The Influence of Canine Aggression and Behavioral Treatment on Heart Rate Variability

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The Influence of Canine Aggression and Behavioral Treatment on Heart Rate Variability

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Abstract

Dog aggression affects many, with nearly 5 million dog bites reported yearly in the United States alone. With the physical, emotional, and monetary costs of bites, it is of considerable interest to identify dogs that are likely to bite. One physiological measure that might serve as an index of aggression is heart rate variability (HRV), which refers to vagally mediated beat-to-beat change in heart rate. Low HRV has been associated with impaired emotional and behavioral regulation and stress in both humans and animals. To assess whether this measure corresponds with aggression in dogs, resting HRV was measured for dogs with and without bite histories. It was observed that dogs with bite histories had significantly lower HRV, and that owner reported aggression negatively correlated with variability. HRV measurements were collected from multiple training classes in order to determine if HRV would increase with behavioral improvement and whether physiological changes would differ between non-aggressive and aggressive dogs. HRV measurements were recorded three times over six weeks of training. Low HRV was observed across most subjects, indicating that training classes were stressful for most dogs. However, some differences emerged between the classes. The lowest variability was observed in a class composed of reactive dogs enrolled in training for the first time (compared to other reactive dogs that had undergone more training). Implications of these results are discussed, as well as potential applications for treating aggressive behavior.
Acknowledgements

First, I would like to thank my research adviser, Dr. Julia Manor. Without her guidance, time, commitment, and encouragement, this project would not have been completed. I am incredibly grateful for her expertise in animal behavior and for her extensive experience working with dogs. From the beginning of the project, when I was just formulating my questions to the end, when I was collecting and interpreting the final data points, she was always available to help, support, and guide me. I am grateful for the countless hours she spent driving around the cities and sitting in living rooms and training classes to collect data. I have become a much better writer and thinker as a result of her suggestions and edits on my many (many) drafts. I am endlessly thankful. I would also like to thank my academic advisor, Dr. Eric Wiertelak, for his guidance and support and for serving on my honor’s committee.

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Note to Readers

This thesis is the product of the last two years of research that I conducted during and after taking Directed Research. This project began during my sophomore year while I was enrolled in Principles of Learning and Behavior (to date my favorite class I have taken at Macalester). Under Dr. Julia Manor, I became intrigued by animal behavior and research and wrote a project proposal for a final class paper on this topic. Some portions of this paper are updated and extended versions of text that was written for my Directed Research paper and subsequent papers and presentations. In order to give a full view of the motivations and findings of this research, this paper is the culmination of the studies that were conducted both for Directed Research and my Honor’s work.
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The Influence of Canine Aggression and Behavioral Treatment on Heart Rate Variability

Dog bites affect nearly 5 million people each year in the United States (American Humane Association, 2014). These acts of aggression occur overwhelmingly on or near the property of the dog owner, and most victims know the dog. Insurance companies pay more than $530 million each year in dog bite claims (Insurance Information Institute, 2015). These situations impose stress and suffering on pet owners who must cope with aggressive dogs, on victims who experience physical and emotional trauma, and on dogs that are extremely fearful, territorial, anxious, and aggressive. No dog owner wants to have to make the decision to euthanize a dangerous dog (or have that option forced upon them). As training techniques develop that help owners and their aggressive dogs, it is of considerable interest and importance to examine the physiological differences that may predict aggressive tendencies as well as physiological changes that may accompany training. With this information, it may be possible to identify dogs that are more likely to bite, and to develop and test the effectiveness of new interventions to assist dogs and owners who are dealing with behavioral challenges.

One physiological measure that may help in predicting behavioral problems is heart rate variability (HRV), which refers to beat-to-beat changes in heart rate. Measurements of heart rate variability reflect the balance between the activity of the sympathetic (SNS) and parasympathetic (PNS) branches of the nervous system. The two branches work in opposition, allowing an individual to respond quickly to stressors and then return to a stable resting state (Yang, Hong, & Tsai, 2010). As a measure, HRV is more informative than heart rate alone because it provides more nuanced information
regarding sympathovagal regulation, which refers to the relative influence of the SNS and PNS on heart rate (von Borrell et al., 2007). Greater inhibitory control is associated with greater autonomic flexibility and adaptive responses to varying environmental demands. The Polyvagal theory has connected autonomic regulation and heart rate variability to various pathological states and behaviors (Porges, 2007; Porges, et al., 2014). According to the theory, inhibitory processes are essential for healthy responding. The related model of neurovisceral integration (Thayer & Lane, 2000; Thayer & Lane, 2009; Pittig, et al., 2012) connects the autonomic, attentional, and affective systems involved in self-regulation processes. The parasympathetic (vagal) innervation of the heart is modulated by prefrontal cortical areas involved in executive function, impulse control and emotion regulation. Higher parasympathetic activation causes higher heart rate variability and is associated with higher prefrontal cortical activation (for a meta-analysis see Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012).

Higher prefrontal activation is related to an individual’s capacity of regulated emotional and physiological responding in stressful situations (Appelhans & Luecken, 2006). More specifically, ventromedial areas of the prefrontal cortex including the orbitofrontal cortex (OFC), dorsomedial prefrontal cortex (MdPFC), and anterior cingulate gyrus (ACG) have been associated with the regulation of emotional behaviors. More lateral prefrontal areas such as the dorsolateral PFC (DLPFC) and ventrolateral PFC (VLPFC) are thought to be involved in higher executive control (Philips, Ladouceur, & Drevets, 2008). The neurovisceral model proposes that affective disorders and behavioral problems, which are characterized by rigid behavioral responses not in accordance with environmental demands, reflect an inability of the prefrontal cortex to
inhibit inappropriate responses. The neuronal overlapping of behavioral-emotional and
cortico-cardiac regulation in prefrontal cortical areas allows for the interpretation of heart
rate variability as a proxy for tonic and trait-like prefrontal activation and an individual’s
behavioral-emotional control capacity. In humans, low HRV has been related to
emotional instability in daily life (Koval et al., 2013), low self-regulation (Segerstrom &
Nes, 2007; Reynard, et al., 2011), lower persistence on a challenging task (Geisler &
Kubiak, 2009), and poorer competence in executive control (Mezzacappa et al., 1998).

The association between heart rate variability, emotional regulation, and
executive control has been observed in many psychiatric disorders. Low HRV is
correlated with bipolar disorder (Henry et al. 2010), depression (Beauchaine, Gartner, &
Hagen, 2000), social anxiety disorder (Alvares et al., 2013), panic disorder (Kang, et al.,
2010), anti-social behavior (Mezzacappa et al., 1997), and schizophrenia (Boettger et al.,
2006). Anxiety and depression may both be broadly thought of in terms of dysregulation
of the emotional system (Phillips, Ladouceur, & Drevets, 2008; Gross & Levenson,
1997). Likewise anger and aggression may indicate a dysfunction in emotional regulation
regions of the brain (Davidson, Putnam, & Larson, 2000). In particular, the PFC seems
to be critical in inhibiting aggressive impulses (Anderson, Bechara, Damasio, Tranel, &
Damasio, 1999; Raine et al., 1998). Given the connection between the PFC and HRV, it
follows that HRV is likely to have a strong connection to aggression as well as to general
dysregulation of other emotional systems.

In an early study on aggression and HRV in humans, Disbrow, Doerr, and
Caulfield (1977) found that parents who abused their children had higher heart rates and
lower heart rate variability while watching an emotional video clip than non-abusers,
suggesting that low HRV may also relate to the regulation of aggression. Other studies have examined heart rate variability and aggressive behavior in clinical populations. Beauchaine, et al. (2000) studied HRV and aggression in depressed and non-depressed patients diagnosed with ADHD and found that HRV and aggression were related differently in the two groups. Depressed patients with HRV higher than the mean of the patient population displayed fewer aggressive behaviors. This group was also more responsive to treatment. That is, higher HRV was correlated with more adaptive behavior in the depressed ADHD group. However, the non-depressed patients with higher than average HRV showed increasing levels of aggression during their treatment. More recently, Henry et al. (2010) used HRV to study the relationship between HRV and different aspects of bipolar mania and schizophrenia. The authors found a significant negative correlation between HRV and aggressive behaviors in patients diagnosed with schizophrenia. These studies provide further support for the relationship between emotional dysregulation, aggression, and heart rate variability.

Although more extensively studied in humans, HRV has also been used in studies of animal health, stress, and behavior (for full review see von Borrell et al., 2007). A negative correlation has been observed between heart rate variability and environmental stress load in calves and cow (Mohr, Langbein, and Nurnberg, 2002). That is, as an individual experienced increasing stress, HRV decreased. Higher HRV has also been related to greater emotion regulation and inhibition of dominant behavior in sheep (Wojniusz et al., 2011). The relationship between aggression, HRV, and cardiac health has also been investigated in rats. Rats high in trait aggression had significantly lower
resting HRV, lower vagal modulation of heart rate at rest and under stress, as well as increased susceptibility to cardiac arrhythmia and cardiac arrest (Carnevali et al., 2013).

Several studies have examined heart rate variability and behavior in dogs. One study measured dogs’ HR and HRV during the approach of a threatening stranger in the presence and absence of the owner (Gásci et al., 2013). The research sought to determine whether the presence of owners could mediate the stress response of the dogs. The dogs that exhibited aggressive reactivity to the stranger (growling, barking, and baring teeth) showed both elevated heart rate and decreased HRV. The presence of the owner during the approach of the stranger modulated the decrease in HRV, indicating that the owner’s presence may have served to counteract the stress response in the reactive dogs. In addition, HRV measurements and saliva cortisol levels were collected in a shelter setting in order to examine the effects of a new handling and training program on the behavior of shelter dogs (Bergamasco et al., 2010). HRV was not significantly related to sociability and diffidence. Instead, saliva cortisol levels were a more effective predictor of friendly behavior. However, the experimenters excluded dogs that showed aggression, as they were primarily interested in the program’s effects on more adoptable (less aggressive) dogs. Thus, the study may have excluded dogs with lower HRV by their selection of more adoptable dogs.

There are numerous types of aggressive behavior in dogs and other animals. Aggressive behavior may be classified according to the trigger, target, motivation, or other factors. Some commonly used categories include fear-induced aggression, resource guarding (possessive aggression), conflict-related aggression (dominance aggression), territorial aggression, predatory aggression, play-related aggression, pain-induced
aggression, and maternal aggression (Luescher & Reisner, 2008). Aggression may be also
categorized as non-affective aggression versus affective aggression. Non-affective
aggression includes play-related aggression and predation, while affective aggression,
also referred to as social aggression, includes offensive (dominant) and defensive
(fearful) aggression. Affective aggression, which serves to increase the distance between
the self and a feared or threatening object, is associated with sympathetic arousal and
limbic activation, especially in the amygdala (Luescher & Reisner, 2008). Higher
sympathetic arousal would be associated with lower HRV. On the other hand, some
consider predation (or “cold aggression”) as a feeding behavior, and not truly aggressive.
Non-affective aggression is not associated with sympathetic arousal or limbic activation,
and so HRV reductions may not be observed in these forms of aggressive behaviors.

Many dogs undergo some form of behavioral training to teach basic manners and
improve problem behaviors. Most such programs are conducted in training centers to
multiple dogs at once, though individual training sessions are also frequently used in
cases of more severe behavioral problems. Though there are many different specific
approaches taken, many basic training courses use positive reinforcement with food and
clickers to train desired behaviors. For issues of aggression or anxiety, systematic
desensitization approaches are also often included in which dogs are gradually exposed to
triggering stimuli that typically provoke the exaggerated reaction (i.e. other dogs, moving
objects, etc.) and are rewarded for showing appropriate responses (Hiby, Rooney, &
Bradshaw, 2004; Luescher & Reisner, 2008). Over time, these courses aim to desensitize
the dog to the triggering stimuli and develop adaptive responses. This training typically
occurs over a period of months, but may be continued for more extended periods of time for dogs whose reactive behaviors are more severe or resistant to change.

Given the connections between temperament, behavior, and physiology, the present studies aimed to examine heart rate variability in aggressive and non-aggressive dogs. In addition to making comparisons between groups, we were motivated to examine whether HRV would change with training. It is possible that as behavior improves and reactive/aggressive responses decrease, HRV changes may be observed. That is, as a dog exhibits fewer anxious or aggressive behaviors, heart rate variability may increase. Alternatively, improvements in behavior may reflect inhibition of formerly observed reactions or newly learned behaviors without accompanying physiological changes that would indicate a true decrease in stress or anxiety. It is of considerable interest to investigate the effects of training courses on physiology in order to determine if changes are at a more superficial level or if they are reflected in deeper changes to the nervous system. Achieving a greater understanding of the physiology of aggression may help us to better develop and refine interventions to address behavioral problems.
Chapter 2: Heart Rate Variability in Aggressive Dogs

The goal of Experiment One was to investigate the relationship between heart rate variability and aggressive behavior in companion dogs. Cardiac activity measurements were collected at rest from two populations: one group with a bite history and one group with no history of aggressive behavior. Given that past research has found relationships between HRV, self-regulation, and aggression in both humans and animals, it was predicted that dogs with a history of aggression would exhibit lower heart rate variability than dogs without a bite history. Additionally, it was predicted that greater levels of aggression would correlate with lower HRV levels.

Method

Animals

The use of animals and the participation of owners was evaluated and approved by the animal and human ethics boards (IRB and IACUC) at the college. Thirty-three dogs (17 males, 32 neutered) were measured, all of whom were living as pets in families in the community. Eighteen subjects belonged to the no-bite history group (non-aggressive). The remaining seventeen had histories of human- or dog-directed bites and were categorized as aggressive. Data was collected from all 33 subjects. Of the 33, 4 were excluded due to repeated problems establishing connection to the heart rate monitoring device. In each of the five homes with multiple dogs, only one dog was considered in order to ensure independence of data points. The subject with the highest Total Aggression score (see Data Analysis below for scoring) from each multi-dog home was considered for analysis. The twenty-two remaining subjects were included in data analysis (eleven in each group).
For the final sample, the aggressive and non-aggressive groups did not differ significantly in terms of age ($M = 6.77, SD = 3.17$ and $M = 6.07, SD = 2.67$ respectively), $t(20) = 0.561, p = 0.581$, or weight ($M = 42.29, SD = 25.38; M = 39.90, SD = 22.54$ respectively), $t(18) = -0.231, p = 0.860$. In the no bite history group, there were 6 dogs from the Sporting Group, 2 from the Terrier Group, 2 from the Toy Group, and 1 Hound. Four of these dogs were mixed breed. In the bite history group, there were 3 from the Hound Group, 3 from the Working Group, 1 Toy Group, 1 Non-Sporting Group, 2 Terrier Group, and 1 Herding Group. Three dogs were mixed breed. Dogs were recruited via word of mouth or from an ad in a daily college newsletter. Most of the aggressive population was drawn from the clients of a local dog trainer who has extensive experience with aggressive dogs. She recruited subjects based on owner willingness to participate. Dogs who could not safely be fitted with the heart rate monitor were excluded from the study.

**Materials and Measures**

**Heart Rate Monitors and Software.** HR data was collected with a Polar© H7 heart rate monitor (Polar©, Kempele, Finland). Polar© heart rate monitors have been used in past HRV studies of both humans (Alvares et al., 2013; Geisler & Kubiak, 2009; Koval et al., 2013) and animal (Mohr, Langbein, Nurnberg, 2002; Wojniusz, 2011). The system collected heart rate data wirelessly when strapped to the chest of the animal and transmitted data via Bluetooth® to an iPhone app (Heart Rate Variability Logger, Marco Altini). While there has been some controversy over the use of commercial heart rate monitors compared to ECG measurements (e.g., see Quintana, Heathers, & Kemp, 2012; Wallén, Hasson, Theorell, Canlon, & Osika, 2012), Polar© heart monitors seem to yield
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data that is closely in agreement with heart rate data collected by a traditional ECG (Weippert, Kumar, Kreuzfeld, Arndt, & Rieger, 2010). The Polar© H7 monitor was chosen for this study over the more traditional Polar© 800 devices because the data appeared to be fairly consistent between the two devices, with the Polar© H7 seeming to maintain better connectivity through the dog’s fur. Furthermore, because the Polar© H7 is less expensive, it would be more affordable for dog training professionals in the field and researchers.

Aggression Survey. Survey items were taken from the temperament assessment survey developed by Goodloe and Borchelt (1998). Questions were included from the categories Aggression to Family Member (e.g., “Growls and/or bares teeth when picked up, held, or rolled over by owner/family member”), Aggression to Strangers (e.g., “Growls and/or bares teeth at home when an unfamiliar person approaches”), Aggression to Unfamiliar Dogs (e.g., “Growls and/or bares teeth away from home when an unfamiliar dog approaches”), Biting (e.g., “Has bitten adult nonfamily person (not including play”), Fear and Avoidance (e.g., “Avoids or is fearful of unfamiliar children”), and Friendliness (e.g., “Displays friendly tail-wagging when greeting an unfamiliar person”) were included. Each question was answered on a five-point scale (1 = Never, 5 = Always). Questions in the Friendliness group were reverse coded. Other survey items were taken from the intake form of a dog trainer, including items related to training history, exercise habits, and bite severity for dogs that had bitten. For the severity of bites, the bites were coded from 1 to 8 with a “snap with no contact” being coded as a 1 and a dog that had “killed another dog” as an 8. No dogs in the present study had bites that had resulted in a death so the scale ranged from 1 to 7. See Appendix A for the complete survey.
Procedure

Upon meeting at the owner’s home, the owner received a consent form and completed the behavioral survey. After completion of the consent form, the dog was outfitted with the heart rate monitor. The fur immediately behind the left front leg was wetted using either a spray bottle or washcloth. The wetted area extended from the center of the chest to midway up the side of the body immediately behind the front leg. The monitor band was then sized to the dog. For larger dogs, the band was wrapped around the body once. For smaller dogs, the band was wrapped twice. Before securing the band, veterinary lubricant was applied to the rubberized surface. The strap was then secured and adjusted so that it was snug but not tight. In almost all cases, the researchers secured the strap. However, for two of the aggressive dogs and one control dog, the owner applied the monitor as instructed by the experimenter for safety of handling and comfort of the dog. Connection to the app was checked and the strap position was adjusted as needed. Once a steady connection was established, the recording began. Heart rate data was recorded for ten minutes (occasionally longer if the connection was lost midway) while the dog was at rest. During this time, the dog was allowed to move and behave normally and was not asked to perform any particular task. Following the ten minutes, the monitor was then removed and wiped clean. The owner received the debriefing form and a small bag of dog treats.

Data Analysis

Each owner completed a survey that contained items related to their dog’s general health, medication, exercise, and behavioral history. The Survey Total score was calculated from aggressive behavior survey responses (items 1-26, see Appendix A).
Items 12, 15, 16, 21, 22 were reverse scored. The number and severity of bites were added to the survey score for a Total Aggression score.

All heart rate data files were processed and analyzed using Artiifact (Kaufmann et al., 2011). For each 10-minute recording file, the most consistent five-minute portion was selected for analysis. Obvious points of disconnection (which typically appeared as spikes greater than 2000ms in the RR curve) were avoided from the selection. If the entire file appeared consistent, seconds 180 to 480 were selected. The software allows for the automatic detection and removal of artifacts, or errors in the measurement. These points, either detected by the program or manually selected, can be processed by linear or cubic spline interpolation, smoothing the RR-curve and correcting data points that may not reflect true measurements of heart rate. However, these automatically detected points were not removed, as the selection criteria were based on expectations from human data. Instead, all files were visually inspected for any potential artifacts. Artifacts detected by both the program and by the visual inspection of data tended to identify points of high change in heart rate amid points of low heart rate change as artifacts. Given that this removes the remaining variability in individuals with low heart rate variability, we chose to take the more conservative approach and keep any potential artifacts in the data for all dogs. The removal of these artifacts would only have made our data more significant by further decreasing the variability in these dogs. Two researchers independently analyzed a subset of the files and showed similar selections for most dogs. For dogs that the selection times differed, there was less than 3% difference in the HRV measures calculated for either time selection.
Only files with a steady five-minute measurement free from disconnections from the device were included in analysis. Disconnections could be detected as spikes greater than 2000ms, which is greater than any potential true arrhythmia, which is a typical feature of heartbeats in dogs. Artifact-processed files were then analyzed using Artiifact. The VLF band was set to be 0.06 Hz, LF to be 0.24 Hz, and HF to be 1.06 Hz based on measurements done in dogs (Houle & Billman, 1999). Artiifact analysis yields all common time- and frequency domain measures of vagally mediated heart rate variability, including RMSDD, pNN50, High-Frequency (HF) power. For the statistical analysis, pNN50 was used as the primary measure of HRV. The pNN50 is a measure that determines the percent of successive RR intervals that differ by more than 50ms. High pNN50 reflects high heart rate variability; the higher the pNN50, the more the intervals differed by more than 50ms. The measure pNN50 is considered to reflect vagal activation and is highly correlated with other measures of HRV (RMSSD, High-Frequency power). In addition, pNN50 is, due to its definition, a much more robust measure than RMSSD (which is highly susceptible to outliers) and HF power (which is based on a frequency band analysis [e.g., Fast-Fourier-Transformation] with high statistical requirements that are more difficult to fulfill in tested dogs compared to instruction-following humans in a resting state).

Results

Aggression Survey

Cronbach’s alpha was calculated for the 26 items taken from Goodloe and Borchelt (1998), \( \alpha = 0.7 \). Total Aggression scores were significantly different between the aggressive (\( M = 70.63, SD = 23.20 \)) and non-aggressive dogs (\( M = 37.36, SD = \))
9.79), \( t(13.431) = 4.38, p = 0.001 \), equal variances were not assumed, \( d = 1.87 \). Dogs with a bite history ranged from 2-30 bites to adults, children, and other dogs \( (M = 8.09, Mdn = 6.0) \). All but one dog in the aggressive group had at least one bite to a human. The one dog that had only bitten another dog had five bites to dogs that included punctures and shaking. The aggression score for this dog was similar to other dogs in the bite history group.

**Heart Rate Variability**

When comparing groups, many more spikes and dips appeared on the RR-curves of nonaggressive subjects, as opposed to the relatively smooth and consistent curves of many of the aggressive subjects (See Figure 1). Dogs with no histories of aggression often showed frequent, rapid changes in HR. In contrast, dogs with bite histories displayed changes in HR that occurred gradually. These differences were apparent when viewing the RR curves of different subjects high or low in HRV.

Given the small sample size, the normality of the pNN50 data was tested using Kolmogorov-Smirnov test for normality. The distribution was not normally distributed for the non-bite group, \( K-S = 0.313, p = 0.004 \), so non-parametric statistics were used for all measures. The aggressive dogs showed lower pNN50 \( (M = 36.6, SD = 29.4) \) than the non-aggressive dogs \( (M = 64.6, SD = 29.1) \). This difference in HRV was significant, \( Mann-Whitney U = 29.00, p = 0.040 \) (See Figure 2). There was also a significant difference between the mean HR of the aggressive and non-aggressive dogs, \( Mann-Whitney U = 23.00, p = 0.013 \), with the HR of the aggressive group higher \( (M = 107.1, SD = 22.4) \) than that of the non-aggressive group \( (M = 82.4, SD = 21.0) \). Spearman’s Correlations were also performed between pNN50, Total Bites, Bite Severity, Total
Aggression score, and mean HR. The pNN50 was significantly negatively correlated with Total Bites $\rho(22) = -0.517, p = 0.014$, Bite Severity, $\rho(22) = -0.476, p = 0.025$, and similarly with Total Aggression score, $\rho(22) = -0.473, p = 0.026$ (See Figure 3). There was also a significant positive correlation between mean HR and Total Bites, $\rho(22) = 0.521, p = 0.013$, Bite Severity, $\rho(22) = 0.539, p = 0.010$, Total Aggression score, $\rho(22) = 0.431, p = 0.045$.

**Discussion**

As predicted, results of the present study suggest that heart rate variability is lower in aggressive dogs than non-aggressive dogs. The results of this study extend previous research related to animal heart rate variability. Like Carnevali et al. (2013) who found significantly lower HRV in high-aggression rats, the present study found that aggressive dogs with a bite history displayed lower HRV than those that were in the non-aggressive group. This HRV difference between groups may be due to impaired emotional regulation reflected by impaired autonomic functioning, which may also explain some of the subjects that were outliers. Specifically, there were several non-aggressive dogs with low HRV. However, owners reported that these dogs were anxious, and one of these dogs was visibly anxious (i.e., cowering and withdrawing) when the heart rate monitor was applied. Low HRV in these dogs was likely due to poorer emotional regulation related to anxiety that had not, at least at the time of the study, manifested as aggression.

Other dogs had bite histories but had high heart rate variability. One dog was reported to have bitten out of surprise, when woken up by a child. This dog’s emotional regulation and aggression may be comparatively normal when compared to some of the
subjects that displayed more severe, recurring, and proactive bites (i.e. displayed affective aggression). That is, this individual may have more appropriate emotional and autonomic regulation, but was operationally defined as aggressive due to having any bite history, regardless of the context. The strong correlation between the number of bites, severity, and HRV as well as the aggression survey and HRV support this.

There are several potential limitations to the present study that should be addressed in future research. It is important to consider that the presence of the investigators may have had a different effect on the two groups. Dogs with histories of aggression (especially human-directed aggression) may be more distressed or anxious by the presence of strangers in the home. Although the researchers were present for data collection in all dogs (with and without bite histories), the emotional and behavioral impact could have been different in each group, contributing to the differences in HRV. This is not necessarily a problem, as it may reflect differences between the groups in terms of reactivity to strangers in the home, which itself is an interesting effect. However, it is necessary to recognize that the state heart rate data measured in the presence of the researchers may not necessarily reflect trait heart rate variability that could be measured during a more typical period without strangers present.

From these results, there are numerous possibilities for future research and applications related to HRV and behavior in companion dogs. Since aggressive dogs were noted to have lower HRV than non-aggressive dogs, HRV information may be used to develop and assess treatments and interventions for problematic behaviors. It is possible that training programs may differentially affect stress responses, reactivity, and HRV in dogs. It may be useful to assess whether program efficacy is related to changes in
HRV, and if so, to use HRV measurements to make methodological refinements during program development.
Chapter 3: Changes in Heart Rate Variability During Training

Several studies have examined the stability of HRV measurements and the extent to which an individual’s HRV is susceptible to change with behavioral or pharmacological treatments. Bertsch and colleagues (2012) repeatedly measured heart rate variability in healthy individuals and found HRV readings to be temporally stable. However, they estimated that approximately 40% of the variance of a single HRV measurement can be explained by situational effects. Evidence from behavioral and pharmacological studies suggests that HRV can be changed over time. Patients have been trained using biofeedback techniques to raise their HRV, which has been found to have positive effects on physical conditions such as asthma (Lehrer, et al., 2004), hypertension (Reinke, et al., 2007), irritable bowel syndrome (Humphreys & Gevirtz, 2000), and chronic pulmonary obstructive disorder (Giardino, et al., 2004) as well as psychological conditions including depression (Karavidas, et al., 2007), and PTSD (Zucker, et al., 2009). Other studies have found HRV increases with pharmacological treatments such as selective serotonin reuptake inhibitors (Balogh, et al., 1993) and methylphenidate beta-sympathetic blockers (Ross, Quitkin, & Klein, 2002), though other studies found HRV decreased with typical and atypical antipsychotics (Linder, et al., 2014). Overall, these results suggest that HRV itself may be targeted to improve physical and emotional and that HRV may be affected by pharmacological treatments aimed to alleviate symptoms.

In dogs, few studies have examined the effects of behavioral interventions on HRV. In one case study, HRV was measured before and after application of bodily pressure to a dog that exhibited significant aggression when introduced to other dogs (Williams et al., 2003). The dog’s HRV was measured before treatment both at rest and
in the presence of an unfamiliar dog. Then, the dog was placed in a chamber that was filled with oats, which supplied a gentle pressure over the entire body (excluding the head) and restricted movement. HRV was measured again when a second unfamiliar dog was introduced. There was a significant increase in HRV when the treatment was applied, which was accompanied by a marked reduction in reactivity to the other dog. Though only the study of one aggressive dog, this suggests that HRV may not only be a good measure of aggressive behavior, but also be a useful way to measure the effectiveness of behavioral interventions.

Experiments Two, Three, and Four aimed to examine the effects of training on aggressive and non-aggressive dogs’ heart rate variability over time. As in Experiment One, it was expected that the aggressive dogs enrolled in classes that aimed to decrease reactivity would display less autonomic variability than non-reactive dogs in basic obedience classes. In addition, we sought to determine how HRV changed with training and if HRV changes would differ between classes. That is, from a predicted lower baseline HRV, aggressive dogs may show greater increases in variability over time than control dogs, who may begin training with higher variability. On the other hand, heart rate variability may remain low due to the inherently stressful and demanding nature of training. Achieving a better understanding of the relationship between physiology and behavior may help us to better develop and refine interventions to address behavioral problems and aggression.
Experiment 2: HRV in Behavioral Adjustment Training (BAT)

Experiment 2 investigated heart rate variability during Behavioral Adjustment Training (BAT) classes at Fetch Dog Training and Behavior. Behavioral Adjustment Training was developed specifically for reactive dogs that display exaggerated fearful or aggressive responses to triggers such as other dogs, humans, noises, or moving objects (BAT 2.0 Overview). BAT courses aim to systematically expose dogs to triggering stimuli in a controlled manner, using negative and positive reinforcement to encourage appropriate behavior. Two dogs were enrolled in each hour-long BAT class. Each dog was given a “pod”, which consisted of a small area (approximately 8 ft. diameter) constructed of low, flexible fencing with one side open. The pod blocked the dog’s view of the rest of the room and the other dog. Dogs and their owners practiced “popping out” from behind the pod and then returning. The goal of popping out was to subject the dog to a slightly stressful situation in a controlled manner, allowing him or her a chance to display appropriate behaviors, which were then rewarded with food treats and negative reinforcement (exiting the stressful situation to the safety of the pod). The courses progressed over six weeks such that the dogs would “pop out” for longer periods of time as they became desensitized to the triggering stimuli such as a stuffed animal dog, the other dog in the class, or a moving skateboard or bike, and displayed more adaptive responding.

Method

Animals

The use of animals and the participation of owners was evaluated and approved by the animal and human ethics boards (IRB and IACUC) at the college. Five dogs were
measured from the three class sections (1 female and 4 males). Three were mixed breed, one was an American Cocker Spaniel, and one was a Cockapoo. Age ranged from 1.43 to 9.77 years ($M = 6.32$, $SD = 4.84$). The subjects were recruited via email from the instructor of the class. Four of the subjects had previously been enrolled in BAT training.

**Materials and Measures**

**Heart Rate Monitors and Software.** The same heart rate monitoring equipment was used in Experiment 2 as discussed above (Polar© H7 heart rate monitor connected via Bluetooth to HRV Logger App). An additional monitor was used in order to record from multiple subjects at once.

**Aggression Survey.** Unlike in Experiment 1, in which a behavioral survey adapted from Goodloe and Borchelt (1998) was used, Experiment 2 utilized the CBARQ survey. The CBARQ was developed to assess behavior and temperamental traits of pet dogs and has been more widely used and validated in scientific research and by service dog organizations than has the Goodloe and Borchelt survey (Hsu & Serpell, 2003; Duffy & Serpell, 2012; Tamimi, et al., 2015). CBARQ, which is administered online, consists of 100 survey items that ask owners to rate their dog on a 5-point ordinal rating scale that corresponds to either severity (with 0 indicating no evidence of the behavior and 4 indicating a severe form of the behavior) or frequency (with 0 indicating “never” and 4 indicating “always”). Owners also had the option to select “not observed/not applicable”. The questions are organized into 14 behavioral subscales including trainability, stranger-directed aggression, owner-directed aggression, dog rivalry, stranger-directed fear, nonsocial fear, dog-directed aggression, dog-directed fear, touch sensitivity, separation-related behavior, excitability, attachment/attention-seeking, chasing, and energy level.
See Appendix B for the complete list of questionnaire items and scoring protocol. Dog owners were sent instructions to complete the survey via email following the first session of in-class recording.

**Procedure**

Before the first class, dog owners were recruited for participation via email. During the first session of the training course, owners completed a consent form and the heart rate monitor was applied as described in Experiment 1. The monitor remained in place for the duration of the hour-long course and was then removed. If the monitor became disconnected during the class period, the recording was stopped, but the strap was left in place until after the class so as not to interrupt training. One to two dogs were measured during each class. Notes were taken during classes regarding the dogs’ behavior and other events. Data was collected during the first week of the course, again three weeks later, and a third time during week six. As in Experiment 1, dogs largely ignored the monitor strap and training was not impaired.

**Data Analysis**

From the CBARQ survey online platform, the fourteen behavioral subscale scores were automatically calculated for each subject. Details of the survey items used for each subscale can be found in Appendix B. Survey questions that dog owners answered as “Not Applicable/Never Observed” were not assigned a value and were excluded from the average score for each subscale. Of particular interest for this study were the seven scales related to aggression and fear. Possible scores for each subscale ranged from 0 to 4. Total Aggression scores were calculated for each subject by summing the four aggression subscales (Stranger-Directed Aggression, Owner-Directed Aggression, Dog-Directed...
Aggression, and Familiar Dog Rivalry). Possible scores for Total Aggression ranged from 0 to 16. A similar Total Fear measure was calculated from the three fear subscales (Stranger-Directed Fear, Nonsocial Fear, Dog-Directed Fear). Possible scores for Total Fear ranged from 0 to 12.

All heart rate data files were processed and analyzed in a similar fashion to Experiment 1. Since recordings were of different lengths, the most consistent five minute portion was selected for analysis. Obvious points of disconnection (which appeared as spikes greater than 2000ms in the RR curve) were avoided from the selection. If the entire file appeared consistent, seconds 500 to 800 were selected. Only files with a steady two-minute measurement free from excessive disconnections from the device were included in analysis. As above, all files were visually inspected for potential artifacts (as indicated by RR intervals greater than 2000ms, the same conservative criterion used in Experiment 1). These points were processed by cubic spline interpolation, smoothing the RR curve and correcting these points that were not true measurements of heart rate. Two researchers independently analyzed a subset of the files and showed similar selections for most dogs. Given that many of the recording files were much longer than in study one, for several subjects, HRV was calculated at multiple three-minute portions of the file and over the entire recording in order to determine that HRV was consistent over the recording. Artifact-processed files were then analyzed using Artiifact. As above, the VLF band was set to be 0.06 Hz, LF to be 0.24 Hz, and HF to be 1.06 Hz based on measurements used in dogs (Houle & Billman, 1999). For the statistical analysis, pNN50 was used as the primary measure of HRV, though Mean HR was also examined.

Results
Aggression Survey

Survey data was obtained from all five subjects. Across subjects, Total Aggression score ranged from 2.00 to 5.00 ($M = 3.04$, $SD = 1.36$). Total Fear ranged from 1.75 to 5.50 ($M = 4.20$, $SD = 1.64$). All five subjects displayed some amount of both Stranger-Directed Aggression and Dog-Directed Aggression, though two subjects scored much higher on the Dog-Directed Aggression subscale than Stranger-Directed Aggression. All owners also reported some amounts of Touch Sensitivity for these subjects.

Heart Rate Variability

Three measurements were collected from three subjects. Only two measurements were collected from one subject due to a missed class session. One measurement was discarded from another subject due to connection issues. Average pNN50 and Average HR values were calculated for each subject by calculating the mean of their pNN50 and HR values across the two or three measurements. Average pNN50 across subjects ranged from 15.40 to 40.51 ($M = 29.92$, $SD = 9.07$), and HR ranged from 104.71 to 149.83 ($M = 130.98$, $SD = 18.80$). Given the small sample, the normality of the pNN50 data was tested using Shapiro-Wilks test for normality. The distribution was normally distributed, $W(5) = 0.882$, $p = 0.317$. Pearson’s Correlations were calculated between Average pNN50, Average HR, Aggression Sum, and Fear Sum. Though the relationships were not significant, Aggression Sum was negatively related to pNN50 ($r(5) = -0.483$, $p = 0.410$) and positively related to HR ($r(5) = 0.507$, $p = 0.383$). Fear Sum was negatively related to pNN50 ($r(5) = -0.448$, $p = 0.449$) and had a marginally significant positive relationship with HR ($r(5) = 0.820$, $p = 0.089$). That is, the more aggressive and fearful behaviors
displayed, the lower the variability and the higher the HR. Higher HR was predictive of lower pNN50 ($r(5) = -0.606, p = 0.279$). The large magnitude of these correlations indicates that there is an effect, but statistical power is limited by the small sample size. More data should be collected in order to more conclusively establish the relationship between these variables.

The lowest average pNN50 values were recorded during Week 1 ($M = 27.18, SD = 14.21$), increasing slightly at Week 3 ($M = 29.48, SD = 14.04$) and Week 6 ($M = 31.80, SD = 15.72$). A repeated-measures ANOVA was calculated for the three subjects from whom three measurements were taken. The difference in subjects’ pNN50 values over the measurements approached significance, $F(2,4) = 2.882, p = 0.168$, $\eta_p^2 = 0.590$.

Overall, three subjects showed slight decreases in pNN50 over the measurements (-3.98, -7.88, -1.93), while two showed increases (+12.24, +41.06). The pNN50 values of each subject in BAT are displayed in Figure 4. The subject with the highest increase was the only first-time enrollee in the class, with all others having been previously enrolled.

**Discussion**

The results from this study suggest that, at least for dogs in this class, training does not have a clear or consistent impact on heart rate variability. That is, the overall trend was of a slight increase in HRV over the six-week course. However, three subjects displayed slight decreases overall, while the other two subjects displayed relatively larger increases (see Figure 4). The dogs in this class displayed average pNN50 values ($M = 29.92, SD = 9.07$) even lower than the aggressive group measured at rest in Experiment 1 ($M = 36.6, SD = 29.4$). The groups are similar in terms of behavioral history and temperament, and the additional stress of the class may have further depressed variability.
There are numerous potential explanations as to why there did not appear to be consistent patterns in the HRV changes over time. The lack of clear trends may be due to the limited sample size; three usable measurements were only collected from three of the five dogs. Another likely explanation may stem from repeated enrollment in BAT classes; four of the five subjects in the class had taken it at least once before. Many had also had extensive private in-home training. As such, these dogs were already quite familiar with both the environment and the general protocol. Interestingly, though only a single case, the one subject who was enrolled for the first time showed a large increase in variability over the measurements, from 10.68% to 51.74% (+41.06). It is possible that the other subjects would have shown comparable trends if they had been measured when they first took the class. The first several times a dog attends a training course, especially a course aimed to improve reactivity, may be an especially stressful situation. As such, first timers could be expected to show the lowest variability versus repeat attendees, who are more at ease and accustomed to the situation, or had already shown maximal increases in HRV, at least in the class setting.
Experiment 3: Heart Rate Variability During Basic Obedience Training

In Experiment 3, heart rate variability was measured over the course of a Basic Obedience course which took place at the Twin Cities Obedience Training Club (TCOTC). This class was an introductory obedience course for young dogs just beginning training. Basic commands were taught using positive reinforcement with treats and clickers. Classes were one hour long and included practicing basic commands such as sit, down, mat training, and loose leash walking. There were approximately ten dogs enrolled in each class section. Classes were held in a large training facility, which was subdivided into three large pens (approximately 100 ft. by 100 ft.).

Method

Animals

The use of animals and the participation of owners was evaluated and approved by the animal and human ethics boards (IRB and IACUC) at the college. Eleven dogs were measured from the three class sections. Four of the subjects were not included in the analysis. One subject was not included due to an aversive response to the application of the monitor, one was absent at the second and third recording sessions, one had too much fur to connect the device, and one was lost to surgery. Of the seven remaining (4 male, 3 female), four were mixed breed, the other three were a Labrador Retriever, Australian Cattle Dog, and Yorkshire Terrier. Age ranged from 0.54 to 2.52 years ($M = 1.05$, $SD = 0.72$). The subjects were recruited before the first week of class following a brief presentation from the experimenters.

Materials and Measures
Heart Rate Monitors and Software. The same heart rate monitoring equipment was used in Experiment 2 as discussed above (Polar© H7 heart rate monitor connected via Bluetooth to HRV Logger App). Two additional monitors were used in order to record from three subjects at once.

Aggression Survey. As in Experiment 2, the CBARQ survey was used and sent out via email. All owners completed the survey.

Procedure

Before the first class, dog owners were recruited for participation following a recruitment presentation. During the first session of the training course, owners completed a consent form. Following the first class, instructions to complete the CBARQ survey were sent via email to dog owners. The heart rate monitor was applied and data recording proceeded as described above.

Data Analysis

Survey and HRV data were processed as described in Experiment 2.

Results

Aggression Survey

Survey data was obtained from all seven subjects. Across subjects, Total Aggression score ranged from 0 (no aggression observed) to 1.05 ($M = 0.48$, $SD = 0.37$). Total Fear ranged from 0 to 2.75 ($M = 1.35$, $SD = 0.87$).

Heart Rate Variability

Three subjects missed a class session, so two data points were collected from each. Two measurements from other subjects were not used due to connection issues with the monitoring device. HRV data was collected three times from two subjects and twice
from five subjects. Average pNN50 and Average HR values were calculated for each subject by calculating the mean of their pNN50 and HR values across measurements. Average pNN50 across subjects ranged from 5.80 to 40.28 ($M = 28.54$, $SD = 11.79$), and HR ranged from 115.84 to 150.26 ($M = 130.06$, $SD = 15.43$). Given the small sample, the normality of the pNN50 data was tested using Shapiro-Wilks test for normality. The distribution was normally distributed, $W = 0.871$, $p = 0.221$. Pearson’s Correlations were calculated between Average pNN50, Average HR, Aggression Sum, and Fear Sum. There was a significant negative correlation between Average HR and Average pNN50, $r(7) = -0.835$, $p = 0.019$. The relationship between Fear Sum and pNN50 approached significance, as did the relationship between Fear Sum and Average HR, such that higher fear was predictive of lower variability ($r(7) = -0.744$, $p = 0.055$) and higher heart rate ($r(7) = 0.639$, $p = 0.122$). Aggression Sum did not appear to be related to pNN50 or HR, likely due to the very low scores for aggressive behavior.

During Week 1, the average pNN50 value was lower ($M = 27.02$, $SD = 12.73$) than at the second measurement ($M = 30.43$, $SD = 19.01$) and then remained stable at the final reading ($M = 30.49$, $SD = 10.69$). Though three measurements were only collected from two subjects, the data were submitted to a repeated-measures ANOVA, which was nonsignificant ($F < 1$) However, the general trend was as predicted: HRV increased over the course of the training class. The pNN50 values for each student by week are displayed in Figure 5. Five subjects displayed an overall increase in pNN50 (increases ranged from 0.52 to 11.57), while two subjects displayed an overall decrease in pNN50 (decreases of -2.98 and -13.71).

**Discussion**
In the Basic Obedience classes especially, there were difficulties in collecting adequate data. Several subjects were lost due to absences or surgery. For those that were measured, there were difficulties connecting multiple Bluetooth devices at once, with the iPhones often connecting to multiple monitors at once. Since the classes were back-to-back with only ten minutes in between, it was a challenge to fit the monitors and establish connectivity. Monitors also became disconnected during classes when subjects were out of range such as when dogs were taken outside to urinate.

As in the BAT class discussed above, there was a slight trend toward increased variability over the three measurements, though this increase was very slight. There was more variability between subjects in Basic Obedience than between subjects in BAT, as seen in Figures 4 and 5, suggesting a greater diversity in temperament and response to the class. However, when averaged across all subjects, variability was essentially equal to that of the older, reactive dogs in BAT and much lower than the non-aggressive control group measured at home in Experiment 1 ($M = 64.6, SD = 29.1$). Unlike the dogs enrolled in BAT, the dogs enrolled in these Basic Obedience classes were all first-time students and much younger. They also scored much lower on aggression and fear. For dogs in Basic Obedience, low variability may be due to the stress inherent in attending a training class. The facility in which the class was held is large, loud, and unfamiliar, with many dogs attending multiple classes that are held simultaneously in one space. There are many sounds, sights, and smells that may have been stressful for these young dogs.

It is of interest to note that dogs did not seem to become less stressed with repeated attendance (at least as indicated by their HRV). While it is unsurprising that the first visit was highly stressful, it could have been expected that these control dogs would
become more accustomed and relaxed over time. However, it could have been that one hour per week over six weeks was insufficient exposure to attenuate stress. It would have been interesting to measure this group at home in order to determine whether HRV was higher in a more comfortable setting. It may also be interesting to collect survey data again at a later point to examine the lasting behavioral impacts of early basic obedience training.
**Experiment 4: Heart Rate Variability During Reactive Rovers**

In Experiment 4, heart rate variability was measured over the course of the Reactive Rovers class at the Animal Humane Society (animalhumanesociety.org). This class was aimed to decrease dog-directed reactivity. Some of the methods were similar to those used in BAT class discussed above. However, a wider variety of activities were used to decrease reactivity. As in BAT, the six dogs in the class each had his or her own “pod”, blocking the dog’s view of the other dogs and humans. As instructed, dogs would exit their pods one at a time to practice walking and changing direction in the open room. As the class progressed, dogs would pass by a stationary non-reactive model dog (handled by the instructor), or would walk alongside the model dog and eventually other reactive dogs. The instructors would also lift the pod curtains in order to allow the dogs to briefly view another dog in the open area. The dog being viewed was faced away and fed in order to distract it and prevent conflict. Dogs were reinforced for adaptive behaviors (i.e. not responding to the other dog). As the class progressed, the curtains were lifted for longer amounts of time as the dogs became less reactive. The various activities were aimed to systematically present the dogs with increasingly challenging, potentially triggering situations as they were reinforced for appropriate responding, thus decreasing aggressive reactivity over time.

**Method**

**Animals**

The use of animals and the participation of owners was evaluated and approved by the animal and human ethics boards (IRB and IACUC) at the college. Four dogs were measured from the three class sections (1 females and 3 males). Three were mixed breed
and one was a Duck Toller. Average age was 15.87 months ($SD = 8.66$). The subjects were recruited preceding the first week of class following a brief presentation from the experimenter.

**Materials and Measures**

**Heart Rate Monitors and Software.** The same heart rate monitoring equipment was used in Experiment 2 as discussed above (Polar© H7 heart rate monitor connected via Bluetooth to HRV Logger App). Three additional monitors were used in order to record from four subjects at once.

**Aggression Survey.** As in Experiment 2, the CBARQ survey was used and sent out via email.

**Procedure**

Before the first class, dog owners were recruited for participation following a recruitment presentation. During the first session of the training course, owners completed a consent form. The heart rate monitor was applied and data recording proceeded as described above.

**Results**

**Aggression Survey**

Survey data was only obtained from two subjects. Total Aggression scores were 3.03 and 3.65 ($M = 3.43, SD = 0.44$). Total Fear scores were 4.33 and 7.00 ($M = 5.67, SD = 1.89$).

**Heart Rate Variability**

Heart rate variability measurements were collected three times from three subjects. One measurement was lost due to equipment failure. Average pNN50 and
Average HR values were calculated for each subject by calculating the mean of their pNN50 and HR values across measurements. Average pNN50 across subjects over the three recordings ranged from 6.52 to 41.87 ($M = 18.75, SD = 15.9$), and HR ranged from 105.24 to 140.14 ($M = 127.69, SD = 15.52$). However, one subject’s final recording, which displayed an anomalous jump in pNN50, was of questionable quality, displaying many disconnections from the device. Average pNN50 was calculated again without that final point, yielding a much lower class average ($M = 14.01, SD = 7.11$). Given the small sample, the normality of the pNN50 data was tested using Shapiro-Wilks test for normality. The distribution was normally distributed ($W = 0.837, p = 0.188$). As only two owners returned the survey, Pearson’s Correlations could not be calculated between Average pNN50, Average HR, Aggression Sum, and Fear Sum. Average pNN50 was significantly negatively related to Average HR, $r(4) = -0.961, p = 0.039$.

At the first recording, the average pNN50 value was higher ($M = 16.87, SD = 10.68$) than at the second measurement ($M = 10.78, SD = 6.68$). At the final recording, when the anomalous point is included, the average pNN50 increased ($M = 32.78, SD = 40.86$). However, excluded that point, the Week 6 average is comparable to Week 3 ($M = 9.33, SD = 6.19$) Overall, two subjects showed overall increases in HRV over the course (+65.18, +6.22) and two showed decreases (-1.04, -12.63). Though three measurements were only collected from three subjects, the data were submitted to a repeated-measures ANOVA. pNN50 values did not differ significantly across weeks, $F(2,4) = 1.124, p = 0.410, \eta^2_p = 0.360$. When the final anomalous recording was excluded, $F < 1$.

Discussion
HRV was shown to increase over time in the Reactive Rovers course, though that trend was largely influenced by a large increase observed in one subject at Week 6. That large increase may not have been a true measurement of HRV, as many disconnections from the device were visible in the file. Without that subject, there would have been a slight decrease in HRV at Week 6 compared to previous recordings, as the other two subjects’ HRV remained quite stable. It is of interest to note the decrease in HRV from the first recording to the second. This decrease may be due to the increasing challenge of the class. At the second recording, the tasks asked of the dogs were much more demanding than at week one. The greater difficulty and stress could explain the HRV decreases at the second recording. By Week 6, however, most dogs appeared more at ease and were less reactive to the other dogs in the room, though the pods were also more widely spaced, increasing the distance between subjects and potentially decreasing the dogs’ stress. At the final week, the dogs showed much more adaptive behaviors as a whole, and were able to walk past others in the class while they were provided guidance and distraction from their owners (such as food rewards and direction changes). During previous weeks, the dogs left class one at a time to prevent conflict, but were able to walk out together during the final session. Despite behavioral changes, HRV was not noted to change significantly.
Between-Group Comparisons

The classes differed significantly in terms of Total Aggression ($F(2,11) = 15.99, p = 0.001$) and Total Fear ($F(2,11) = 11.76, p = 0.002$). Post-hoc tests revealed that both BAT and AHS differed from TCOTC on both fear and aggression, but did not differ from each other (see Figure 7). Overall, pNN50 values were much lower in the training classes (Experiments 2, 3, and 4) than the values obtained in Experiment 1 at rest. Across the reactive dogs in BAT, average pNN50 ($M = 29.92, SD = 9.07$) was comparable to the average pNN50 of the Basic Obedience dogs ($M = 28.54, SD = 11.79$). The average pNN50 in AHS was lower than the other two classes when the questionable recording from Week 6 is excluded ($M = 14.01, SD = 7.11$) (See Figures 8.1 and 8.2). With the anomalous point included, average pNN50 values obtained from each class did not differ significantly, $F(2,13) = 1.114, p = 0.358$. The difference between classes was marginally significant when that point was excluded, $F(2,13) = 3.416, p = 0.064$. Post-hoc tests revealed that AHS displayed significantly lower variability than the other two groups, which did not differ.

All classes showed lower variability than the aggressive group ($M = 36.6, SD = 29.4$) and the non-aggressive group ($M = 64.6, SD = 29.1$) measured at rest from Experiment 1. When looking at individuals in each class, it is of interest to note large between-subjects differences in the Basic Obedience class compared to BAT and Reactive Rovers (see Figures 4, 5, and 6). Dogs in Reactive Rovers appeared much more similar to each other overall than dogs in other classes (with the exception of Subject 1 at Week 6). There may be greater differences in temperament and stress-response among
dogs in Basic Obedience than among the dogs in other classes, who may be more similar to each other.

The recordings were submitted to a two way mixed ANOVA with recording (Week 1, Week 3, Week 6) as the within-subjects factor and class (BAT, TCOTC, AHS) as the between-subjects factor. Few subjects could be included in this test, as many subjects were only measured at two time points and were thus excluded from the analysis. Excluding the anomalous point at Week 6, there was no significant main effect of recording, $F(2,8) = 1.208, p = 0.348, \eta^2 = 0.232$ (with the point included, $F(2,10) = 0.390, p = 0.687, \eta^2 = 0.071$). That is, over all classes, pNN50 did not differ significantly over time. The main effect of class approached significance, $F(2,4) = 4.033 p = 0.110, \eta^2 = 0.668$ (with the point included, $F(2,5) = 0.564, p = 0.601, \eta^2 = 0.184$). No significant recording X class interaction was observed, $F(4,8) = 0.588, p = 0.681, \eta^2 = 0.227$ (with the point included, $F(4,10) = 1.337, p = 0.322, \eta^2 = 0.348$, See Figures 9.1 and 9.2).

When considering Week 3 alone using a one-way ANOVA, the difference between classes approached significance ($F(2,14) = 2.540, p = 0.120$), with AHS showing lower variability than the other classes. Excluding the anomalous point at Week 6, the differences between classes followed a similar pattern ($F(2,7) = 2.085, p = 0.195$).
Chapter 4: General Discussion

The present experiments examined the relationship between HRV, aggressive behavior, and training. The research was motivated by past research in humans and animals that has connected HRV to numerous physical, emotional, and behavioral states. Low HRV may reflect impaired parasympathetic function/vagal tone and ANS dysregulation (Henry et al., 2010). Vagal tone refers to heart rate control exerted by the vagus nerve, which is connected to the same neural structures in the prefrontal cortex, amygdala, and hippocampus that are directly involved in emotional and behavioral regulation (Koval et al., 2013). ANS dysregulation and low HRV may reflect impairment in the ability of the prefrontal cortex to inhibit the amygdala, which is essential in the cardiovascular and autonomic response to stressors and relevant to aggressive behavior. As such, heart rate variability can be used as an indicator of an individual’s behavioral-emotional control capacity (Geisler & Kubiak, 2009; Henry et al., 2010; Koval et al., 2013). Numerous studies in humans and animals have demonstrated this link between HRV and behavioral and psychological functioning, finding decreased parasympathetic influence over heart rate in instances of psychological dysregulation.

The present experiments add to the small body of research that has focused specifically on canine HRV. Experiment 1 found differences between aggressive and non-aggressive dogs that also displayed clear differences in their reactions to the presence of the researchers. These results are in accordance with past research that examined dogs’ reactions to the approach of a threatening stranger both in the presence and absence of their owners (Gásci et al., 2013). Gasci et al. did not find significant changes in HR or HRV in dogs that did not display growling/barking during the stranger’s approach.
However, for dogs that displayed anxious or aggressive responses, the authors found an elevation in HR accompanied by a decrease in HRV. They suggest that these changes from baseline reflect a higher stress response in this group, in accordance with the results from Experiment 1.

However, the results from the training classes present a less clear picture than the group differences observed in Experiment 1. Heart rate variability did not appear to increase significantly over the weeks of training in either the Behavioral Adjustment Training or Basic Obedience course. There was a very slight upward trend, but no clear patterns emerged when dogs were considered individually. For the AHS class, HRV started lower than in BAT and Basic Obedience and decreased at the second recording, perhaps due to the increasingly demanding activities as the weeks went on. At the final recording, two dogs’ HRV remained relatively stable, while one increased considerably, resulting in an average overall increase over the recordings. Without that outlier, the variability at Week 6 was comparable to Week 3, and much lower than BAT and Basic Obedience. In each class, some subjects’ variability showed an overall decrease, while others’ increased over time (see Figures 4, 5, and 6). At a given recording, other events that occurred before class could impact a dog’s HRV. For instance, for one reactive dog, the monitor could not be safely applied at the second recording. The owner explained that the dog was on edge due to having had its nails clipped earlier. Other stressful and unpredictable events may explain some of the individual differences that were observed.

When compared to the variability measurements collected in-home from Experiment 1, the dogs from the Basic Obedience class much more closely resembled the aggressive group than control group. It would be of interest to examine these dogs in their
homes in order to determine if the stress imposed in the training context could explain the low in-class variability. Bertsch and colleagues (2012) estimated that approximately 40% of the variance of a single HRV measurement can be explained by situational effects, so this explanation is plausible. Though they examined HR, not HRV, Maros and colleagues (2008) determined significant differences in heart rate in individual dogs in different situations, suggesting that HRV likely varies by context as well. This group’s low HRV may not be due to self-regulatory impairments or aggression, but situational stress. Situational stress would, of course, affect all dogs, with further decreases in HRV potentially resulting from aggressive temperament. Though the Basic Obedience group would have been expected to show better adaptation to unfamiliar circumstances, one hour a week for six weeks may not have been enough time for anxiety to decrease. As mentioned above, most of the dogs enrolled in BAT had taken the class before. Perhaps these dogs had shown increases when they first took the course and we were measuring them after maximal improvements. Since they had taken the class before, it is possible that the low variability noted was due mainly to reactive temperament and not the situational stress, as they had already become accustomed to the setting and tasks.

The dogs from AHS, who showed even lower variability than BAT and TCOTC at the first two recordings, support these explanations. Unlike in BAT, these dogs were first time students. Their low variability could be explained by both the stress of first-time enrollment as well as aggressive temperament. In addition, the structure of the AHS class was more demanding than BAT; there were six dogs present, tasks were more varied and challenging, and they progressed in difficulty more quickly than in BAT. As such, it is unsurprising that lower variability was observed at the second recording, when
the tasks were more difficult. In comparison to the first class, when contact with other
dogs was minimal, by the second recording at week three, dogs were allowed greater
exposure to the other students. They were asked to walk past and alongside another dog
and were given greater visual access to other dogs, situations that were highly triggering
of reactive behaviors. By Week 6, reactivity had decreased and there were noticeable
behavioral improvements that were not accompanied by changes in HRV, at least when
measured in class.

Inhibiting reactive responses may impose constant stress on aggressive dogs. So,
while we may observe behavioral improvements, they may not be accompanied by
physiological changes that would be indicative of decreased stress. This hypothesis is in
conflict, however, with the results found in the case study of one aggressive dog’s
response to an intervention (Williams, et al., 2010). In that study, a reactive dog’s HRV
was measured before and after the application of gentle bodily pressure. The dog was
placed in a chamber, which was then filled with oats to the level of the neck, preventing
the dog from moving. During the application of gentle pressure, reactivity decreased and
HRV increased. However, this is just a single case. In the present studies, some
individuals showed increases in HRV over the course of training, while others showed
decreases.

It is possible that HRV increases were observed in the cases of decreased
reactivity, while the subjects that displayed decreases in HRV did not have behavioral
improvements. In the future, closer attention should be paid to behavior changes at an
individual level. In the present experiments, behavioral scores were only obtained once,
as many owners did not complete the survey right away. Future research should make
more concrete comparisons between behavior before and after training. Then, it would be possible to determine whether there are HRV differences between dogs that show behavioral improvements and dogs that do not. It is also possible that the application of pressure in the case study first led to increased variability, which then resulted in decreased reactivity. The methods used by Williams and colleagues should be repeated with more subjects in order to determine if the HRV increases are a consistent effect and the directionality of the relationship. That is, do HRV increases precipitate decreasing aggression or does decreased aggression lead to increased variability?

There are several limitations of these studies that should be addressed in future research related to HRV and behavior in dogs. There were large correlations between aggression, fear, and HRV, but they were not found statistically significant due to the limited sample size and inconsistent data collection, so more dogs should be measured in order to further support the relationships observed. There were technical difficulties in connecting multiple Bluetooth devices at once, so future research should continue to explore better techniques for successfully using multiple monitors. In addition, there were only several dogs in each class from whom three usable measurements were collected, limiting the ability to draw meaningful comparisons. Future research could revisit these classes and collect data from more subjects. Further, video recording during classes and in homes may be used in order to note significant events that may have affected heart rate. At present, data was analyzed without consideration of the events occurring at specific time points during the recording. It may be of interest to determine whether HRV could change within one course period with different exercises or events.
There are many possibilities for future research and applications related to HRV and behavior in companion dogs. Further investigations should occur in different types of training classes with more subjects in order to better understand the relationship between HRV and behavior. Some past research has examined the effects of different kinds of training on dogs’ stress and anxiety. Much of the past work was focused on behavioral indicators of stress and different behavioral outcomes of reward-based versus punishment-based training. Not surprisingly, these studies have noted better outcomes when reward-based training methods are used (Hiby, Rooney, & Bradshaw, 2004; Herron, Shofer, & Resiner, 2008). One study looked specifically at behavioral interventions for aggressive dogs, noting much poorer outcomes when “confrontational” training methods were used (Herron, Shofer, & Reisner, 2008). These studies, however, typically examine the effects of owners’ training approaches at home, not in the context of training classes, which may impose additional stress. Further, physiological indicators of stress were not assessed, which may have yielded information that behavioral observations alone cannot. Future research may seek to determine if HRV can predict which dogs are likely to improve and if there are certain training approaches and techniques that are more likely to be effective. Once the relationship between HRV and training is more fully understood, HRV measurements may be used to make methodological refinements during program development.

In terms of pharmacological interventions, Henry et al. (2010) suggested that treatments known to increase vagal activation, as measured by increases in HRV, might improve disordered behavior. Other studies have noted HRV increases specifically with SSRIs and other pharmacological treatments (Balogh, et al., 1993; Linder, et al., 2014).
Since low serotonin levels have been associated with aggressive behavior in humans and dogs, it is unsurprising that SSRIs may be used to improve aggression and may be associated with increases in HRV (Apter, et al., 1990; Reisner, Mann, & Stanley, 1996; Davidson, Putnam, & Larson, 2000; Peremans, et al., 2005). It would be of interest to investigate whether drug-based improvements are moderated by changes in HRV and if drugs or treatment techniques that are specifically aimed to increase HRV could be employed to improve behavior.

In Experiment 1, HRV differences were noted between aggressive and non-aggressive dogs, which may reflect impaired autonomic functioning and impaired self-regulatory capacity. Low variability was also noted in several subjects who were not aggressive, but displayed anxious and fearful behaviors, further supporting the connection between low HRV and more general emotional dysregulation. The results from the first study were then extended to a training context. Results indicated low variability across all subjects, suggesting that training imposes stress on all dogs, though perhaps to a greater extent in reactive dogs. Although the present study could not determine that training has a uniform impact on HRV across all dogs, the differences noted between the in-home and in-class measurements suggest that training does have an impact on physiology. While being training classes may be stressful, that is not to say that they are harmful or should not be used to improve behavior. Future research should continue to investigate how context, behavior, temperament, and HRV are related. As we come to understand the way in which HRV is related to aggression and other emotional regulation and behavioral problems, we may be better able to create interventions that are more likely to be effective. By doing so, we may be able to lessen the stress and suffering
of dogs and owners alike who are coping with aggression and behavioral problems. As treatments are developed, it may be possible to decrease the number of devastating bites and the need for euthanasia.
Chapter 4: Bibliography


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HEART RATE VARIABILITY AND CANINE BEHAVIOR


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This website provides an overview of the Reactive Rover training course.


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Figure 1. Two representative R-R curves for a dog without a bite history (A) and a dog with a bite history (B).
Figure 2. HRV measured by pNN50, the percent of IBIs that differ by more than 50ms, was significantly different between the aggressive group (with bite history) and the non-aggressive group (no bite history). Error bars represent standard error of the mean.
Figure 3. This figure displays the significant negative relationship between pNN50 (the percent of adjacent RR intervals that differ by more than 50ms) and Total Aggression score.
Figure 4. This figure displays pNN50 across weeks for students in Behavioral Adjustment Training. Subjects 2 and 5 showed overall increases in HRV, while 1, 3, and 4 showed decreases. A large increase in variability was observed in Subject 5, while all other dogs’ HRV showed more slight changes over the recordings.
Figure 5. This figure displays pNN50 by recording in the Basic Obedience class. Of note are the numerous missed measurements due to either technical failures or absences from class, which limited our ability to establish conclusive patterns across the entirety of the course. When compared to BAT and Reactive Rovers, there is more variability between subjects.
Figure 6. This figure displays pNN50 for students in the Reactive Rovers course. Two subjects showed overall increases in variability, while two showed decreases. The large jump observed from Subject 1 skewed the average HRV at week 6 of the other two subjects, who displayed only slight changes from the previous recording. However, this point may not have been a true measurement, as many disconnections from the device were visible in the recording.
Figure 7. These figures display Total Fear Scores and Total Aggression Scores by class. Classes differed significantly in terms of Total Fear ($F(2,11) = 11.76, p = 0.002$) and Total Aggression ($F(2,11) = 15.99, p = 0.001$).
Figures 8.1 and 8.2. These figures show average pNN50 value by class over all recordings. The top graph displays average pNN50 with the questionable recording from Week 6 in AHS included. The difference between classes was not significant, $F(2,13) = 1.114$, $p = 0.358$. With that point excluded, the difference was marginally significant, with subjects in AHS displaying lower variability than the other classes, $F(2,13) = 3.416$, $p = 0.064$. 
Figures 9.1 and 9.2. These figures display mean pNN50 value by class and recording.

The top figure includes the anomalous point from Week 6 in AHS. Without that point, there was no significant main effect of recording, $F(2,8) = 1.208, p = 0.348, \eta^2_p = 0.232$. The main effect of class was marginally significant, $F(2,4) = 4.033, p = 0.110, \eta^2_p = 0.668$. No significant recording X class interaction was observed, $F(4,8) = 0.588, p = 0.681, \eta^2_p = 0.227$. 
Appendix A: Survey From Experiment 1

Macalester College
1600 Grand Ave.
St. Paul, MN 55105

Thank you for participating in this study! Below will be several questions related to your dog and his or her behavioral history. Please answer each question to the best of your ability.

**Dog name:**

**Dog sex:**
- [ ] Male
- [ ] Female

**Breed:**

**Neutered/Spayed:**
- [ ] Yes
- [ ] No

**Age:**

**Weight:**

Is your dog currently taking any medication?  
- [ ] Yes
- [ ] No

If yes, please list any medication your dog is taking and the purpose of each medication.

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

Please briefly describe any training classes, work with a private trainer or training you have personally done with your dog:

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

How do you exercise your dog(s)? Please describe both an average day and week.

______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________
______________________________________________________________________

For each item below, please rate your dog on the frequency of the behavior from 1 (never) to 5 (all of the time).

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>All of the time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grows and/or bares teeth when hugged, pulled, or restrained by owner.</td>
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<tr>
<td>Grows and/or bares teeth when picked up, held, or rolled over by owner/family</td>
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<tr>
<td>Behavior</td>
<td>Yes</td>
<td>No</td>
<td>Comments</td>
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<tr>
<td>Growls and/or bares teeth when owner/family member reaches to pet.</td>
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<td>Growls and/or bares teeth when groomed, bathed, or wiped by owner/family member.</td>
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<tr>
<td>Has bitten owner/family member (not including play).</td>
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<tr>
<td>Growls and/or bares teeth when owner/family member approaches dog's food or tries to remove food.</td>
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<td>Steals toys, clothes, or other objects and guards them in a threatening manner.</td>
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<tr>
<td>Growls and/or bares teeth at home when an unfamiliar person approaches.</td>
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<tr>
<td>Growls and/or bares teeth away from home when an unfamiliar person approaches.</td>
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<tr>
<td>Growls and/or bares teeth away from home when an unfamiliar dog approaches.</td>
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<tr>
<td>Accepts being petted by an unfamiliar person.</td>
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<tr>
<td>Growls and/or bares teeth at home when an unfamiliar dog approaches.</td>
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<tr>
<td>Growls and/or bares teeth away from home when an unfamiliar dog approaches.</td>
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<tr>
<td>Displays friendly tailwagging when greeting an unfamiliar person.</td>
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<tr>
<td>Has bitten adult nonfamily person (not including play).</td>
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<tr>
<td>Initiates fights with unfamiliar dogs.</td>
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<tr>
<td>Has bitten another dog.</td>
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<tr>
<td>Growls and/or bares teeth when another dog or cat approaches dog's food or tries to take food away.</td>
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<tr>
<td>Has bitten nonfamily child (not including play).</td>
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<tr>
<td>Is gentle with small children.</td>
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<tr>
<td>Displays friendly tailwagging when greeting at unfamiliar dog.</td>
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<tr>
<td>Plays with most other nonfamily dogs.</td>
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<tr>
<td>Avoids or is fearful of unfamiliar persons (adults).</td>
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<tr>
<td>Avoids or is fearful of unfamiliar children.</td>
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<tr>
<td>Avoids or is fearful of nontargeting unfamiliar dogs.</td>
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</tbody>
</table>


Has your dog bitten an adult (not including play)? □ Yes □ No
If yes, how many times? __________________________

Has your dog bitten a child (not including play)? □ Yes □ No
If yes, how many times? __________________________
Has your dog bitten another dog (not including play)? ☐ Yes ☐ No

If yes, how many times? _______________________

If your dog has bitten - tell us about the severity of the bite(s):
Please check all that apply if there have been more than one bite

☐ Dog snapped, but did not make contact with skin or clothing
☐ Skin/clothing contact by teeth with little or no pressure - no marks or bruising.
☐ Skin/clothing contact by teeth with scratches, red mark(s), and/or bruising - no punctures
☐ Punctured skin one or more times but with relatively little additional damage. No stitches were required
☐ Punctured skin, dog bit and held, or bit and shook head side to side.
☐ Dog bit multiple times during one incident (dog bit, opened his/her mouth, and bit again).
☐ Bites required significant medical care by either a doctor or veterinarian
☐ Dog has killed another dog

Please write any other comments or observations about your dog below:
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Appendix B: CBARQ Questionnaire Items

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Factor and item structure of the C-BARQ. All items are scored on a five-point scale from 0 to 4, with 0 indicating never and 4 indicating always, with the option of selecting “not observed/not applicable” when needed.

1 (Subscale): Trainability (frequency scale)
- Dog returns immediately when called while off leash
- Dog obeys a “sit” command immediately
- Dog obeys a “stay” command immediately
- Dog seems to attend to or listen closely to everything the owner says or does
- Dog is slow to respond to correction or punishment
- Dog is slow to learn new tricks or tasks
- Dog is easily distracted by interesting sights, sounds, or smells
- Dog will fetch or attempt to fetch sticks, balls, and other objects

2 (Subscale): Stranger-directed aggression (severity scale)
Dog acts aggressively
- When approached directly by an unfamiliar adult while being walked or exercised on a leash.
- When approached directly by an unfamiliar child while being walked or exercised on a leash
- Toward unfamiliar persons approaching the dog while it is in the owner’s car
- When an unfamiliar person approaches the owner or a member of the owner’s family at home
- When an unfamiliar person approaches the owner or a member of the owner’s family away from home
- When mailmen or other delivery workers approach the home
- When strangers walk past the home while the dog is in the yard
- When an unfamiliar person tries to touch or pet the dog
- When joggers, cyclists, roller skaters, or skateboarders pass the home while the dog is in the yard
- Toward unfamiliar persons visiting the home

3 (Subscale): Owner-directed aggression (severity scale)
Dog acts aggressively
- When verbally corrected or punished by a member of the household
- When toys, bones, or other objects are taken away by a member of the household
- When bathed or groomed by a member of the household
- When approached directly by a member of the household while it is eating
- When food is taken away by a member of the household
- When stared at directly by a member of the household
- When stepped over by a member of the household
- When a member of the household retrieves food or objects stolen by the dog

4 (Subscale): Dog rivalry (severity scale)
Dog acts aggressively
- Towards another (familiar) dog in your household.
- When approached at a favorite resting/sleeping place by another household dog
- When approached while eating by another household dog
- When approached while playing with/chewing a favorite toy, bone, object by another household dog

5 (Subscale): Stranger-directed fear (severity scale)
Dog acts anxious or fearful
- When approached directly by an unfamiliar adult while away from the home
- When approached directly by an unfamiliar child while away from the home
- When unfamiliar persons visit the home
- When an unfamiliar person tries to touch or pet the dog
HEART RATE VARIABILITY AND CANINE BEHAVIOR

6 (Subscale): Nonsocial fear (severity scale)
Dog acts anxious or fearful
- In response to sudden or loud noises
- In heavy traffic
- In response to strange or unfamiliar objects on or near the sidewalk
- During thunderstorms, firework displays, or similar
- When first exposed to unfamiliar situations
- In response to wind or wind-blown objects

7 (Subscale): Dog-directed aggression (severity scale)
Dog acts aggressively
- When approached directly by an unfamiliar male dog while being walked or exercised on a leash
- When approached directly by an unfamiliar female dog while being walked or exercised on a leash
- Toward unfamiliar dogs visiting the home
- When barked, growled or lunged at by an unfamiliar dog

8 (Subscale): Dog-directed fear (severity scale)
Dog acts anxious or fearful
- When approached directly by an unfamiliar dog of the same or larger size
- When approached directly by an unfamiliar dog of a smaller size
- When unfamiliar dogs visit the home
- When barked, growled or lunged at by an unfamiliar dog

9 (Subscale): Touch sensitivity (severity scale)
Dog acts anxious or fearful
- When examined or treated by a veterinarian
- When having its nails clipped by a household member
- When groomed or bathed by a household member
- When having feet towed by a household member

10 (Subscale): Separation-related behavior (frequency scale)
- Shaking, shivering or trembling when left or about to be left on its own
- Excessive salivation when left or about to be left on its own
- Restlessness/agitation/pacing when left or about to be left on its own
- Whining when left or about to be left on its own
- Barking when left or about to be left on its own
- Howling when left or about to be left on its own
- Chewing or scratching at doors, floor, windows, and curtains when left or about to be left on its own.
- Loss of appetite when left or about to be left on its own

11 (Subscale): Excitability (severity scale)
- When a member of the household returns home after a brief absence
- When playing with a member of the household
- When the doorbell rings
- Just before being taken for a walk
- Just before being taken on a car trip
- When visitors arrive at its home

12 (Subscale): Attachment/attention-seeking (frequency scale)
- Dog displays a strong attachment for a particular member of the household
- Dog tends to follow a member of household from room to room about the house
- Dog tends to sit close to or in contact with a member of the household when that individual is sitting down
- Dog tends to nudge, nuzzle, or paw a member of the household for attention when that individual is sitting down Dog becomes agitated when a member of the household shows affection for another person
- Dog becomes agitated when a member of the household shows affection for another dog or animal

13 (Subscale): Chasing (frequency scale)
- Dog acts aggressively toward cats, squirrels, and other animals entering its yard
- Dog chases or would chase cats given the opportunity
- Dog chases or would chase birds given the opportunity
- Dog chases or would chase squirrels, rabbits and other small animals given the opportunity

14 (Subscale): Energy level (frequency scale)
- Dog is playful, puppyish, and boisterous
- Dog is active, energetic, and always on the go

Miscellaneous (frequency scales)
15 Escapes or would escape home or yard given a chance
16 Rolls in animal droppings or other ‘smelly’ substances
17 Eats own or other animals’ droppings or feces
18 Chews inappropriate objects
19 Mounts objects, furniture, or people
20 Begs persistently for food when people are eating
21 Steals food
22 Nervous or frightened on stairs
23 Pulls excessively hard when on the leash
24 Urinates against objects/furnishings in your home
25 Urinates when approaches, petted, handled or picked up
26 Urinates when left alone at night, or during the daytime
27 Defecates when left alone at night, or during the daytime
28 Hyperactive, restless, has trouble settling down
29 Stares intently at nothing visible
30 Snaps at (invisible) flies
31 Chases own tail/hind end
32 Chases/follows shadows, light spots, etc.
33 Barks persistently when alarmed or excited
34 Licks him/herself excessively
35 Licks people or objects excessively
36 Displays other bizarre, stranger or repetitive behavior(s)

C-BARQ(100) scoring method

The C-BARQ provides a set of quantitative scores for the following fourteen different subscales or categories of behavior:

1. Stranger-directed aggression: Dog shows threatening or aggressive responses to strangers approaching or invading the dog’s or the owner’s personal space, territory, or home range.

2. Owner-directed aggression: Dog shows threatening or aggressive responses to the owner or other members of the household when challenged, manhandled, stared at, stepped over, or when approached while in possession of food or objects.

3. Dog-directed aggression: Dog shows threatening or aggressive responses when approached directly by unfamiliar dogs.

4. Dog rivalry: Dog shows aggressive or threatening responses to other familiar dogs in the same household.
5. Stranger-directed fear: Dog shows fearful or wary responses when approached directly by strangers.

6. Nonsocial fear: Dog shows fearful or wary responses to sudden or loud noises, traffic, and unfamiliar objects and situations.

7. Dog-directed fear: Dog shows fearful or wary responses when approached directly by unfamiliar dogs.

8. Touch sensitivity: Dog shows fearful or wary responses to potentially painful or uncomfortable procedures, including bathing, grooming, nail-clipping, and veterinary examinations.

9. Separation-related behavior: Dog vocalizes and/or is destructive when separated from the owner, often accompanied or preceded by behavioral and autonomic signs of anxiety including restlessness, loss of appetite, trembling, and excessive salivation.

10. Attachment and attention-seeking: Dog maintains close proximity to the owner or other members of the household, solicits affection or attention, and displays agitation when the owner gives attention to third parties.

11. Trainability: Dog shows a willingness to attend to the owner and obey simple commands. Dog is not easily distracted, tends to be a fast learner, responds positively to correction, and will fetch or retrieve objects.

12. Chasing: Dog chases cats, birds, and/or other small animals, given the opportunity.

13. Excitability: Dog displays strong reaction to potentially exciting or arousing events, such as going for walks or car trips, doorbells, arrival of visitors, and the owner arriving home; has difficulty calming down after such events.

14. Energy level: Dog is energetic, “always on the go”, and/or playful.

In addition, the C-BARQ provides useful information on the occurrence of a further 22 miscellaneous behavior problems ranging from coprophagia to stereotypic spinning/tail-chasing.

Each subscale is represented by a number of 5-point scales (questions). Some are graduated scales that measure severity of particular behaviors (e.g. aggression, fear) and are numbered from 0–4 in the questionnaire. The remainder are frequency scales which should be scored as: Never = 0, Seldom = 1, Sometimes = 2, Usually = 3 and Always = 4, except for items 5, 6 & 7 in Section 1. FOR THESE SCALES ONLY, reverse the scores to: Never = 4, Seldom = 3, etc.

To calculate behavior subscale scores, use the following formulae:
“Stranger-directed aggression” score = (questionnaire items 10 + 11 + 12 + 15 + 16 + 18 + 20 + 21 + 22 + 28)/10.

“Owner-directed aggression” score = (items 9 + 13 + 14 + 17 + 19 + 25 + 30 + 31)/8.

“Dog-directed aggression” = (items 23 + 24 + 26 + 29)/4

“Dog-directed fear” = (items 45 + 46 + 52 + 53)/4.

“Dog rivalry” (familiar dog aggression) score = (items 32 + 33 + 34 + 35)/4

“Trainability” score = (items 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8)/8—remember to reverse scoring order for items 5, 6 & 7 (see above).

“Chasing” score = (items 27 + 74 + 75 + 76)/4

“Stranger-directed fear” score= (items 36 + 37 + 39 + 40)/4

“Nonsocial fear” score = (items 38 + 41 + 42 + 44 + 47 + 48)/6

“Separation-related problems” score = (items 54 + 55 + 56 + 57 + 58 + 59 + 60 + 61)/8

“Touch sensitivity” score = (items 43 + 49 + 50 + 51)/4

“Excitability” score = (items 62 + 63 + 64 + 65 + 66 + 67)/6

“Attachment/attention-seeking” score = (items 68 + 69 + 70 + 71 + 72 + 73)/6

“Energy” score = (items 91 + 92)/2

Items 1–76 & 91–92 cannot be removed from the questionnaire without potentially reducing the reliability and/or validity of one or other of the behavior subscales. Other “Miscellaneous” items are optional, and can be removed from the questionnaire as desired. If retained, they should be scored individually, 0–4.

NB: This version of the C-BARQ has been modified since Hsu & Serpell (2003) to improve the reliability of some existing factors, and to include new “Dog rivalry (familiar dog aggression)” and “Energy” factors. The subscales “Dog rivalry”, “Chasing”, “Touch sensitivity”, “Trainability”, “Energy” and “Excitability” have not been formally validated, although they have been shown to have predictive validity in long-term studies of guide dogs (Duffy & Serpell, 2012).

Missing values: Owners may be unable to answer some of the C-BARQ questions for a variety of reasons. These non-responses should be recorded as missing values and the
subscales scores calculated as the average of the remaining completed item scores. As a general rule, if more than 25% of the items in a subscale are missing values, the subscale should not be calculated.

References:
