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Feasibility of using ecological momentary assessment to measure the effects of interactions with pet dogs on psychophysiological reactivity in adolescents with social anxiety

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Abstract

Adolescence is a key developmental period for the onset of social anxiety, as it is a time of social transitions and stressors. Therefore, it is important to identify protective factors within the environment that can prevent and/or reduce the effects of social anxiety in addition to existing evidence-based treatments. The presence of a supportive pet dog may be one way of reducing the effects of acute social stressors for youth, but these effects have not been tested robustly in real-world settings. This study aimed to assess the feasibility of using ecological momentary assessment (EMA) to assess physiological responses to pet interactions in real-life scenarios among adolescents with social anxiety ($n = 37$). Results indicated that this protocol was perceived as feasible by youth participants and allowed for integration across different data streams. Participant use of a wearable sensor to collect electrodermal activity was generally successful, with an average of 12 h of data collected per participant. However, the use of a timestamp button

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AUTHOR CONTRIBUTIONS

Conceptualization (MKM, ECA); methodology (MKM, ECA); investigation/data collection (EKK, EDH, MKM); data curation (EKK, EDH); formal analysis (EKK, ECH, ECA); writing-original draft (EKK, MKM); writing - review & editing (EDH, ECA); supervision (MKM, ECA); project administration (MKM); funding acquisition (MKM, ECA).

CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

ETHICAL DECLARATION

The research procedures were approved by the Tufts University Institutional Review Board (protocol #1022).

on the sensor was not an effective strategy for data collection. These findings suggest that EMA using self-report activity diary data combined with continuous psychophysiological measurement using wearable sensors is generally a feasible person-centered approach for measuring adolescent-dog interactions in a way that maintains ecological validity.

Keywords

human-animal interaction; social anxiety; companion animals; adolescents; ecological momentary assessment; psychophysiology

Introduction

Social anxiety disorder is the most prevalent anxiety disorder in the United States (7–13% lifetime prevalence; Bögels *et al.*, 2010; Leichsenring and Leweke, 2017). Social anxiety is linked to a host of maladaptive developmental outcomes, including depression, substance abuse, and conduct disorder (Rapee and Spence, 2004; Bögels *et al.*, 2010). Given that social anxiety typically begins before the age of 18 years (Otto *et al.*, 2001), with an average age of onset of 13 years (Leichsenring and Leweke, 2017), adolescence is a particularly important developmental period for exploring innovative methods for intervening and preventing the negative sequelae that can result from social anxiety disorder. The COVID-19 pandemic further exacerbated rates of social anxiety through social isolation and lack of access to peers, as emerging research is showing that anxiety (including social anxiety) and depression have increased for youth during the pandemic (Hawes *et al.*, 2021). Furthermore, youth with social anxiety often lack access to mental health services (Colognori *et al.*, 2012); in one study nearly 80% of those under age 17 who were defined as needing mental health care services did not access them (Kataoka *et al.*, 2002). Therefore, there is a clear need to understand ways of further supporting youth with social anxiety.

DOG INTERACTIONS AND ADAPTIVE COPING WITH SOCIAL ANXIETY

Specifically, one area of particularly high clinical and practical value is identifying how to promote adaptive coping to help adolescents manage social anxiety, given its prevalence among adolescents and associated deleterious outcomes associated with social anxiety disorder (Leigh and Clark, 2018). Adaptive coping relies on both behavioral and cognitive strategies for managing stressors (Holahan *et al.*, 2017) and is a key feature of many treatment approaches for social anxiety. Human-animal interaction (HAI) with a pet dog may support two key elements of adaptive coping: support seeking (through comfort and instrumental support; Melson and Schwarz, 1994) and regulation of physiological arousal (Kertes *et al.*, 2017).

Companion dogs can provide social and emotional support through stable social contact, positive social interactions, and social facilitation (Melson and Schwarz, 1994; Wood *et al.*, 2005; Wood *et al.*, 2015). Youth often turn to their pets for emotional support and comfort when distressed (Melson and Schwarz, 1994; Zilcha-Mano *et al.*, 2012; Carr and Rockett, 2017). Attachment to a pet can serve as an emotional buffer during times of stress and has been associated with the utilization of socially-oriented coping skills (Mueller and Callina, 2014). Pet relationships often provide a way for youth to process their emotions during times of stress as an outlet for emotional disclosure. Pets can also be a catalyst for facilitating social interactions between people (Wood *et al.*, 2005; Wood *et al.*, 2015), further providing an avenue for both comfort and instrumental support.

Dog interactions may also contribute positively to the reduction of physiological arousal (Beetz *et al.*, 2012; Polheber and Matchock, 2014; Kertes *et al.*, 2017; Pendry and Vandagriff, 2020; Binfet *et al.*, 2021). Hyperarousal is a key feature of social anxiety (Banerjee, 2008), and the reduction of arousal can be one approach to regulating stress. Evidence has shown that during a social stressor, a pet dog can buffer perceived social stress (Kertes *et al.*, 2017) and support positive affect (Kerns *et al.*, 2018; Crossman *et al.*, 2020; Janssens *et al.*, 2021). Further, emerging evidence indicates that interacting with an animal can attenuate physiological responses related to stress by impacting the hypothalamic-pituitary-adrenal axis cascade in ways that support adaptive responses through support and appraisal modulation (Pendry and Vandagriff, 2020), as well as physical touch (Beetz *et al.*, 2012; Polheber and Matchock, 2014; Binfet *et al.*, 2021). For a recent systematic review between companion animal bonds and psychosocial outcomes among youth, see Groenewoud *et al.* (2023).

Despite existing evidence suggesting that a dog relationship may be a protective factor supporting key elements of adaptive coping in adolescents with social anxiety, there is a need for more sensitive methods to explore the role of HAI in this context. There have been mixed results in HAI literature about the effect of pets on youth, therefore more research is needed that explores this relationship on a more granular level. HAI research has historically relied heavily on self-report measures, and there is a need for expanding measurement and methodological approaches to capture objective responses to HAI (Rodriguez *et al.*, 2021). Self-report data, particularly retrospective self-report data, is limited in its ability to identify how specific behaviors or interactions relate to immediate psychological, behavioral, or physiological changes and could also be subject to potential bias (e.g., social desirability, demand characteristics, etc.), but at the same time provides access to valuable insights from participants (Haeffel and Howard, 2010). As such, one approach is to take more person-centered methodological approaches that can integrate real-time self-report data with other objective measures, such as physiological reactivity. Hyperarousal is a key feature of social anxiety (Banerjee, 2008), so therefore understanding what factors promote the reduction of arousal is an important indicator of adaptive coping.

Furthermore, little research in HAI focuses on the role of dogs in the contexts of daily life over a longer time period (i.e., not during an isolated acute stressor). Particularly for youth with social anxiety, interactions with dogs in more structured settings (i.e., therapeutic interventions with therapy dogs) may not be optimal as they involve social interactions with the animal handlers who are often not familiar to the participants. In fact, prior research with adolescents with social anxiety found that therapy dog interactions were not effective in reducing anxiety during an acute laboratory stress task (Mueller *et al.*, 2021). In the specific context of adolescent social anxiety, the relational nature of interacting with one's own dog in a familiar setting in daily life may have a more significant impact on adaptive responses to physiological arousal than contact with a novel therapy dog. Since a condition such as social anxiety can affect adolescent functioning across many different contexts (e.g., family interactions, peer interactions, coping with stressful events), we need to understand the complex interplay between the social and psychophysiological processes involved in interacting with a pet dog within a non-intervention setting.

ECOLOGICAL MOMENTARY ASSESSMENT IN HAI

Ecological momentary assessment (EMA) is a type of research methodology that allows for frequent, repeated sampling, allowing participants to report their experiences in real-time (Shiffman *et al.*, 2008). Given the immediate nature of the data collection, EMA is less prone to recall bias and has higher ecological validity, with participants engaging in real-life experiences (Shiffman *et al.*, 2008). This approach may be particularly useful in exploring the role of pet dogs in adolescents' daily lives, in that it allows participants to report their activities in a real-life setting, thereby capturing what youth are doing with their dogs in their daily lives (vs. in a structured laboratory setting). Furthermore, EMA can involve collecting continuous physiological data as well as participants' self-report data regarding their behaviors, emotions, and interactions. EMA using mobile phone platforms combined with wearable devices for physiological data collection has been successfully used in children and adolescents with high levels of compliance (Wen *et al.*, 2017). There are relatively few studies of EMA in the context of HAI research, although those who have used this methodology have found it to be successful (e.g., Janssens *et al.*, 2021). However, to our knowledge, there are no applications of EMA in the context of companion pets for youth participants with anxiety. In order to inform the use of larger-scale studies of HAI in adolescents with social anxiety, there is first a need to understand the feasibility, benefits, and challenges of this approach in this particular population.

THE PRESENT STUDY

This study tested the feasibility and usefulness of using EMA to measure HAI through the combination of a mobile phone app and a wearable physiology sensor in a sample of adolescents with social anxiety. We simultaneously assessed participants' self-reported experiences with their pet dog(s) as well as social interactions along with continuously collected peripheral physiology data (via electrodermal activity) to explore if these data sources could be combined in future studies to test differential patterns of psychophysiological arousal before and after dog interactions. Specifically, we assessed (1) the feasibility of collecting activity diary data on dog interactions, social interactions, and physical activity through an EMA mobile app over two 24-hour periods in an adolescent sample, (2) the feasibility of integrating self-report EMA data with electrodermal activity data to explore patterns of arousal before and after dog interactions, and (3) participants' perceptions of ease of use of the EMA app and the wearable sensor to inform future study design. We hypothesized that collecting continuous physiology data would be feasible in an adolescent population and would provide data to assess, with precision, the immediate effects of interacting with a dog on bodily arousal.

Methods

All study procedures were approved by the Tufts University Institutional Review Board (protocol #1022). Youth assent and parental consent were obtained prior to participation in both the screening survey and the full study protocol. Data were collected from April 2021 to September 2022.

PARTICIPANTS AND RECRUITMENT

Participants were recruited for this study using convenience sampling from across the United States via social media as well as an existing participant database from the research team's lab. Interested participants and their parents/guardians who contacted the research team were sent a link to an online eligibility screening survey via the REDCap (Research Electronic Data Capture) tools hosted at Tufts Medical Center. Inclusion criteria included: being an adolescent aged 14–17 living in the United States, having at least one pet dog at the time of the study, not having allergies to adhesives (due to the wearable wristband sensors), and having access to an internet-enabled mobile phone or tablet. We also screened participants for social anxiety using the Social Anxiety Scale for Adolescents (SAS-A; La Greca and Lopez, 1998), and enrolled participants who reported high levels of social anxiety as measured by scoring ≥50 on the SAS-A. We also enrolled five participants who reported low levels of social anxiety (<36) on the SAS-A as a comparison for feasibility.

Unlike other anxiety disorders, social anxiety is particularly common among adolescents and average onset occurs during early- to mid-adolescence (Rapee and Spence, 2004). Early adolescence is characterized by a shift in autonomy and independence that is marked by increased distance from family/parent relationships (Laursen and Hartl, 2013) and adolescents spend more time with peers, and less time with family (Larson and Richards, 1991). Therefore, the age range of 14–17 was chosen to capture a developmentally important time period for social interactions and social anxiety.

Eligible participants and their parents/guardians were then contacted to review the consent and full study information with a trained researcher over Zoom using a secure university account. The researcher provided the parental consent and youth assent forms prior to the consent meeting for families to review. The researcher then reviewed all the study procedures and consent documents with teenagers and their parents/guardians. If they decided to participate, they signed the consent forms and returned them to the study team. The sample consisted of 41 consented participants, 37 of those participants completed the study protocol. Of the 37 participants, 35 completed the pre-study questionnaire that contained information about pet relationships and coping strategies. Due to this study's focus on feasibility and that we are not specifically testing hypotheses, we did not conduct an a priori power analysis to determine sample size.

Participants (n = 37) ranged in age from 14 to 17 and the average age was 15.76 (SD = 1.25). Seventy percent (n = 26) of participants identified as female, 22% (n = 8) as male, 5% (n = 2) as non-binary, and 3% (n = 1) preferred not to say. The majority of participants (86%, n = 32) of participants identified as white, 8% (n = 3) preferred not to say, 5% (n = 2) identified as Black/African American, 3% (n = 1) identified as Asian, and 3% (n =

1) identified as more than one race. Additionally, 5% of participants identified as Hispanic/Latino/a (n = 2), and 95% (n = 35) selected that they did not identify as Hispanic/Latino/a. Thirty-two participants reported high levels of social anxiety as measured by scoring ≥50 on the SAS-A in addition to the five comparison participants who reported low levels of social anxiety (<36).

PROCEDURE

Consenting participants were mailed a data collection package, which included printed study protocol instructions (including a QR code enabling download of the EMA mobile phone app), an Empatica E4 sensor (which is a wearable wristband) with Biopac electrodes (see Measures for additional information), and a stamped and addressed return envelope for the study materials. A member of the research team then scheduled a meeting – either via Zoom or telephone – to review how to use the E4 sensor, assist with downloading the data collection app, and review the overall study protocol, which included the three elements outlined below.

Part 1: Pre-study questionnaire—Participants were emailed a pre-study questionnaire to complete via the online survey platform Qualtrics. Participants were asked to enter a unique ID given to them by the research team and answer questions regarding their relationships with their pets and the types of proactive coping strategies that they used to manage anxiety.

Part 2: EMA activity diary—Participants completed an EMA activity diary during the two-day study period, which occurred an average of 15 days (range 2–42 days) after being sent the Part 1 questionnaire (dependent on participants' schedules and when they wished to complete Part 2). The activity diary was collected in real-time through the LifeData mobile app, which is a secure HIPAA-compliant experience sampling platform specifically designed for use in clinical trials and is compatible with both iOS and Android phones (Available at: https://www.lifedatacorp.com/). The data collected through the LifeData app were timestamped, allowing for integration with the wearable sensor measurements.

Participants were asked to record any interactions with their dog, another person, or when they engaged in a physical activity (see Measures for additional information). When these interactions took place, they were asked to: (1) press the wearable sensor time marker button at the start and end of interactions/activity – if they forgot at the start of the activity, they were asked to still press the button at the end of the activity, (2) complete the EMA prompts pertinent to the interaction, which involved recording the time, duration, and nature of social interactions, dog interactions, or physical activities. Participants were automatically reminded at 9 AM, 1 PM, 5 PM, and 9 PM local time to log any interactions that happened within the last 4 h that were not already logged. At the end of each day, they were instructed to log the end time under the appropriate session option.

After participants ended the second study day in the LifeData app, they were prompted to complete a brief feasibility questionnaire in the app assessing ease of completing the protocol, perceived accuracy of recall, and feasibility of wearing the Empatica wearable sensor. Participants were then debriefed and sent study incentives (a $65 USD gift card) via email.

Part 3: Physiological measurement—Electrodermal activity (EDA) was recorded as skin conductance level (SCL) using Empatica E4 wearable sensors (Garbarino *et al.*, 2014). Participants wore the wearable sensor wristbands on their non-dominant hands. EDA was measured using 7 cm long wire leads connecting the E4 wearable sensor to disposable, pre-filled (0.5% chloride salt) Ag/AgCl (11 mm inner diameter) Biopac electrodes, which were attached to the palm of the participant's non-dominant hand to improve recordings. Participants were instructed to remove the sensor if they were going to be submerged in water (e.g., swimming, bathing), and were provided with extra electrodes if replacement was necessary. At the end of each day prior to going to bed, participants were instructed to remove the E4 sensor and power it down to save battery.

MEASURES

Screening survey

Social Anxiety Scale for Adolescents (SAS-A): The SAS-A, developed by La Greca and Lopez (1998), was used to screen participants for social anxiety. As recommended by La Greca (1999), those scoring 50 or higher were considered high anxiety, and those scoring 36 or lower were considered low anxiety. The SAS-A was designed for use in adolescence and has been validated extensively across many samples and in multiple languages (La Greca and Lopez, 1998; Garcia-Lopez *et al.*, 2011). The SAS-A contains 18 items that include three domains of social anxiety: fear of negative evaluation from peers, social avoidance and distress in new situations, and generalized social avoidance. The SAS-A demonstrated excellent reliability in this sample (α = 0.93).

Pre-study questionnaire

Pet relationships: Participants were asked how many pets were in their household, and the species of those pets. The Network of Relationships Inventory–Pet (NRI–Pet) was used to assess overall relationships with pets (Cassels *et al.*, 2017). The NRI–Pet is a 12-question measure validated for use in youth samples that contains four factors each containing three items: satisfaction, companionship, disclosure, and conflict. The items are scored on a 5-point scale which ranges from 1 (not at all/a little bit or none) to 5 (very much/a lot). Cronbach's alpha for each of the subscales demonstrated acceptable reliability: satisfaction (α = 0.81); companionship (α = 0.81); disclosure (α = 0.89); conflict (α = 0.87).

Coping with stress: Participants were asked to indicate how much they used specific adaptive coping strategies when feeling stressed out. Response options included being alone, spending time with family, spending time with a close friend, spending time with a pet, posting on social media, watching favorite movies/shows, exercising/sports, playing video/online games, spending time outdoors, creating content for social media, and video hangouts. The 11-item measure is scored on a 4-point scale, ranging from 1 (mostly disagree) to 4 (mostly agree), with an option to select "Does not apply to me." This measure was adapted from a prior study on youth-pet interactions that assessed similar coping strategies (e.g., Charmaraman *et al.*, 2022).

Activity diary prompts—Using an adaptation of a similar protocol used in prior research (Joseph *et al.*, 2014; Thomas *et al.*, 2019), adolescents were asked to record their interactions with their dogs, other people, and physical activities. There were the following sets of questions labeled within the app on which participants could click and complete when the interactions/activities took place.

Dog interaction: (1) what time they interacted with the dog; (2) how long was the interaction; (3) what were they doing with their dog during the interaction (e.g., petting, walking, feeding, playing); and (4) who else was present (parents, friends, other people, other pets).

Social interaction: (1) what time the interaction took place and duration of interaction; (2) who was present during the interaction; (3) where the interaction took place (e.g., in person, online, phone); (4) if the dog was present during the interaction; and (5) four Likert scale items rated on a 5-point scale from 1 (strongly disagree) to 5 (strongly agree) regarding the quality of the interaction (if they were treated badly during the interaction, if there was a conflict during the interaction, if the interaction was pleasant, if the interaction was enjoyable).

Physical activity: (1) start time and duration of activity; (2) type of activity (e.g., running, playing a sport); and (3) if anyone else (including the dog) was present during the activity.

Feasibility questionnaire—At the end of each participant's 2-day data collection period, they were asked to complete a brief survey in the LifeData app assessing their perceptions of the ease of completing the protocol. They were asked to rate how easy it was to use the LifeData app and the Empatica E4 sensor (each on a scale from 1 [Strongly disagree – not easy] to 5 [Strongly agree – easy]). Participants reported if they experienced any problems with using either the app or the wearable sensor (yes/no) and if yes, to indicate what the problems were. They were also asked to report their perception of how easy or hard it was for them to accurately report their interactions and activities on a scale from 1 (very easy) to 10 (very challenging). Finally, we included an open-response option asking participants to share any thoughts about the study procedures, including the format of reporting interactions and activities.

Electrodermal activity (EDA)—Heart rate, temperature, and accelerometer data were also collected by the Empatica E4 sensor. Skin conductance level was recorded at 4 Hz by the E4 sensor which was used as our measure of EDA. A similar protocol yielded success in our team's past research on animal-assisted interventions and social anxiety in adolescents (Mueller *et al.*, 2021), and the E4 has been demonstrated to reliably capture physiological changes associated with stress response (Ollander *et al.*, 2016).

DATA ANALYSIS

Data from the pre-study questionnaire as well as the feasibility questionnaire were analyzed using descriptive statistics/frequencies. Daily diary activities were also reported using frequencies, as well as calculating the duration of different types of activities (i.e., dog interactions, social interactions, physical activity) using the time stamps associated with each activity reported. In three cases, participants recorded the same activity via both a user-entered session and through the prompt-notification session, creating a duplicate. Prior to analysis, these three duplicate activity cases were identified by concordant time stamps and removed from analysis. We compared the valence of social interactions (positive to negative) between interactions where a dog was present compared to those not present using an *F*-test.

To assess the feasibility of using wearable sensors to measure physiological activity during daily interactions with pets, we calculated the percentage of usable data during the two 24-hour recording periods. EDA data were screened for quality using an automated procedure developed and validated by Kleckner *et al*. (2018). Based on this procedure, EDA was screened for quality based on four criteria: EDA out of range, EDA changing too quickly, temperature out of range, and proximity to (within 5 seconds) invalid portions based on the first three criteria. These criteria were designed to capture the times the sensors were not worn, as well as instances of movement-related artifacts. The percentage of usable data each day was used as an indicator of feasibility for this measurement method in the context of youth companion-animal interactions.

To explore if using the wearable sensor's marker function to indicate when dog interactions started and stopped, we compared how closely the marker presses were aligned with corresponding activity time stamps from the LifeData app, categorizing them as being within 2 min of each other, 2–5 min apart, or more than 5 min apart. Integration of EDA data with daily diary activity was analyzed by aligning activity diary data via timestamps with the EDA activity and plotting these two sources of data on a figure for visual inspection of patterns of EDA before and after different activities.

Results

PET RELATIONSHIPS

In addition to dogs, participants reported the following pets in their households: cats (n = 12), horses (n = 1), fish, birds, reptiles, rabbits, or small rodents (n = 11), cows, pigs, goats, or other large animals (n = 1), and other (i.e., hedgehog; n = 1).

The possible scores for each NRI–Pet subscale range from 3 to 15. In response to the satisfaction subscale, participants were very satisfied with their pet relationships, responding with an average score of 14.00 (SD = 1.41). For the companionship subscale, participants responded with an average score of 10.91 (SD = 2.50). Participants responded with an average score of 7.71 (SD = 3.63) for the disclosure subscale and an average score of 5.06 (SD = 2.36) for the conflict subscale.

SELF-REPORTED COPING STRATEGIES

Participant responses to the coping measure can be found in Table 1, with spending time with a pet reported as the most frequently used strategy.

ECOLOGICAL MOMENTARY ASSESSMENT – DAILY DIARY ACTIVITY

Participants reported in the EMA app the time and duration of their activities during the 2-day study period. Of the 37 participants enrolled in the study, 31 (84%) completed the full 2 days, 6 (16%) completed 1 day or less. There were no meaningful differences in completion rates between high and low-anxiety participants with both groups showing high levels of completion; 26 (81%) of high-anxiety participants completed the full 2 days; 5 (100%) of low-anxiety participants completed the full 2 days. Of the 140 dog interactions reported, 136 of those interactions had duration data logged for a total of 3516 min (58 h, 36 min). Participants reported interacting with their dogs for an average of 51.2 min per day (range 0–372 min), and the average individual interaction lasted 25.9 min. Descriptive statistics for minutes of duration per day for each type of activity are reported in Table 2. The characteristics of dog interactions (e.g., location, type of interaction, other people present) are reported in Table 3.

For social interactions with other people ($n = 186$), participants reported 76 (41%) interactions with parents, 47 (25%) with siblings, 76 (41%) with friends, 18 (10%) with other family members, 18 (10%) with teachers, and 38 (22%) with others. Participants reported the location of the interaction and 159 (85%) of social interactions were in person, 10 (5%) were online, 11 (6%) were over the phone (text, FaceTime, phone call), 4 (2%) were on social media, and 2 (1%) other. For 48 (29%) of social interactions, participants reported their dog being present. The average valence of positivity/negativity of social interactions was $M = 4.10$ (range: 1 [negative] to 5 [positive]). There was no significant difference ($F = 0.004$, $p = 0.95$) in the average valence of social interactions between people with the dog present for the interaction ($M = 4.29$, $SD = 0.78$) and those without the dog present ($M = 4.04$, $SD = 0.80$).

For physical activities, 17 (36%) reported walking, 12 (26%) running/jogging, 4 (9%) playing a sport, 4 (9%) swimming, 3 (6%) biking, and 17 (36%) other. For 6 (13%) physical interactions, participants reported their dog being present.

ELECTRODERMAL ACTIVITY (EDA)

Of the 36 participants with EDA data, 34 (94%) completed both days of EDA collection, and 2 completed 1 day (6%), for a total of 70 days of EDA data collection. Based on Kleckner *et al.*'s (2018) automated screening procedure, out of the 70 total collected study days, the results indicate that 21 days (30%) contained greater than 80% usable data, 16 days (23%) contained 60–80% usable data, 10 days (14%) contained 40–60%, 13 days (19%) contained 20–40% and 10 days (14%) contained less than 20% usable data. The median percentage of valid data per day was 61.8% ($M = 57.9\%$, $SD = 30.7$, range 0–99.9%). In total, about 443 valid hours of EDA data were collected, with an average of about 12 h ($SD = 7$, range 0–29 hours) of usable data per participant. While some participants had segments of unusable data, overall we were successfully able to capture EDA data for substantial periods of time for most all participants.

Participants were asked to use the Empatica E4 "marker" feature (pressing a button on the wristband) to indicate when their interactions with their dogs started and stopped. To assess the feasibility of using this marker feature to accurately indicate dog interactions, we analyzed how closely aligned the E4 marker presses were with when participants reported the interactions in the LifeData app via timestamp data. Of the 334 interaction events reported in the EMA app across all participants, 67 (20%) were within 2 minutes of a marker, 32 (10 %) were between 2 and 5 minutes of a marker, and 235 (70%) were more than 5 minutes away from a marker.

DATA INTEGRATION

To assess the feasibility of integrating data integration from the EMA app and wearable sensor technology, to explore patterns of psychophysiological reactivity before and after dog interactions, we merged the daily diary interactions logged on the app with participants' EDA data using timestamps. Participants logged the time interactions occurred via the EMA app, which was then overlaid onto the EDA data. Figures 1 and 2 illustrate an example of data integration from participants. Figure 1a and b shows examples from two different participants of a full day of EDA (measured via skin conductance level [SCL]) integrated with activity timestamps from the EMA data collection. In Fig. 1a, the participant logged two dog interactions and three social interactions in the EMA app as noted by the blue and green lines. In Fig. 1b, the participant logged EMA social interactions, as well as E4 time markers. Figure 1b also demonstrates an example of a participant taking the wristband off, as participants were instructed not to wear the wristband in water. Figure 2 shows a smaller time segment in greater detail for a participant to illustrate the quality of EDA data. The blue line represents the time logged via the EMA app for an interaction the participant had with their dog. The quality of the EDA data before and after the interaction marker is high, showing that this is a feasible method for exploring patterns of physiological reactivity before and after an interaction. Overall, the use of both the E4 and EMA app was successful in data collection and worked congruently.

FEASIBILITY QUESTIONNAIRE

In the feasibility questionnaire, participants ($n = 33$) rated how easy it was to use the LifeData app on a scale from 1 (not easy to use) to 5 (easy to use), with an average rating of 4.24 ($SD = 0.90$), range 2–5. Only 1 (3%) of participants reported having a problem with the app. On average, participants reported that rating interactions on the app were relatively easy (average rating: 3.88, $SD = 2.45$), with a range of 1 (very easy) to 10 (very challenging). Comments about the ease of rating interactions included concerns about remembering what time interactions took place and remembering to log interactions as they were happening.

For the E4 sensor, participants rated how easy it was to use the sensor on a scale from 1 (not easy to use) to 5 (easy to use), with an average ease of use rating of 3.59 ($SD = 1.13$) for the Empatica sensor, with a range of 2–5. Only 11 (33%) of participants reported having a problem with the sensor, which included nine comments about the adhesive palm sensor pads not sticking/falling off the hand, and two issues regarding battery life. Other open-ended comments included, "reporting interactions and activities was easy. I did not have any challenges using the app or wristband" and "It was pretty easy to use. I had a bit of trouble trying to get the things to stick to my hand but that was the only issue."

Discussion

The purpose of this study was to descriptively assess the feasibility of using EMA to assess adolescent-dog interactions via a mobile app and wearable sensor, and whether the data generated from this protocol could be integrated in a way that would be useful for understanding patterns of psychophysiological reactivity before and after dog interactions. Overall, the results suggested a high level of feasibility and utility in using this approach with teenagers and their pet dogs.

With regard to feasibility, a high percentage of participants were able to complete both data collection days for both the EMA app (86%) and the wearable sensor (94%). Adolescents were able to report a range of dog interactions, social interactions, and physical activity, reflecting a breadth of experiences. Furthermore, despite the potential for movement artifacts and difficulty with physiological data collection in a real-world setting, the wearable sensors generated a high percentage of usable data. HAI research that has incorporated physiological measures has often relied on heart rate and salivary cortisol, and this study provides an alternative or complementary approach that may be an effective measurement tool in some settings. Salivary cortisol is a widely used approach for measuring arousal, but does not allow for the measurement of continuous physiological responses and requires a high level of participant or researcher engagement to collect saliva at appropriate intervals. Using EDA as an alternative or additional approach for measuring continuous psychophysiological reactivity may be a way to assess how specific interactions between youth and pets may be linked to continuous physiological changes.

Integrating the EMA and EDA data was successful, with visualizations showing that the EMA interactions were able to be overlaid on the EDA data to show patterns of psychophysiological reactivity before and after the start of dog and social interactions. This data integration will be a useful tool in future hypothesis-testing research to assess increases and decreases in reactivity before and after dog interactions. This will enable researchers to explore when youth may be seeking out their dogs for contact (e.g., if there are consistently higher levels of EDA prior to an interaction, or if social interactions appear to trigger physiological reactivity), as well as what the psychophysiological effects of those interactions may be (such as a decrease in EDA after initiating a dog interaction). Combining self-report EMA data with EDA data allows researchers to explore in more time-sensitive detail the antecedents and consequences of dog interactions in real-life settings.

While the integration of the EMA app data and the EDA data was successful, the use of the sensor "marker" feature did not appear to be an accurate way to track interactions. The majority of participants did not press the E4 marker within 5 min of logging the interaction time in the EMA app. This suggests that participants either forgot to press the marker during an interaction, or they estimated the time of day the interaction took place incorrectly. This suggests the need for accurately measuring when interactions take place. Additionally, segments of data collected by the wearable sensor were considered invalid following Kleckner *et al.*'s (2018) automated screening procedure. While not all data collected was usable, the benefit of using continuous data collection is the large amount of data collected per participant (12 hours of data on average per participant) and the ability to use the EMA data in conjunction with the EMA data. While there is not a well-established "cut off" for acceptable data percentages of EDA, our ability to integrate the EDA and EMA data in a meaningful way for substantial portions of time for most participants suggests this approach is feasible for generating useful information.

From the participants' perspective, they perceived the study protocol as relatively easy for them to complete. Some participants reported challenges with the adhesive sensor pads not sticking to their palms, but these challenges did not seem to impact the data quality or ability to complete both days of the data collection period. They noted some learning curves in figuring out how to use the wearable sensors, underscoring the importance of high-quality training sessions prior to starting the study. Participants also indicated that it was not always easy to remember what time dog or social interactions took place and the importance of remembering to log interactions as they happened. This finding suggests that future research should explore the relative usefulness of user-initiated entries as compared to notification-initiative entries, and whether variable or fixed prompt schedules are more effective in this population (Vachon *et al.*, 2019).

It is important to note that there was some attrition from consent to engaging in the study procedure (four participants dropped out after consenting). In all of these cases, the participants did not complete the study protocol due to adolescent/family scheduling and not being able to find time to complete the study. This suggests that it may be necessary to work with families to ensure that the study protocol is designed in a way that more flexibly integrates into youth's schedules. This will be critical in allowing participation for diverse youth and families and to ensure that participation is not limited to youth who have high levels of discretionary time or parental support.

Some substantive descriptive patterns emerged from the data which may inform future research questions using this type of methodology. Participants reported that spending time with pets was a key aspect of how they coped with stress and anxiety and also reported relatively high levels of relationship quality. There was a wide range of time spent with dogs per day, from "no time at all" to "more than 6 h per day." Relationship quality and/or time spent with a pet are crucial factors in predicting youth outcomes (e.g., Marsa-Sambola *et al.*, 2017; Hawkins *et al.*, 2022). Exploring these variables as moderating or mediating factors for how dog interactions may impact stress responses should be a priority in future work. Furthermore, teenagers spend over 2 hours per day socially interacting with other people, and therefore co-occurrence of dog and social interactions may be relevant to assess.

STUDY LIMITATIONS

This study was intended to assess the feasibility and usability of an innovative method for understanding the role of dogs in the household for youth with social anxiety, and therefore the results were not intended to be generalizable. Nonetheless, it is important to note that the sample used for this study was a convenience sample and therefore likely not representative of the breadth of experiences that youth with social anxiety have with their dogs. In addition, the sample was recruited online and required access to an internet-enabled device, which may have further limited our sample. For example, for youth who may have limited or no access to internet-enabled devices, participating in this type of study protocol could be of higher burden and there may be different barriers to participation that could be addressed with specific design features. In addition, this study took place during the COVID-19 pandemic, when online and remote methods of interacting were common; it may be that as pandemic-related restrictions lift, the willingness of teenagers to participate in this type of study could change, or that they may need different supports in order to succeed; in other words, social behaviors may not generalize outside of the context of the pandemic. This sample was also predominantly white and female, therefore future sampling strategies should aim to increase diversity in racial and gender identities. Furthermore, future research that undertakes hypothesis testing should use more diverse sampling techniques as well as larger sample sizes overall.

In addition to sampling, there were other procedural limitations that could be optimized in future research. For example, our data collection took place in a variety of geographic climates in the United States throughout the calendar year, which means that weather conditions could be variable, which could potentially confound information about the feasibility of participants wearing the sensors for a large percentage of the day. For example, extreme heat could make it difficult to wear the sensors outside due to sweating, exacerbating a reported difficulty that some participants reported. However, none of the participants specifically noted weather-related challenges.

Although participants were not instructed to change their behaviors during the course of the study, it is possible that the study was impacted by the Hawthorne Effect (Merrett, 2006) as well as novelty bias, which could affect validity. However, it is likely that both of these limitations would be corrected during the course of a full study (as opposed to a trial) where participants were observed for a longer period of time. Additionally, while we asked participants to assess their perceived accuracy of recall, we were not able to measure objectively how accurate they were at reporting their behaviors and interactions.

CONCLUSIONS AND FUTURE DIRECTIONS

In summary, this feasibility study indicated that the use of EMA (specifically, combining self-report activities and emotions with continuously collected physiological data) is a promising approach for studying individual variability and momentary effects of dog interactions for teenagers with anxiety. Future research should use this approach with larger samples to test hypotheses about when and how adolescents seek out contact with their dogs, the physiological antecedents and consequences of these interactions, and how human social interactions can impact these patterns of behavioral and physiological measures. Furthermore, research approaches that include person-centered methods have the opportunity to strengthen human-animal interaction research more broadly by capturing patterns of both inter- and intra-individual differences that are inherent to these interactions.

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DATA ACCESS STATEMENT

De-identified data are available upon request from the corresponding author.

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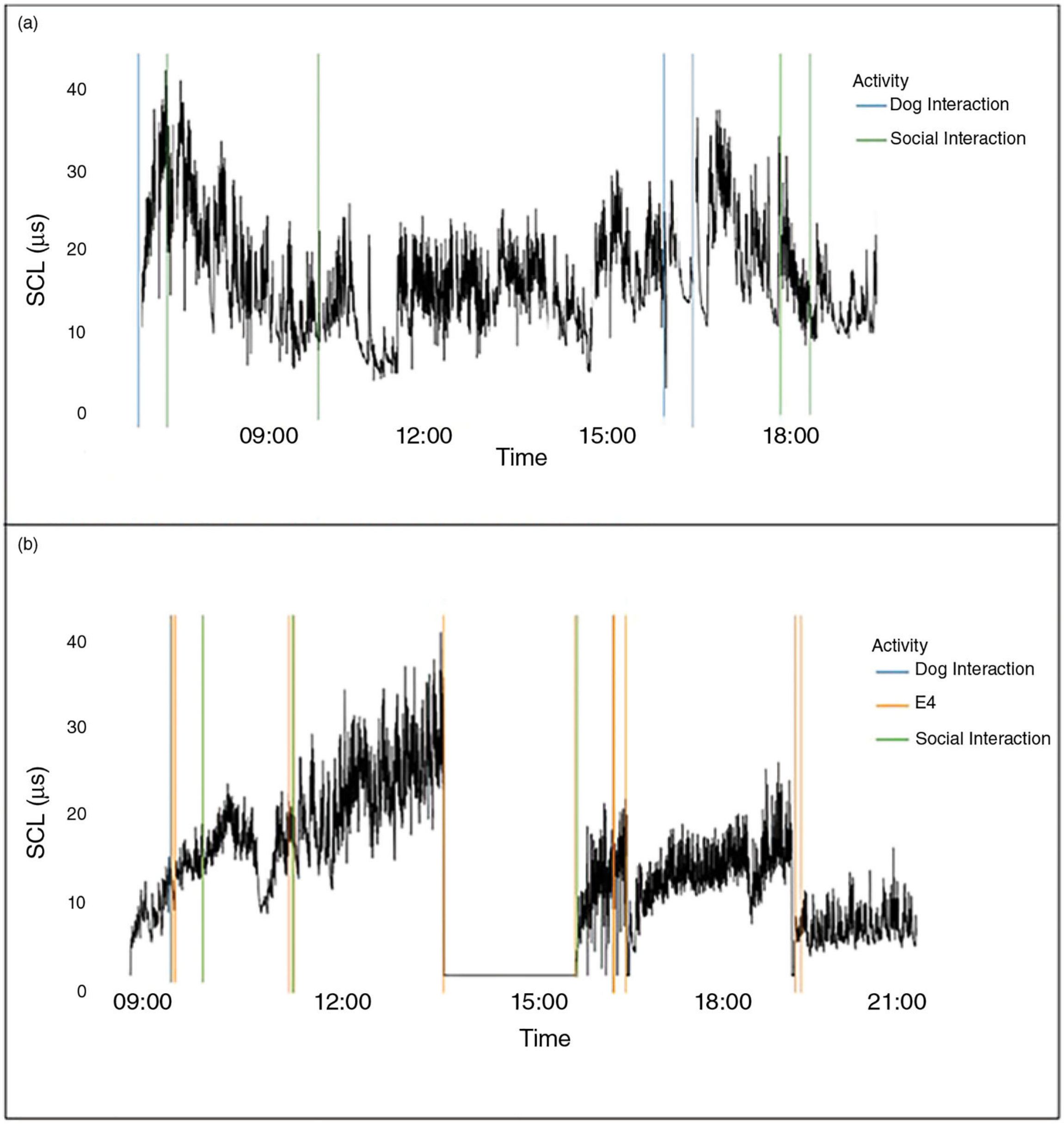

Fig. 1.

Example of a full day of EDA/SCL data from two participants integrated with EMA activity markers: (a) example of participant EDA data with EMA interaction markers; and (b) example of participant EDA data with E4 and EMA interaction markers.

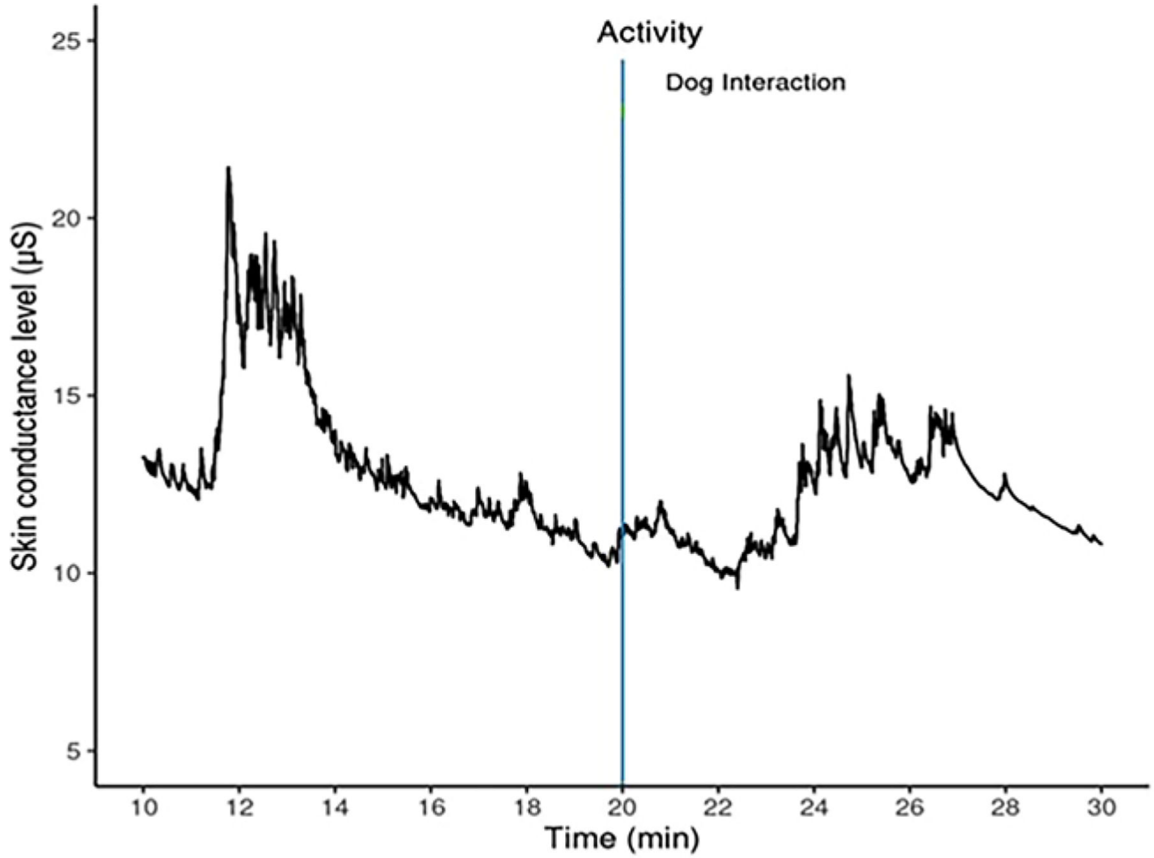

Fig. 2.
Example 20 min time segment of EDA data with dog interaction logged from EMA.

Table 1.

Participant-reported frequency of coping strategy use (1 mostly disagree to 4 mostly agree).

Activity	*M*	*SD*	No. of NA/does not apply to me responses
Spending time with pet(s)	3.86	0.35	3
Spending time with a close friend	3.50	0.76	0
Watching my favorite movies or shows	3.47	0.63	2
Spending time outdoors or in nature	3.23	0.89	2
Being alone	3.00	0.98	0
Spending time with family	3.00	1.00	1
Exercising or sports	2.77	1.09	1
Playing video or online games	2.65	1.08	1
Video hangouts (e.g., Zoom, Google, Skype)	1.81	0.98	6
Creating video content for social media (e.g., TikTok)	1.44	0.70	5
Posting about it on social media	1.21	0.49	3

Table 2.

Duration of activities and interactions (minutes per day).

	M	Median	*SD*	Range
Dog interactions	51.2	30.5	66.4	0–372
Social interactions	138.1	143.0	103.4	1–452
Physical activity	30.3	13.8	39.4	0–178

Table 3.

Characteristics of dog interactions.

Activities (*n* = 135)	***n* (% of total interactions)**
Dog on couch or bed	53 (39)
Petting	84 (62)
Walking/running	27 (20)
Playing fetch or a game	33 (24)
Obedience/training	8 (6)
Riding in the car	8 (6)
Other	12 (8)
Others present during interaction (*n* = 137)	***n* (% of interactions)**
Parent	48 (35)
Sibling	15 (11)
Other family member	1 (0.7)
Another pet	22 (16)
Friend	2 (1)
Other	1 (0.7)
No one else was there	70 (51)