should continue to grow the connection between nature exposure and human-animal interaction studies to build our understanding of cognition in response to animal interactions.

Keywords: affect, animal-assisted interventions, cognitive performance, directed attention, human-animal interaction

Introduction

When many of us are frustrated or stressed, we turn to our pets for a reprieve. In fact, human-animal interactions (HAIs)—the mutual and dynamic exchanges between humans and non-human animals (Griffin et al., 2019; Thayer & Stevens, 2019)—can improve aspects of human health and well-being. This is of particular public interest in light of the rapidly increasing presence of dogs in hospitals, schools, and therapeutic contexts (Barker & Wolen, 2008; Friedmann & Son, 2009; Hosey & Melfi, 2014). These brief, unstructured interactions between individuals and unfamiliar dogs can evoke positive mood (Beetz et al., 2012; Crossman et al., 2020) and mitigate behavioral and physiological responses to stress (Odendaal & Meintjes, 2003; Lass-Hennemann et al., 2014; Barker et al., 2016; Fiocco & Hunse, 2017; Ein et al., 2018).

While affective and stress benefits of HAIs are well-studied, cognitive benefits are comparatively under-studied. Given the well-established relationships between affect, stress, and cognition (Forgas & Eich, 2013; Shields et al., 2016), the effect of HAI on affect and stress could trickle down to influence cognition. In particular, interventions such as exposure to natural landscapes, mindfulness, and yoga all improve affect and stress and can have positive benefits on aspects of cognition, especially executive functions such as attentional control and working memory (Bratman et al., 2012; Moynihan et al., 2013; Gothe et al., 2016).

A few studies have investigated effects of HAI on cognition. Trammell (2017) replicated effects of human-dog interactions on self-reported affect but found no differences between HAI and control groups' performance in a long-term memory paradigm. Long-term memory, however, is not a part of the executive function system, so it is perhaps unsurprising that it is not influenced by HAI. Working memory and attentional control, on the other hand, components of executive function (McCabe et al., 2010). Yet interacting with a dog does not seem to influence working memory (Gee et al., 2014, 2015; Hediger & Turner, 2014) or attentional control (Hediger & Turner, 2014). With so few studies, we face a need to quantify the influence of HAIs on cognition.

Our aim in the present study was to examine the influence of human-animal interactions on affect and cognitive performance in adults. In Experiment 1, we sought to replicate

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positive affective effects of HAIs observed in previous research (Handlin et al., 2011; Beetz et al., 2012; Thelwell, 2019; Crossman et al., 2020) and test whether HAI enhances executive functioning. We selected tests of attentional control and working memory and also a long-term memory task to assess cognitive performance outside of executive function. We hypothesized that HAI would evoke greater improvements in mood and executive function but not long-term memory compared to a control condition. We tested these hypotheses using a between-groups, pre-post intervention design where we administered affective and cognitive tasks both before and after either a 3-minute human-animal interaction or control activity. In Experiment 2, we sought to replicate our findings as well as self-reported stress- and anxiety-reducing effects of HAI observed in previous research (e.g., Grajfoner et al., 2017).

Experiment 1

Methods

Participants. We recruited participants who did not have a physical or emotional aversion to dogs (i.e., allergy, fear) from the University of Nebraska-Lincoln (UNL) Department of Psychology subject pool between Sep-Nov 2018. When recruiting participants, we did not include any information about dogs in the study description to avoid introducing self-selection bias into our sample. We also did not include references to dogs in the consent procedure to avoid building expectations about interacting with dogs. We collected data from 73 undergraduate students of whom 60 (82.2%) were female and who were on average 19.2 (SD = 1.4) years of age (Table S1). There were 39 individuals (53.40%) who currently lived with at least one pet in their primary residence and 62 (84.90%) who lived with at least one pet as a child. All participants received one hour of research credit in exchange for their participation.

Measures. Unless otherwise indicated, all stimuli were presented and all responses were collected with Psychopy version 1.90.2 (Peirce et al., 2019) on a computer with a 16 inch monitor in a private room with only the participant and experimenter present.

Affect. We assessed participants' affect with the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988). Participants viewed 10 positive and 10 negative adjectives (e.g., "excited", "disinterested") and rated each from one (*very slightly or not at all*) to five (*extremely*) as they pertained to how they felt (Cronbach's $\alpha_{\text{positive}} = 0.87$, $\alpha_{\text{negative}} = 0.86$).

Cognitive tasks. We administered four separate cognitive tasks: Deese-Roedinger-McDermott (long-term memory), Necker cube pattern control (attentional control), backwards digit span (working memory), and n-back (working memory).

Deese-Roedinger-McDermott. We used the Deese-Roedinger-McDermott long-term memory (DRM) paradigm to examine participants' capacity for long-term memory retention (Roediger & McDermott, 1995; McEvoy et al., 1999). During the presentation phase of this task, participants passively viewed a set of words presented one at a time. In the recall phase at the end of the experiment, participants indicated whether they recognized words that were or were not presented earlier (Table S2). We calculated d' to capture both correct recognitions and false alarm rates (Tajika, 2001).

Necker Cube Pattern Control. We used the Necker Cube Pattern Control Test to measure participants' attentional control (Orbach et al., 1963; Cimprich, 1993; Sahlin et al., 2016). The Necker cube is an optical illusion that consists of a cube outline that lacks visual cues to indicate its orientation (Figure S1a); with continued viewing, the viewer observes shifts in perspective between back-in-focus and front-in-focus. In this task, participants were prompted to observe the cube and record perceived perspective shifts for 30 s. After this initial trial, they were prompted to observe the cube in a second trial while purposefully holding each focus for as long as possible and minimizing shifts. We calculated the difference in the number of shifts reported between the first and second trials as a measure of participants' attentional control.

Backwards digit span. We presented participants with a backwards digit span task to measure their working memory capacity (Berman et al., 2008). In this task, participants viewed sequences of numbers presented individually for one second each, then wrote the sequence down on a sheet of paper in the reverse order from which it was presented (Figure S1b). If the participant correctly recorded an entire sequence in reverse order, that response was coded as correct. We measured performance by identifying participants' digit span *index*, or the greatest span they reversed correctly before failing two consecutive sequences of the same length (Schutte et al., 2017).

N-back. We administered an n-back task as an additional measure of working memory capacity (Cohen et al., 1994; Rich, 2007). In this task, participants observed a stream of phonologically distinct letters (B, F, K, H, M, Q, R, X; Kane et al., 2007) and responded when the current stimulus was presented n (two) trials prior (Figure S1c). We assessed participants' working memory performance on the n-back task by calculating d'.

Pet-related measures. In addition to standard demographic metrics (e.g., age and sex), at the end of the experiment, we asked participants whether they owned pets as a child and whether they currently owned pets. We also assessed participants' attitudes towards pets with the Pet Attitude Scale (PAS; Templer et al., 1981, 2004). Participants rated the extent to which they agreed with 18 statements (e.g., "House pets add happiness to my life, or would if I had one") from one (*strongly disagree*) to seven (*strongly agree*; Cronbach's α = 0.91). For those assigned to the HAI condition, we administered an additional questionnaire used by Gee et al. (2015) to assess participants' evaluation of the quality of the dog interaction. Participants rated from one (*strongly agree*) to four (*strongly disagree*), or *refused to answer/did not know* the extent to which they agreed with 11 statements (e.g., "I felt more relaxed when the dog was present") pertaining to their comfort, discomfort, ambivalence, and desire to interact with the dog.

Procedures. After participants arrived to the experimental session, they completed informed consent and sat calmly for three minutes to attain a resting state. Then, the researcher instructed the participant to begin the experiment on the computer at their desk. The researcher remained seated in the room throughout the duration of the experiment. The experiment was partitioned into three components, pre-condition, condition, and post-condition, which correspond to the time before, during, and after the animal-interaction or control experimental condition, respectively.

Pre-condition. Participants experienced the task set in the following order: PANAS, DRM (presentation phase), Necker cube, digit span, and n-back. We administered the affect task first to capture affect upon arrival, the DRM second to allow time to elapse between presentation and recall phases, then followed these with the remaining cognitive tasks in a fixed order for the sake of simplicity.

Condition. Participants were randomly assigned to either a three-minute animal interaction (*human-animal interaction* or *HAI*) or control condition before arrival.

HAI. We employed JRS's pet dog for every animal-interaction session. Before introducing participants to the dog, the researcher asked participants if they had a physical or emotional aversion to dogs; no participants reported any dog aversions. The researcher then brought in the dog, inviting the participant to pet and verbally interact with the dog calmly.

Control. Researchers provided participants with a sheet of paper with a full page of Latin text printed on it and instructed them to circle every "e" and "f" for "the next few minutes". Researchers emphasized that the task would not be graded and incorrect answers would incur no penalty. The researcher collected the sheet after the three minutes passed; no data were extracted from the activity.

Post-condition. Participants completed the tasks again in the following order: PANAS, Necker cube, digit span, n-back, and DRM (recall phase). They then completed the Pet Attitude Scale, and those assigned to the HAI condition also completed the animal experience questionnaire. All participants answered standard and pet-related demographic questions (e.g., age, number of pets owned) to conclude the experiment.

Ethics. All procedures were conducted in an ethical and responsible manner, in full compliance with all relevant codes of experimentation and legislation and were approved by the UNL Internal Review Board (protocol # 19552) and Institutional Animal Care and Use Committee (protocol # 1599). All participants gave written consent to participate, and they acknowledged that de-identified data could be published publicly.

Analysis. We analyzed data from 73 participants, with 36 participants experiencing the animal-interaction condition and 37 experiencing the control condition.

Participant characteristics. We compared pre-condition scores for affective measures, cognitive tasks, and pet-related measures (PAS, pet history) between animal interaction and control groups using independent samples t-tests (or Wilcoxon rank sum test in the case of test violations) to ensure that any experimental differences could not be attributed to participant characteristics. There were no significant between-group differences in any measure (Table 1).

Data analysis. We used R (Version 4.0.2; R Core Team, 2020) for all analyses (see Supplementary Materials for packages used). Data, analysis scripts, supplementary methods, tables, and figures, and the reproducible research materials are available in Supplementary Materials and at the Open Science Framework (https://osf.io/v7wxt/).

Condition effects. All tasks completed before and after the experimental condition (PANAS, Necker cube, digit span, n-back) were analyzed using analysis of covariance to examine the effects of condition on post-scores controlling for pre-scores (Table 2; O'Connell et al., 2017). We also calculated Bayes factors (BF) for the effect of condition, which provide the weight of evidence for the alternative hypothesis relative to the null hypothesis (Wagenmakers, 2007).

Moderation analyses. We conducted follow-up exploratory analyses to identify potential moderators of the relationship between animal interaction and cognitive performance. We constructed a single cognitive composite measure for this analysis from Necker cube, digit span, and n-back post - pre difference scores by averaging their z-scores (Van Hedger et al., 2019). We tested whether positive and negative affect change (i.e., post - pre difference scores; PANAS) and pet attitude (PAS) explained the relationship between experimental condition and composite cognitive performance change. For each moderation analysis, we used multiple linear regression with predictors *condition*, *moderator*, and *condition*$\times$*moderator* and outcome *post - pre cognitive composite*. We report model fit results alone, as no moderation model accounted for more than a negligible amount of the variance in the data.

Animal experience correlations. We also conducted follow-up exploratory analyses to identify correlations between the pet-related measures, affect, and cognitive performance com-

Table 1
Pre-condition scores

	Experiment 1					Experiment 2				
Measure	*n*	HAI *M*	Control *M*	*p*	*BF*	*n*	HAI *M*	Control *M*	*p*	*BF*
Pet measures										
Pet Attitude (PAS)	73	5.63	5.74	0.84	0.18	83	5.9	5.84	0.67	0.17
Pets now (N(%))	–	12 (33.3)	27 (73.0)	–	–	–	22 (52.4)	25 (61.0)	–	–
Pets as a child (N(%))	–	28 (77.8)	34 (91.9)	–	–	–	33 (78.6)	34 (82.9)	–	–
Affective measures										
Positive affect (PANAS)	73	2.83	3.04	0.24	0.44	83	3.09	2.96	0.45	0.30
Negative affect (PANAS)	73	1.51	1.45	0.79	0.17	83	1.4	1.44	0.96	0.17
Anxiety (VAS)	–	–	–	–	–	83	36.45	28.83	0.11	0.60
Stress (VAS)	–	–	–	–	–	83	39.36	33.73	0.18	0.34
State anxiety (STAI)	–	–	–	–	–	83	34	36.22	0.25	0.32
Trait anxiety (STAI)	–	–	–	–	–	83	38.55	40.88	0.37	0.25
Cognitive tasks										
Average shifts (NCPC)	70	-1.12	-0.76	0.63	0.27	80	-1.15	0.15	0.19	0.36
Index (Digit span)	70	6.12	6.69	0.25	0.31	77	6.13	5.84	0.43	0.21
d' (N-back)	73	-0.08	0.08	0.74	0.20	80	0.3	-0.09	0.19	0.49

posite.

Results

Affect. To test the effect of animal interaction on affect, we compared positive and negative PANAS scores following the HAI and control condition. Figure 1 shows the effect of condition on positive and negative affect (Table 2; Figure S2). Analyses of covariance indicate very strong evidence that positive affect is greater post-condition for those who experienced HAI than those who did not, controlling for pre-interaction scores ($F(1, 70) = 30.21$, $MSE = 0.15$, $p < .001$, $\hat{\eta}^2_G = .301$, $BF > 100$). For negative affect, on the other hand, there is not sufficient evidence to determine whether the log post-condition scores differed between control and HAI groups ($F(1, 70) = 4.32$, $MSE = 0.03$, $p = .041$, $\hat{\eta}^2_G = .058$, $BF = 1.47$).

Cognitive tasks. To test the effect of animal interaction on cognition, we compared scores on four cognitive tasks following HAI and control conditions. There is no evidence to suggest that animal interaction and control groups differed on any cognitive task post-condition (Table 2; Figures 2 and S3). Specifically, there is moderate evidence that there is no difference between control and HAI groups for d' in the long-term memory task post-condition scores ($W = 689.00$, $p = .639$, $r = 0.06$, $BF = 0.19$). Similarly, the analyses of covariance provide evidence of no difference between groups—controlling for pre-condition scores—for the number of switches in the Necker cube attentional control task ($F(1, 67) = 0.76$, $MSE = 12.85$, $p = .385$, $\hat{\eta}^2_G = .011$, $BF = 0.34$), the backwards digit span index for working memory ($F(1, 67) = 0.31$, $MSE = 1.98$, $p = .578$, $\hat{\eta}^2_G = .005$, $BF = 0.28$), and the n-back d' for working memory ($F(1, 70) = 0.12$, $MSE = 1.09$, $p = .726$, $\hat{\eta}^2_G = .002$, $BF = 0.24$).

Exploratory analyses. We tested affect and pet attitude as potential moderators of the effect of HAI on cognition. There is substantial evidence to suggest that there were no observable moderators on the effect of experimental condition on composite cognitive performance. Specifically, the moderation model did not outperform an intercept-only model for positive affect change ($R^2 = .01$, $F(3, 63) = 0.30$, $p = .828$; $BF = 0.04$), negative affect change ($R^2 = .02$, $F(3, 63) = 0.41$, $p = .746$; $BF = 0.04$), or pet attitude ($R^2 = .04$, $F(3, 63) = 0.86$, $p = .468$; $BF = 0.07$).

We found that pet attitude positively correlated with interaction quality measures from Gee et al. (2015) and the change in positive PANAS between pre- and post-condition (Figure S4a). The cognitive performance composite score did not correlate with any pet-related measures.

Discussion

Our first investigation of the effects of HAI on affect and cognition replicated effects of HAI on affect but did not evoke predicted improvements in cognitive performance. Specifically, a three-minute animal interaction bolstered positive affect more so than a control activity. But we did not observe improvements in attentional control or working memory. Our follow-up moderation analyses indicated that affect and pet attitude did not moderate a relationship between experimental condition and cognitive performance.

Table 2
Post-condition scores

	Experiment 1					Experiment 2				
Measure	*n*	HAI *M*	Control *M*	*p*	*BF*	*n*	HAI *M*	Control *M*	*p*	*BF*
Affective										
Positive affect (PANAS)	73	3.25	2.74	< 0.01	> 100	83	3.25	2.77	< 0.01	> 100
Log negative affect (PANAS)	73	0.21	0.29	0.04	1.47	82	0.13	0.25	< 0.01	9.25
Anxiety (VAS)	–	–	–	–	–	83	14.28	23.28	< 0.01	10.9
Stress (VAS)	–	–	–	–	–	83	17.12	25.44	0.01	3.03
Cognitive										
d′ (DRM)	72	0.16	0.07	0.64	0.19	82	-0.11	0.20	0.4	0.21
Attention shifts (NCPC)	70	-1.66	-2.41	0.39	0.34	80	-1.93	-1.51	0.52	0.3
Index (Digit span)	70	7.30	7.11	0.58	0.28	77	6.52	6.83	0.39	0.33
d′ (N-back)	73	-0.04	0.04	0.73	0.24	80	0.11	0.00	0.61	0.26

Note:
Post-condition scores controlling for pre-condition scores.

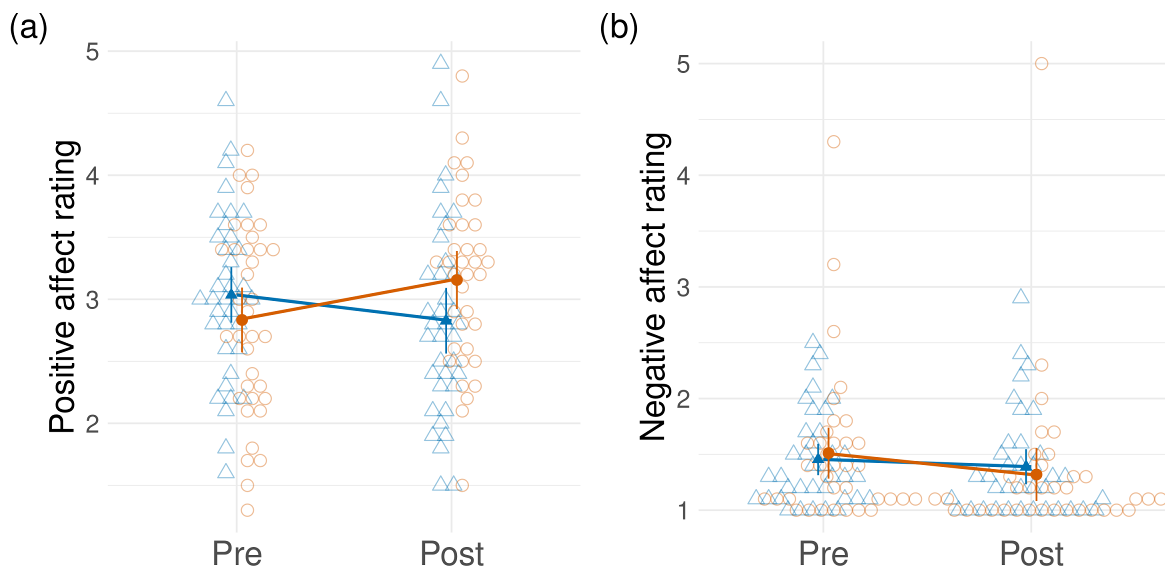

Figure 1. Affect scores pre- and post-condition for control and HAI (human-animal interaction) groups in Experiment 1. Scores show (a) positive PANAS ratings and (b) negative PANAS ratings. Open triangles represent individual control participant scores, open circles represent individual HAI participant scores, closed triangles and circles represent condition group means, error bars represent 95% confidence intervals.

Experiment 2

Our aim with Experiment 2 was to replicate Experiment 1 and extend the investigation to the influence of HAI on anxiety and stress. We assessed self-reports of anxiety and stress throughout the experiment using visual analogue scales. We again conducted follow-up exploratory analyses to identify potential moderators of the relationship between experimental condition and cognitive performance.

Methods

Participants. We recruited a new sample of participants between Nov 2018 to Apr 2019 from the University of Nebraska-Lincoln psychology subject pool who did not have a physical or emotional aversion to dogs (i.e., allergy, fear), again without providing information about dogs in the study description or consent materials. We analyzed data from 83 of 84 participants, excluding one person who progressed through the study without completing the experimental manipulation. Of the 83 eligible participants, 60 (79.5%) were female and were on average 19.9 (*SD* = 1.8) years of age (Table S1). There

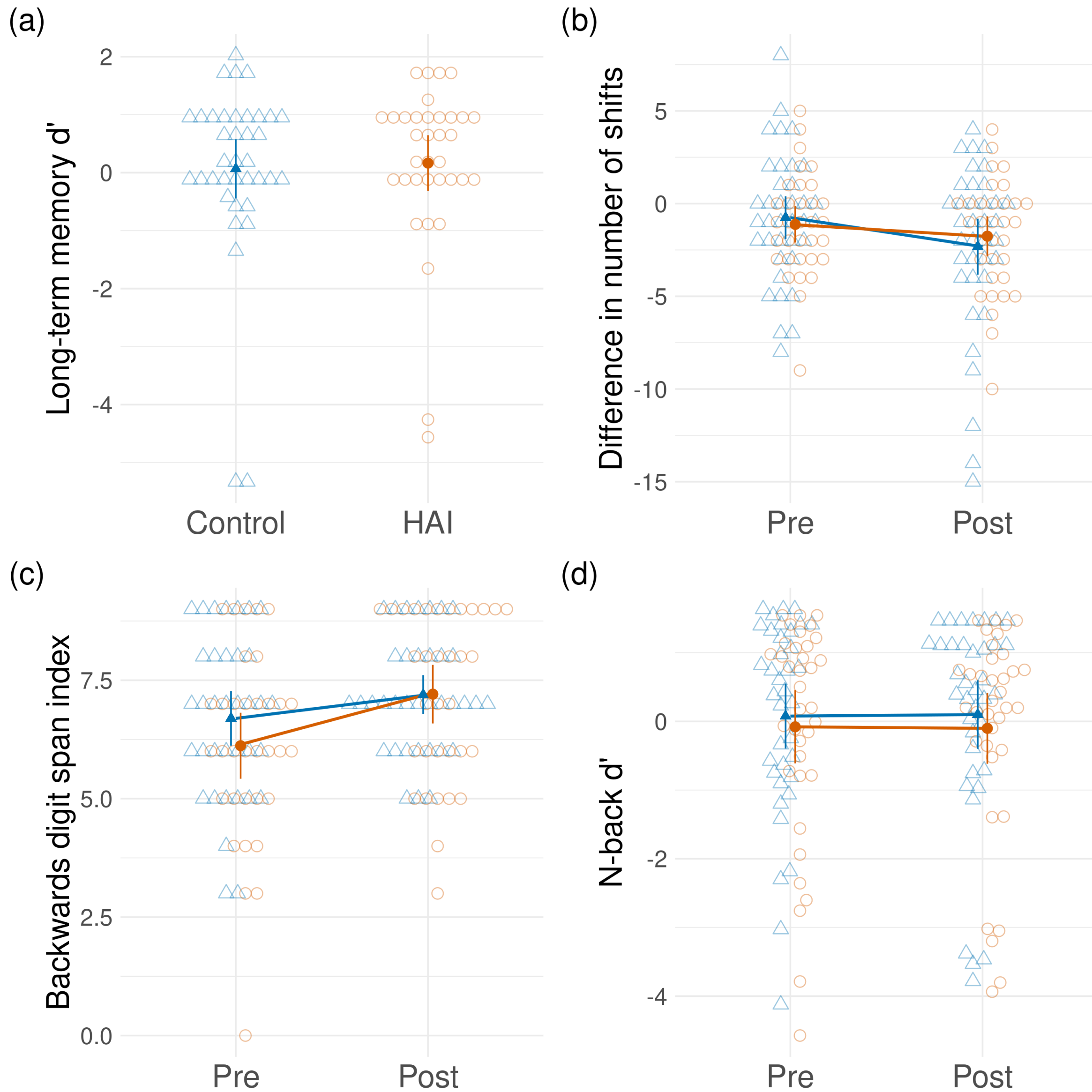

Figure 2. Cognitive performance for control and HAI (human-animal interaction) groups in Experiment 1. (a) Long-term memory d' from the Deese-Roedinger-McDermott task was calculated only post-condition. Pre- (Pre) and post-condition (Post) performance was calculated for (b) the difference in number of attentional shifts between the two Necker cube trials, (c) the index for the backwards digit span task, and (d) d' for the n-back task. Open triangles represent individual control participant scores, open circles represent individual HAI participant scores, closed triangles and circles represent condition group means, error bars represent 95% confidence intervals.

were 47 individuals (56.6%) who currently live with at least one pet in their primary residence and 67 (80.7%) who lived with at least one pet as a child. All participants received one hour of research credit in exchange for their participation.

Measures. In addition to the measures used in Experiment 1, we also explored the influence of human-animal interaction on affect through measures of anxiety and stress.

Affect. We assessed participants' present and general feelings of anxiety with the State and Trait Anxiety Inventory (STAI; Spielberger et al., 1999). Participants were presented with 20 statements (e.g., "I feel calm") and rated each from one (*not at all*) to four (*very much so*) to describe their feelings in the moment (*state*; Cronbach's $\alpha_{\text{state}} = 0.91$), then rated another set of 20 to describe their feelings in general (*trait*; Cronbach's $\alpha_{\text{trait}} = 0.94$). We also measured present feelings of anxiety with the single-item Anxiety Visual Analogue Scale (AVAS;

Cella & Perry, 1986). Participants indicated how anxious they felt in the moment via mouse-click between poles *not at all anxious* and *extremely anxious* on a 100-tick horizontal line. Participants also indicated how stressed they felt in the moment with the similar Stress Visual Analogue Scale (SVAS; Cella & Perry, 1986).

Pet-related measures. In addition to the pet-related measures used in Experiment 1, the researcher present additionally logged the amount of time the participant spent physically interacting with the dog.

Procedures. All procedures from Experiment 1 carried over to Experiment 2. However, instead of beginning with the Positive and Negative Affect Schedule, participants first completed Anxiety and Stress Visual Analogue Scales (*baseline*), then STAI prior to PANAS. Participants also completed Visual Analogue Scales immediately preceding the 3-minute animal interaction/control condition (*pre-condition* or *pre*), immediately following the condition (*post-condition* or *post*), and following completion of the experiment (*post+20*).

Analysis. Of the 83 eligible participants, 42 participants experienced the animal-interaction condition and 41 experienced the control condition.

Participant characteristics. There were no between-group differences in pre-condition scores for any affective measures, cognitive tasks, or pet-related measures (Table 1).

Data analysis. We utilized the same data analysis approach for Experiment 2 and also used this approach to analyze AVAS and SVAS (immediately before and after intervention). For moderation analyses, we tested all Experiment 1 moderators in addition to state and trait anxiety (from STAI), anxiety change from immediately pre- to post-condition (from AVAS), and stress change from immediately pre- to post-condition (from SVAS). We also included these additional measures in exploratory correlations between pet experience, affect, and cognition for those who experienced the animal interaction.

Results

Affect, anxiety, and stress. Figures 3a&b demonstrate the effect of condition on positive and negative affect (Table 2; Figure S5a&b). As observed in Experiment 1, analysis of covariance revealed that there is very strong evidence that positive affect was greater post-condition for those who experienced the animal interaction than those who did not, controlling for pre-condition scores ($F(1, 80) = 18.68$, $MSE = 0.25$, $p < .001$, $\hat{\eta}^2_G = .189$, $BF = 446.53$). Contrary to Experiment 1, there is strong evidence that log negative affect was lower for those in the animal interaction group than the control group ($F(1, 79) = 8.92$, $MSE = 0.03$, $p = .004$, $\hat{\eta}^2_G = .102$, $BF = 9.25$).

The effect of condition on anxiety and stress ratings is demonstrated by Figures 3c&d and S5c&d and Table 2. There is strong evidence that anxiety was lower post-condition for HAI compared to control ($F(1, 80) = 9.50$, $MSE = 172.00$, $p = .003$, $\hat{\eta}^2_G = .106$, $BF = 10.90$) and moderate evidence that stress was lower for those who experienced HAI than control ($F(1, 80) = 6.20$, $MSE = 228.68$, $p = .015$, $\hat{\eta}^2_G = .072$, $BF = 3.03$) when controlling for pre-condition scores.

Cognitive. There is no evidence to suggest that human-animal interaction and control groups differed on any measure of cognition (Table 2; Figures 4 and S6). Specifically, there is moderate evidence that there is no difference between HAI and control groups for the long-term memory task at post-condition ($W = 750.00$, $p = .401$, $r = 0.09$, $BF = 0.21$), the average switches in the Necker cube controlled attention task ($F(1, 77) = 0.43$, $MSE = 8.19$, $p = .516$, $\hat{\eta}^2_G = .005$, $BF = 0.30$), and the n-back working memory task ($F(1, 77) = 0.26$, $MSE = 0.92$, $p = .610$, $\hat{\eta}^2_G = .003$, $BF = 0.26$). There is not sufficient evidence to determine whether animal-interaction and control groups differed for the the digit span working memory task ($F(1, 74) = 0.76$, $MSE = 2.42$, $p = .385$, $\hat{\eta}^2_G = .010$, $BF = 0.33$).

Exploratory analyses. In line with Experiment 1, there is no evidence that the same variables nor the anxiety- and stress-related variables moderated the relationship between experimental condition and composite cognitive performance. Specifically, there is evidence that condition-cognition moderation models did not outperform intercept-only models for pet attitude ($R^2 =< .01$, $F(3, 68) = 0.07$, $p = .973$; $BF = 0.03$), positive affect change ($R^2 = .05$, $F(3, 68) = 1.15$, $p = .336$; $BF = 0.08$), negative affect change ($R^2 = .03$, $F(3, 68) = 0.64$, $p = .589$; $BF = 0.05$), stress change from pre- to post-condition ($R^2 = .02$, $F(3, 68) = 0.36$, $p = .781$; $BF = 0.03$), anxiety change from pre- to post-condition ($R^2 =< .01$, $F(3, 68) = 0.06$, $p = .979$; $BF = 0.02$), STAI-State anxiety ($R^2 = .04$, $F(3, 68) = 1.02$, $p = .390$; $BF = 0.08$), and STAI-Trait anxiety ($R^2 = .04$, $F(3, 68) = 1.00$, $p = .400$; $BF = 0.07$).

We replicated finding positive relationships between pet attitude and interaction quality and the change in positive PANAS and no relationships with cognitive performance composite (Figure S4b). Pet attitude also correlated with change in negative PANAS, trait anxiety, feelings of stress, and feelings of anxiety.

Discussion

Our findings from Experiment 2 provided nearly identical results to those we observed in Experiment 1. We observed once more that a three-minute HAI bolstered positive affect more so than a control; however, unlike in Experiment 1, HAI reduced negative affect. Further, human-animal interaction evoked lower stress and anxiety than the control. We did not observe differential improvements in attentional control or working memory between HAI and control groups. All follow-up moderation analyses mirrored those conducted in

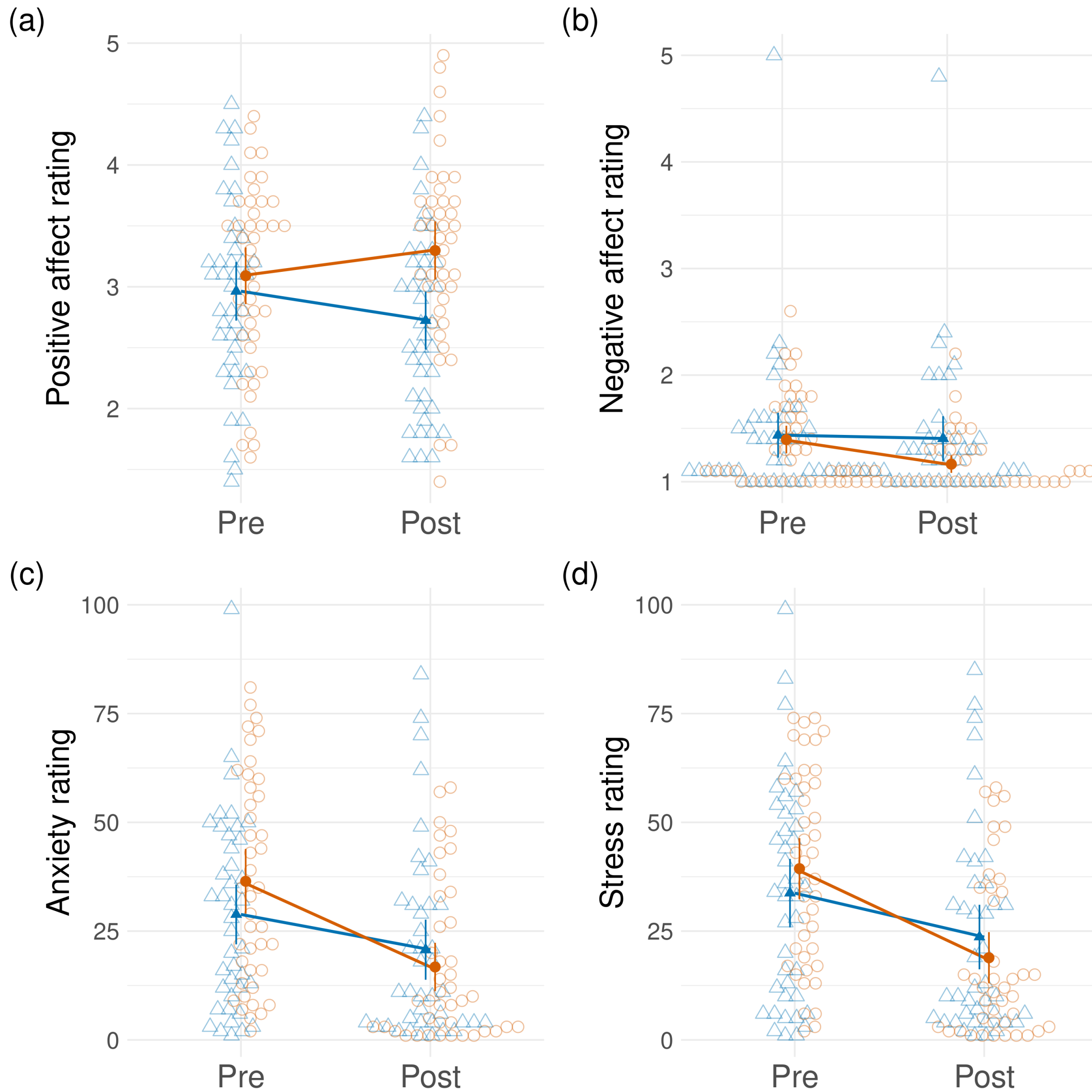

Figure 3. Affect scores pre- and post-condition for control and HAI (human-animal interaction) groups in Experiment 2. Scores show (a) positive PANAS ratings, (b) negative PANAS ratings, (c) anxiety ratings, and (d) stress ratings. Open triangles represent individual control participant scores, open circles represent individual HAI participant scores, closed triangles and circles represent condition group means, error bars represent 95% confidence intervals.

Experiment 1 such that affect change, ratings of anxiety and stress change, pet attitude, and state and trait anxiety did not influence the relationship between experimental condition and cognitive performance.

General Discussion

Taken together, our findings provide support for the efficacy of animal interaction on affect but no evidence to suggest that animal interaction influences executive function. Specifically, there was greater positive affect improvement in HAI compared to control groups in both Experiments 1 and 2. Though we did not have evidence of effects of HAI on negative affect in Experiment 1, this likely resulted from a smaller sample size. With the larger sample size of Experiment 2, we found that negative affect was reduced more in human-animal interaction than control groups. Anxiety and stress measures included in Experiment 2 captured more pronounced decreases in anxiety and stress for HAI compared to control groups. Nevertheless, measures of cognitive performance (long-term memory, working memory, and attentional control) did not

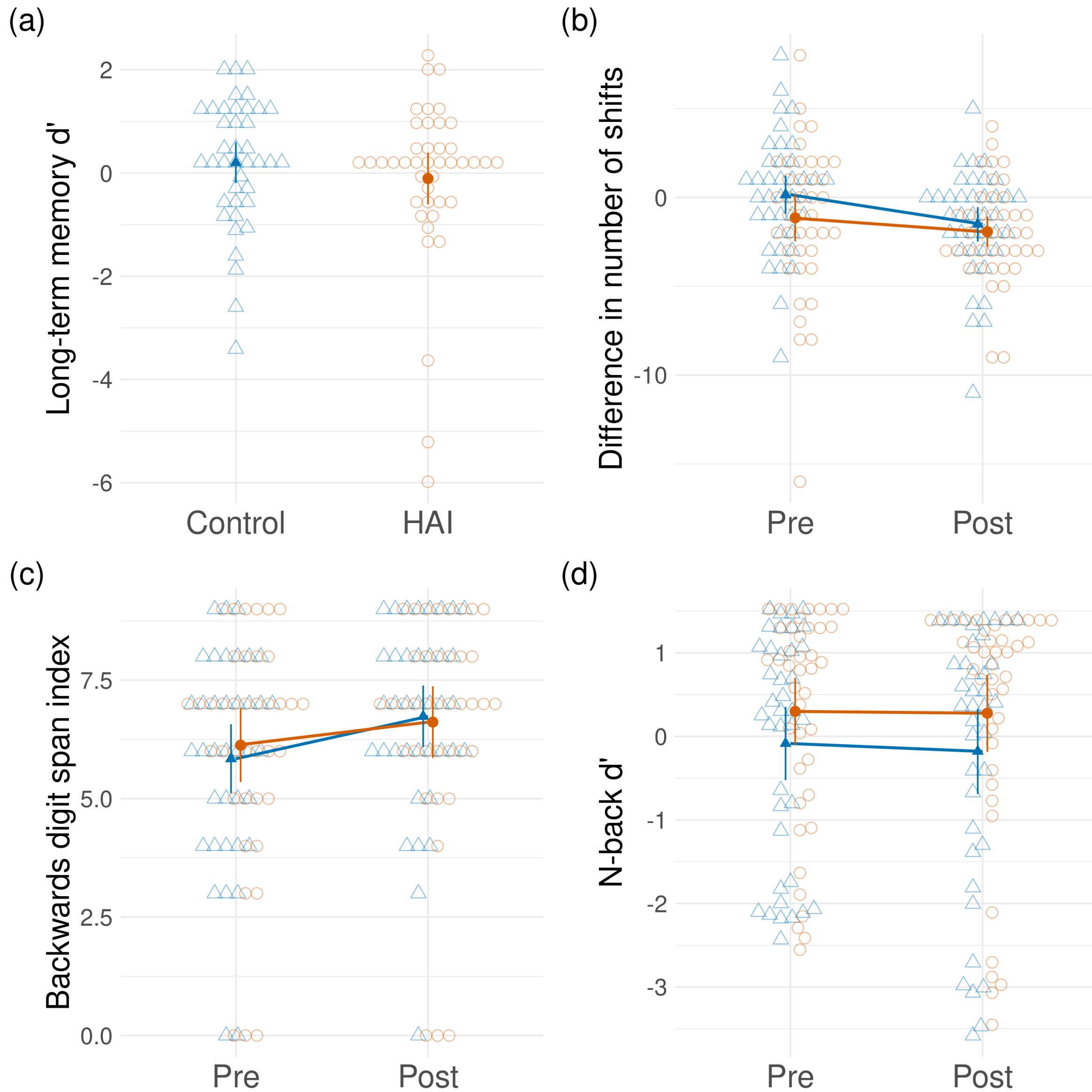

Figure 4. Cognitive performance for control and HAI (human-animal interaction) groups in Experiment 2. (a) Long-term memory d' from the Deese-Roedinger-McDermott task was calculated only post-condition. Pre- (Pre) and post-condition (Post) performance was calculated for (b) the difference in number of attentional shifts between the two Necker cube trials, (c) the index for the backwards digit span task, and (d) d' for the n-back task. Open triangles represent individual control participant scores, open circles represent individual HAI participant scores, closed triangles and circles represent condition group means, error bars represent 95% confidence intervals.

differ between HAI and control groups in Experiments 1 or 2.

Improvements in affect following brief interactions with an unfamiliar animal are commonly observed in experimental HAI manipulations (Beetz et al., 2012; Lass-Hennemann et al., 2014; Crossman et al., 2015; Grajfoner et al., 2017). Our evidence of a positive affect-boosting effect of animal interaction in both experiments validates our experimental design. We observed similar improvements in negative affect, anxiety, and stress in Experiment 2. Given the modest effect sizes observed here, three minutes may be a *minimally* effective interaction period. In fact, a recent dose-response investigation found that low doses of HAI (i.e., three minutes) elicited stress improvement in a majority of participants but that *maximal* improvement relative to time spent was reached with 15 minute doses (Fournier, 2019). Thus, longer interaction durations could induce changes in cognition not observed here.

Given the evidence that HAI influences affect and stress, which in turn influence cognition, we expected HAI to influence cognition. In particular, we expected HAI to influence executive functioning because HAI shares characteristics with another literature—exposure to natural landscapes—that does influence attentional control and working memory. Both HAI and exposure to nature have been tied to biophilia, the notion that humans have an innate affinity for life and life-like processes (Wilson, 2009). The biophilia hypothesis has spawned theories that (1) aesthetic features of nature reduce autonomic responses to stress (Ulrich, 1981) and (2) experiences in nature restore cognition by replenishing attentional capacities (Kaplan & Kaplan, 1989; Kaplan, 1995).

Because animals are an inherent part of nature, and HAI has been tied to biophilia as well, the nature exposure literature created a conceptual framework for predicting that HAI could influence executive functioning. However, our results—and the results of others (Gee et al., 2014, 2015; Hediger & Turner, 2014; Trammell, 2017)—run counter to the findings in the exposure to nature literature. This suggests two possibilities. First, there may just be a fundamental difference between exposure to nature and interacting with animals. Perhaps biophilia may elicit strong affective effects in both nature and animal interactions because they share a similar experiential component. However, the improvement in affect triggers downstream effects on cognition differently with animals and nature. Similarly, cognitive restoration observed following experiences in nature may not be attributable to biophilia alone because these effects are dependent on aesthetic features unique to natural environments, whereby cognitive improvement is facilitated by a more complex mechanism. In this case, future research should focus heavily on individual and cultural differences in measures that may moderate affective responses to animals, such as pet attitudes, to better understand the profile of individuals and groups best suited for animal interventions (Melson, 2011).

An alternative possibility is that our experimental paradigm did not trigger latent cognitive effects of HAI. Perhaps exposure to nature can reach the threshold for triggering these effects easily, but the threshold is higher or harder to reach for animal interactions. Thus, experimental design could be critical for studying HAI effects on cognition. Decisions about durations of exposure, number and order of cognitive tasks, and the presence of stress induction could be important in eliciting effects of animal interactions (Fournier, 2019; Griffin et al., 2019), as has been demonstrated in the exposure to nature literature (Shanahan et al., 2016; Cox et al., 2017; Stevenson et al., 2018; Stenfors et al., 2019). Further, individual and cultural differences in interactions with nature can moderate its effects on well-being. Similarly, individual and cultural differences in interactions with animals necessitates inclusion of measures that may moderate affective responses to animals, such as pet attitudes, to better understand the profile of individuals and groups best suited for animal interventions (Melson, 2011; McCune et al., 2014, 2020).

There is a gap in the human-animal interaction literature with regard to the place of HAIs in relation to cognitive performance. HAIs and cognitive performance are disproportionately understudied compared to the presence of HAIs in academic contexts (Gee et al., 2017). This has resulted in the experimental design attributes of interaction delivery, duration, and features to be a function of convenience and guesswork as opposed to driven by theory. The field is in need of a grounding framework to systematically grow this understanding. The neighboring domain of exposure to nature literature may provide a suitable, rigorously studied foundation (Kaplan & Berman, 2010; Bratman et al., 2012; Schertz & Berman, 2019). By taking advantage of the cognitive frameworks embedded within the exposure to nature literature, HAI practitioners provide themselves with the chance to standardize investigations of cognitive performance and draw theoretically sound inferences from their findings. Evidence of this sort is well-positioned to inform decisions regarding the implementation of HAIs in schools and other performance-dependent contexts for healthy and clinical populations. A deeper understanding of the influence of HAIs on cognition can also provide necessary footing to investigate whether observations are moderated by life experiences, such as growing up in an urban or rural community, race/ethnicity, socio-economic status, or personal history with animals. With affiliative animals like dogs so accessible in daily life, it is crucial to profile the restorative potential of these therapeutic agents by furthering research into the influence of animal interactions on cognition.

Conclusion

In the present study, we addressed a need to strengthen theory-driven tests of the influence of human-animal interaction on cognition. We observed positive effects of HAI in affective measures—including positive affect, negative affect, anxiety, and stress—but did not observe improvement in cognitive performance. Future research should continue to grow the connection between nature exposure and human-animal interaction studies to build our understanding of cognition in response to animal interactions.

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Conflict of interest

The authors declare no conflicts of interest.

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