AGILE: AGility Innovations Leveraging Electronics

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ABSTRACT

For over fifty years, human handlers and their dogs have been participating in the sport of canine agility. Agility involves collaboration between human and dog participants to navigate safely at high speed through pre-designed obstacle courses. While the sport is generally regarded as safe for the dog participants, emerging research has recently shown that over 40% of agility dogs will suffer an injury while training or competing. Despite the sport being relatively mature, very little research has so far been conducted to quantify the performance and welfare of dogs who participate in the sport of agility. In this paper, we present the AGILE project which aims to leverage electronic sensors to measure and analyze external load factors, recognize patterns of activity within the sensor data, and communicate the measurements and recognized activities to handlers. We have created a custom collar-worn activity monitor and assessed the viability of utilizing this unit for collecting agility activity data by conducting an experiment with 22 trained agility dogs. Additionally, we have developed a prototype smartphone application based on input and feedback from agility handlers. Finally, we have evaluated the efficacy of our application to meet the needs of agility handlers with a user study.

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1 INTRODUCTION

The sport of canine agility, which involves human handlers and dogs navigating obstacle courses together, is one of the fastest-growing canine sports in the world [11]. While the sport provides a unique opportunity for engaging dogs in positive cognitive and physical activities, it is not without risk. A recent survey of 4,701 dogs competing in agility competitions found that nearly 42% of agility dogs were injured during their participation in or training for agility sport activities. Our AGILE project aims to leverage wearable sensors coupled with analytics and visualization software to measure external load factors, recognize patterns of activity within the sensor data, and communicate the measurements and recognized activities to handlers. Ultimately, the AGILE team plans to employ these hardware and software innovations to optimize agility performance, evaluate the relationship between load factors and injury, and prevent injuries.

This paper presents the formative steps of the broader AGILE project. Before any large-scale implementation and deployment of wearable sensors and data analytics platforms, we must ensure our tools for measurement are functioning as intended and our analytics software is usable and interpretable by our end users. To evaluate the effectiveness of wearable sensors for measuring external load factors incident on dog athletes during agility activities, we have designed and constructed a collar-worn wearable computer that collects and transmits sensor readings in real-time while dogs participate in agility activities. With this prototype wearable device, we conducted a data collection study with 22 dogs navigating single agility obstacles over multiple repetitions. In this paper, we present a preliminary analysis of this data to gauge the effectiveness of our prototype system.

In addition to our wearable system, we have developed a prototype smartphone application to give agility handlers a reliable and accurate means for measuring and monitoring their dog's athletic activity load to help reduce the incidence of injuries. While several applications currently exist (such as Smarter Agility and AgiNotes) for manually logging and tracking dog agility activities, our application is the first to integrate a wearable system for the automatic tracking of agility activities [4][1]. To better understand the needs and wants of agility handlers and their dogs, we conducted a series of semi-structured interviews. From these interviews, we developed prototypes, gathered user feedback, and arrived at a final prototype that allowed for moderated task-based user testing.

2 PRIOR LITERATURE

While animal (particularly dog) worn computers are becoming commonplace within both ubiquitous computing research as well as commercial products, this work contributes a first step towards investigating wearable computers to improve dog athletic performance and reduce the incidence of injuries during agility sports activities. The AGILE project builds on prior work in dog-worn computers to inform our device form factor, electronics, and software implementations. Additionally, we leverage the findings from studies that have previously utilized sensors to monitor dog health during physical activities.

2.1 Dog-Worn Computers

With the proliferation of wearable computing technologies for human-worn computers in the past several decades, the research area of dog-worn wearable computers has also made significant progress. Dog-worn computers have proven useful for long-term measurement of activities, measurement of reactions to changes in environmental conditions, and have even augmented the abilities of working dogs [9][6] [8][15]. Recently, commercial products have become available such as the FitBark and Whistle collar-worn activity monitors [2][17]. These products effectively perform similar functions for dogs as a Fitbit or Apple Watch fitness tracker would serve for humans [3][5]. While the maturation and democratization of electronics have made it more accessible than ever before to develop wearable computers, unique challenges exist in designing wearable computers for dogs. Above all, the potential wearable devices must not cause any discomfort to dogs, who cannot choose to adjust or remove a wearable themselves. This constraint often imposes strict size and weight restrictions on the device. Additionally, devices designed for dog athletics monitoring must be constructed in such a way that they do not interrupt or impede the normal performance of athletic activities, and do not present a safety risk. In this paper, we will detail the design, construction, and capabilities of a custom dog wearable computer which is suitably lightweight and low profile for the measurement of agility sports activities.

2.2 Dog Health and Performance Analysis

While very little research currently exists utilizing sensors to analyze dog health and performance during agility activities, there have been several prior works that leveraged sensors to analyze dog gaits and assess lameness. For instance, works from Hayati et al. and Ladha et al. utilize wearable IMU sensors to detect injury and assess lameness in dogs [7, 10]. Additionally, Ramey et al. explored the utilization of an IMU coupled with a strain gauge to monitor injuries in sled dogs [13]. Most recently, Vitt et al. found promise in utilizing 9 degrees of freedom (DoF) IMUs for the discrimination of physical activities (including agility course obstacles) of different intensities [16]. The 9 DoF IMU validation work summarized the clinical relevance of IMUs as a potentially valuable tool for assessing pain in dogs while engaging in physical activities. While several studies have used one to several IMUs for assessing pain, lameness, or injuries in dogs during physical exertion, the AGILE project is one of the first research projects to focus on utilizing activity monitors to improve canine training performance in agility while also examining any possible relationships between agility sports participation and injuries.

3 METHODS

The two primary components of the AGILE project are the sensing collar hardware and software along with a smartphone app that allows handlers to view their dog's collar data.

Development of the smartphone application was an iterative process that began with baseline information gathered from a previously conducted agility survey from Sundby et al.[14]. Next, we interviewed agility handlers to gather further insights about their user needs and pain points. Armed with these requirements, we developed a high-fidelity prototype application and conducted a task-based user study with agility handlers to evaluate the application's ease of use and effectiveness in addressing the identified user needs.

The sensing collar development relied on a circuit board that we created for a separate sensing-based research project. Since the board was already equipped with an IMU, barometer, and the necessary power circuitry, we were able to adopt the electronics for utilization in our AGILE collar. In order to equip the board for use as an activity monitor for agility dogs, we created a custom flexible enclosure that could be attached to a collar. To evaluate the effectiveness of our custom activity monitor for measuring physical forces and pressures during agility activities, we conducted a data collection session with 22 agility dogs and their handlers.

3.1 Human User Research

In order to further understand the needs and wants of agility handlers when it comes to activity monitors and their accompanying user interface applications, we conducted a semi-structured interview with seven agility dog handlers. Of the seven handlers interviewed, five were amateur agility competitors, one was an agility coach, and one was a veterinarian. Five of these handlers reported that their dogs had been injured during agility activities. Our key goals in the structured interviews were to assess the main priorities of each handler when training and competing. Additionally, we sought to understand the motivations for each handler to maintain their dog's health and what factors most influence each handler's training methods. Key findings from these interviews were:

- handlers were always searching for the best possible ways to train their dogs while keeping them healthy,
- training session feedback was highly desirable to improve future training sessions,
- agility training requires large amounts of planning and effort in order to improve performance while preventing injuries.

From these findings, we distilled goals for each of three user groups: handlers, coaches, and veterinarians. The handler user group was most interested in tracking performance progress and preventing injuries. The coaches user group was most interested in detailed and specific training feedback for handlers. Finally, veterinarians were most interested in viewing performance data with accompanying videos to assess dog health and detect injuries.

3.2 Application Design

Once our user groups and goals were established, we formulated functional and non-functional design requirements for our smartphone application. The established requirements are listed in Table 1. From the requirements, application feature brainstorming and prioritization were conducted to establish how each requirement would be met by the application. Situation-based tasks within our proposed application, known as user journeys, were utilized to further identify specific interface elements and capabilities of the application that could meet the needs of users within the use cases of the application. For example, agility handlers do not monitor their phones while actively running dogs during training and competition runs, so the application must take this into account and prioritize reviewing data after sessions are completed. Some elements, however, such as repetition counts, are necessary to view during the training session so the application must display some information in real-time. The user journeys led us to consider three key application interfaces: performance data, training log, and calendar planning. Each inference from the application can be seen within Appendix A. The interfaces are separated into distinct application tabs. The performance data tab allows the user to view logged activity data across various time periods including agility activities with specific repetition counts, as well as non-agility exercise activity data. To facilitate the advance planning of dog activities, the calendar interface assists handlers in mapping out their dog's physical activities in advance. A logbook tab provides handlers with a place to store notes and observations about activities as well as view videos, session ratings, and specific activity data and trends. Finally, the home interface tab displays a high-level overview of the daily scheduled activities, data trend highlights, and a record option for capturing activity data.

Functional Requirement	Non-Functional Requirement
Log video, collar data, and notes from agility training and competition sessions	Fast and easy to learn and use
Ability to view and label dog performance data	Universally understandable content
Plan training routines in advance	Clean and minimalist design
Educate handlers on how to better care for their agility dogs	

Table 1: The four functional and three non-functional design requirements which were established for our application based on findings from our semi-structured interviews

Figure 1: The activity monitor collar with sensors, microcontroller, and battery inside of the 3D TPU printed enclosure.

3.3 Activity Monitor Collar

As shown in Figure 1, the main hardware component of the AGILE project is a bespoke microcontroller-based sensing package that attaches to a neck-worn collar. The sensing package is based on an ESP32 microcontroller which provides a dual-core processor for simultaneous sensor sampling and data processing coupled with WiFi connectivity for real-time data streaming. In order to capture measurements of the physical forces agility athletes experience, the sensing package incorporates both an MPU6500 6 DoF inertial measurement device (with a 3 DoF accelerometer and 3 DoF gyroscope) and a BMP390 piezoelectric-based barometer. The sensing package also contains power regulation and battery management circuitry to enable charging and discharge management of the sensing package's 390mWh single-cell lipo battery. To facilitate quick power cycling of the device while dogs are wearing it, a magnetic reed switch-based soft power switching circuit is also integrated into the device. When a magnet is held near the collar, the device switches on. Once the device is on, if a magnet is held near the device for 5 seconds or longer, the device deactivates itself.

By leveraging the ESP-NOW WiFi-based wireless data transfer protocol, our sensor collar's firmware is able to transmit sensor readings in real-time at 100 Hz. To keep the operation of the collar as simple as possible, the firmware is programmed such that as soon as the collar is powered on by a magnet swipe, it immediately begins polling sensors and transmitting data. In practice, once the collar is placed onto a dog, a magnet is swiped near the collar, and within a fraction of a second the handler can begin to see measurements from the unit. While the collar is broadcasting sensor measurements, a second computer with a receiving ESP32 microcontroller logs the sensor readings printed from the receiver's serial port into a CSV file. As the sensor readings are received on the logging side, each measurement is time-stamped before being logged into the CSV file. While time-stamping the measurements on the receiving side does incorporate a delay between the sample being collected and being time-stamped, it eliminates the need for the collar-worn device to synchronize time with the outside world. The elimination of this synchronization reduces the start-up time and setup process of the sensor collar.

To ensure consistent sensor measurements without obstructing any of a dog's natural range of motion, we chose to locate our device on a collar. Most agility dogs are already familiar with wearing a collar so our collar-based device should not impede their regular athletic performance. In the interest of safety, we choose to integrate our device onto a commercially available off-the-shelf (COTS) breakaway collar. The collar includes a quick-release clasp which allows the collar to fall off of the dog in the event of a snag against an agility obstacle. The sensor collar electronics package was attached to the breakaway collar via a 3D-printed thermoplastic urethane (TPU) and nylon webbing. The 3D-printed TPU enclosure incorporates loops on either end to allow a strip of nylon webbing to pass through the loops and outside the back of the enclosure. After a strip of webbing is threaded through the enclosure's loops, it is stitched onto the breakaway collar.

3.4 Activity Monitor Evaluation Experiment

To evaluate the ability of our custom collar-worn activity monitor to collect sensor data while dogs perform agility activities, we organized a structured data collection experiment. Our experiment was approved by the Institutional Animal Care and Usage Committee of Georgia Institute of Technology under protocol: A100512U. We tested 22 trained pet agility dogs of various sizes, ages, and breeds. The dogs represented a variety of breeds including four Labrador retrievers, six border collies, three Weimaraners, two Doberman pinschers, an airedale, a sheltie, an Italian greyhound, and three mixed breeds. Histograms of the dogs' ages and measured height at the withers are shown in Figure 2. During this experiment, each dog performed 3 to 4 repetitions of each of the following agility activities:

- running on the flat agility surface (as a baseline),
- 12 weave poles,
- tunnel (c-shaped, slightly curved),
- dog walk,
- a-frame,
- teeter,
- jump (winged).

Since the dogs varied in size, adjustments to the jump obstacle were made to accommodate each dog's official competition jump height. Each individual repetition of the agility activities was recorded as an individual file from the activity monitor collar. Prior to every repetition, the handler tapped the collar three times in order to designate that the repetition was beginning. After tapping the collar, the handler guided the dog through the agility activity. Once the dog completed the agility obstacle, the recording was concluded. During these recordings, the collar wirelessly streamed the sensor readings in real-time at 100 Hz to a nearby computer that received the wireless transmissions, time-stamped the sensor readings upon arrival, and saved the sensor readings to a CSV file.

During the experiment, we monitored the serial stream of data to ensure the agility monitor collar was functioning properly. Since the collar was being worn by dogs, we monitored the battery level of the collar in real time via the serial stream in order to determine when to change or charge the battery inside the collar.

3.5 Data Analysis

After data collection was complete, we loaded each CSV file from the experiment into a pandas data frame [12]. Next, we resampled the data to 50Hz to eliminate timing irregularities between samples.

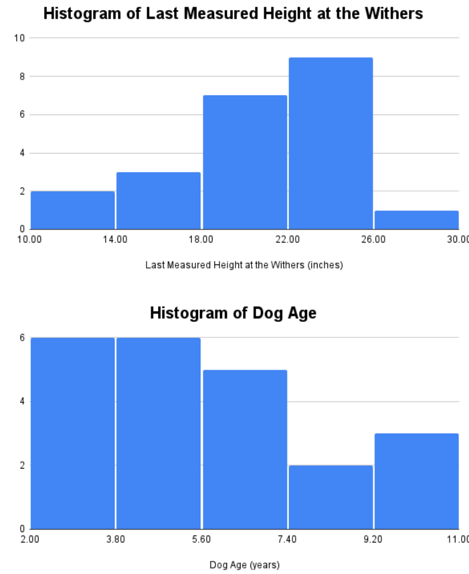

Figure 2: The distributions of dog ages and heights as measured at their withers.

Finally, we applied a low pass filter with a 20 Hz cutoff frequency to the data to reduce high-frequency noise. After all preprocessing steps were applied, we plotted each activity recording file. For ease of visualization, an accelerometer magnitude and gyroscope magnitude data frame column were generated for each of the recording files. Many of the recording files contain up to a minute of extraneous data before and after the agility activity. Additionally, there was often a delay of several seconds between the synchronization taps and the beginning of the agility activity. Before we conducted any analysis, we manually trimmed down the files to remove these sections of extraneous data such that the recordings include only the activity. For example, for each repetition of the jump activity, we trimmed the file to include only the run towards the jump, the jump itself, and a few strides after the landing. Once trimming was complete, we conducted a high-level analysis of the data, computing the average length of each activity and an effort metric for each activity by dividing the cumulative sum of acceleration magnitude by the length of the activity.

4 RESULTS

4.1 Smartphone Application

To evaluate our prototype smartphone application, moderated, task-based usability testing sessions were conducted in person at the Sirius Dog Agility Trial and virtually during the Atlanta Kennel Club Agility Trial. Seven handlers participated in our tests by completing four tasks each and were encouraged to think aloud throughout the process. After each task, we asked follow-up questions to gain quantitative and qualitative insights. After analyzing each session, we were able to discover commonalities and consistencies with the feedback we received from test participants about the overall app and each feature that formed our findings. For the overall app, we found that users are very likely to use this design solution when launched. It also revealed that the navigation needs improvement in some areas, users want to gain objective information about their dog's progress and condition, and those who are poor planners would want to be more organized. For specific feature feedback, we used a difficulty Likert scale of five being extremely difficult and one being extremely easy. The home tab was easy to navigate but caused confusion with the icons that affected navigation ease - some suggested adding labels to icons with the least amount of affordance. The calendar tab was deemed very easy to complete because of its intuitive and familiar architecture. The logbook tab was also seen as easy to navigate, but the font size for the tab menu was too small and light for older users to notice easily. Lastly, the data tab was neither hard nor easy to navigate and complete the task, this outcome is mainly due to confusion about the meaning of icons and the absence of labels for the graph axes. Fortunately, these issues were consistent across many of the participants and can be easily corrected with simple design iterations.

4.2 Activity Monitor Experiment

The statistics for the entire population can be seen in Table 2 for the average duration and Table 3 for the average effort. Duration, measured in seconds, of each activity includes both the lead-in and lead-out in addition to the activity itself. We calculated the average effort metric by taking the sum of the accelerometer magnitude through time for each activity repetition divided by the duration of the activity repetition. On average across the population, the weave poles were the longest activity, but the tunnel was the activity with the highest cumulative effort. The jump was the shortest of all activities on average but was the second highest in the amount of cumulative effort. To further understand the comparative effort each obstacle required, we have included the average length and effort required of running on the flat surface with no obstacles. All of the obstacles aside from the tunnel took a longer amount of time to complete than the baseline running on flat conditions. The majority of non-baseline activities required less effort on average compared to the baseline running on flat condition.

Obstacle	Average Duration (Seconds)	Duration Standard Deviation (Seconds)
Running on flat	4.18	0.75
Tunnel	4.10	0.61
Weave Poles	6.11	1.13
A Frame	4.73	0.71
Teeter	4.31	0.85
Dogwalk	5.34	0.93
Jump	3.98	0.52

Table 2: The average and standard deviation of duration for each activity, measured in seconds

5 DISCUSSION

While the analysis presented in this work is limited to a set of descriptive statistics computed from the experimental data, the

Obstacle	Average Effort	Effort Standard Deviation
Running on flat	1.30	1.28
Tunnel	1.37	1.41
Weave Poles	1.02	1.16
A Frame	0.98	1.00
Teeter	0.88	0.92
Dogwalk	0.95	1.03
Jump	1.28	1.25

Table 3: The average and standard deviation of effort for each activity, calculated by dividing the sum of the accelerometer magnitude over time by the activity duration.

experiment itself can be deemed a success due to the reliability of the activity monitor system. Our bespoke collar-based activity monitor was able to successfully record inertial and pressure data of 711 discrete agility activities across 22 dogs during our experiment. Additionally, we subjectively found the collar easy to use and quick to deploy in the field research setting of our experiment. The combination of magnetic on and off switching functionality coupled with real-time data streaming via the ESP-NOW protocol made the collar quick to cycle between dogs with very little time being required to verify correct sensor functionality at the beginning of each repetition recording. The 6 DoF IMU coupled with the pressure sensor provides data that is subjectively easy to visually discriminate between agility obstacles. Several anecdotal activity repetitions which illustrate the visually recognizable features of the agility obstacles are included in the above figures. For instance, Figure 3 shows the regularity of back-and-forth rotations visible in the gyroscope magnitude data during the weave poles is distinct from all other obstacles. Similar distinct features from IMU data can be observed in the jumps in the accelerometer magnitude data, shown in Figure 4, since the acceleration plateaus while the dog is in midair. Surprisingly, we noticed distinct pressure features that were observed as dogs entered and exited the tunnel obstacles. We speculate that the entry into the tunnel produces a pressure wave as the dog is transitioning from a high volume of air into a semi-enclosed volume (and vice versa for the exit) as shown in Figure 5.

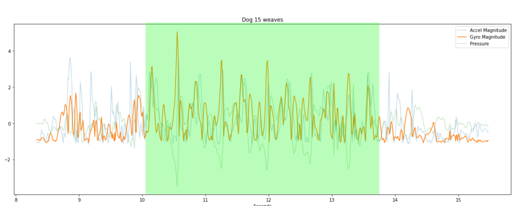

Figure 3: The highlighted region shows where the dog is navigating through the 12 weave polls. Individual weaves can be seen in the peaks of the gyroscope magnitude.

Our high-level data analysis revealed that the baseline condition required the most effort from the dogs according to our effort metric. While this may seem counter-intuitive, we hypothesize this is correct but perhaps means our baseline is more of an upper limit

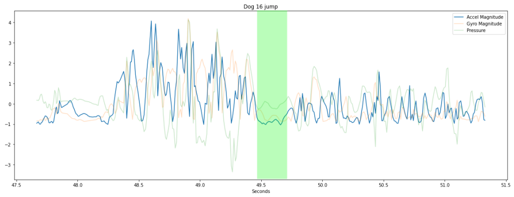

Figure 4: The highlighted region shows when the dog is in the air over the jump. A plateau is visible in the accelerometer magnitude while the dog is in midair.

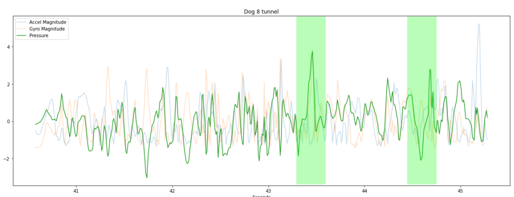

Figure 5: The highlighted regions show when the dog is entering and exiting the tunnel. When entering the tunnel a pressure spike is measured by the barometer and a decrease in pressure is measured when the dog exits the tunnel.

for comparison. In practice, instead of our isolated single-obstacle-based activities, agility activities link several obstacles together one after another. For scenarios where a dog is running towards or away from an obstacle or where a dog is transitioning between two obstacles, they are rarely ever running as fast or as hard as they would be in an all-out sprint. Additionally, in our case with single isolated obstacle-based activities, dogs never sprint the entire way through a repetition since they must slow to navigate through, over, or around the activity. Taking this into consideration, the baseline can be utilized to compare which obstacles were most similar to the amount of effort which would normally be involved with a dog sprinting.

6 CONCLUSION

Despite the rapid rise in popularity of the dog agility sport, little research has been conducted to explore the utility of activity monitors to increase the performance of agility dog athletes and the safety of the sport in general. This project has established a set of tools for studying the physical forces which canine agility athletes experience as they participate in the sport. Our collar-worn activity monitor has proved successful in the reliable collection of inertial and pressure data during agility activities. We observed that agility activities can be visually detected from the sensor data and that the accelerometer, gyroscope, and barometer provide critical information for different obstacles. Additionally, our prototype smartphone app has undergone initial user testing to validate its potential usefulness to agility handlers, trainers, and veterinarians.

As this is a continuing project, our future work includes employing machine learning techniques to build classifiers that can automatically identify agility activities and analyze agility performance. We also plan to study longitudinal data to identify anomalies in canine agility performance and correlate those to possible injuries or fatigue. We will continue to integrate our wearable sensors with our smartphone app to provide agility handlers with a real-time assessment of their dogs' performance, as well as a post-analysis of trends that will inform training and competing plans. This study was the initial step towards making the intense performance sport of agility quantifiable, and hopefully, safer for our canine athletes.

ACKNOWLEDGMENTS

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REFERENCES

[1] 2023. AgiNotes. https://www.aginotes.com
[2] 2023. FitBark Dog GPS & Health Tracker | FitBark Store US. https://www.fitbark.com/store/fitbarkgps/
[3] 2023. Fitbit Official Site for Activity Trackers & More. https://www.fitbit.com/global/us/home
[4] 2023. Smarter Agility Online Dog Agility Tools. https://www.smarteragility.com/
[5] 2023. Watch. https://www.apple.com/watch/
[6] Zach Cleghern, Evan Williams, Sean Mealin, Marc Foster, Timothy Holder, Alper Bozkurt, and David L. Roberts. 2020. Behavioral and Environmental Analytics from Potential Guide Dogs with IoT Sensor Data Informed by Expert Insight. In *Proceedings of the Seventh International Conference on Animal-Computer Interaction*. ACM, Milton Keynes United Kingdom, 1–12. https://doi.org/10.1145/3446002.3446121
[7] Hasti Hayati, Fatemeh Mahdavi, and David Eager. 2019. Analysis of Agile Canine Gait Characteristics Using Accelerometry. *Sensors* 19, 20 (Jan. 2019), 4379. https://doi.org/10.3390/s19204379 Number: 20 Publisher: Multidisciplinary Digital Publishing Institute.
[8] Melody Moore Jackson, Clint Zeagler, Giancarlo Valentin, Alex Martin, Vincent Martin, Adil Delawalla, Wendy Blount, Sarah Eiring, Ryan Hollis, Yash Kshirsagar, and Thad Starner. 2013. FIDO - facilitating interactions for dogs with occupations: wearable dog-activated interfaces. In *Proceedings of the 2013 International Symposium on Wearable Computers (ISWC '13)*. Association for Computing Machinery, New York, NY, USA, 81–88. https://doi.org/10.1145/2493988.2494334
[9] Cassim Ladha, Nils Hammerla, Emma Hughes, Patrick Olivier, and Thomas Ploetz. 2013. Dog's life: wearable activity recognition for dogs. In *Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing (UbiComp '13)*. Association for Computing Machinery, New York, NY, USA, 415–418. https://doi.org/10.1145/2493432.2493519
[10] Cassim Ladha, Jack O'Sullivan, Zoe Belshaw, and Lucy Asher. 2017. GaitKeeper: A System for Measuring Canine Gait. *Sensors* 17, 2 (Feb. 2017), 309. https://doi.org/10.3390/s17020309 Number: 2 Publisher: Multidisciplinary Digital Publishing Institute.
[11] Sassafras Lowrey, CTDI Published: Mar 10, 2023 | 3 Minutes Updated: Mar 13, and 2023. 2023. History of Dog Agility: The Evolution of the Fast-Paced AKC Sport. https://www.akc.org/expert-advice/sports/history-dog-agility-akc-sport/
[12] Wes McKinney. 2010. Data Structures for Statistical Computing in Python. In *Proceedings of the 9th Python in Science Conference*, Stéfan van der Walt and Jarrod Millman (Eds.). 51–56.
[13] Charles Ramey, Arianna Mastali, Cole Anderson, William Stull, Thad Starner, and Melody Jackson. 2023. WAG'D: Towards a Wearable Activity and Gait Detection Monitor for Sled Dogs. In *Proceedings of the Ninth International Conference on Animal-Computer Interaction (ACI '22)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3565995.3566042
[14] Annika E. Sundby, Arielle Pechette Markley, Abigail B. Shoben, and Nina R. Kieves. 2022. Internet Survey Evaluation of Demographic Risk Factors for Injury in Canine Agility Athletes. *Frontiers in Veterinary Science* 9 (2022). https://www.frontiersin.org/articles/10.3389/fvets.2022.869702
[15] Giancarlo Valentin, Joelle Alcaidinho, Ayanna Howard, Melody M. Jackson, and Thad Starner. 2015. Towards a canine-human communication system based on head gestures. In *Proceedings of the 12th International Conference on Advances in Computer Entertainment Technology*. ACM, Iskandar Malaysia, 1–9. https://doi.org/10.1145/2832932.2837016
[16] Molly A. Vitt, Aaron Rendahl, Sara E. Pracht, Brooke M. Knotek, B. Duncan X. Lascelles, Wanda Gordon-Evans, and Michael G. Conzemius. 2023. Nine-axis inertial measurement unit output discriminates activities of varying intensity in the dog. *American Journal of Veterinary Research* 84, 3 (March 2023). https://doi.

org/10.2460/ajvr.22.10.0178 Publisher: American Veterinary Medical Association Section: American Journal of Veterinary Research.
[17] Whistle. 2023. A Behind-the-Scenes Look at the Technology that Powers Whistle Devices - Whistle Blog. https://www.whistle.com/blogs/vet-insights/a-behind-the-scenes-look-at-the-technology-that-powers-whistle-devices

A SMARTPHONE APPLICATION SCREEN SHOTS

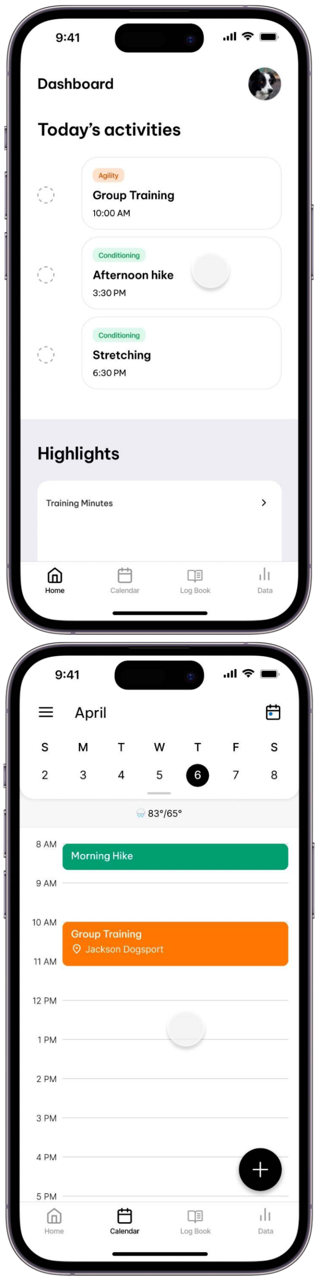

Figure 6: The (a) Home and (b) Calendar interface tabs of the application.

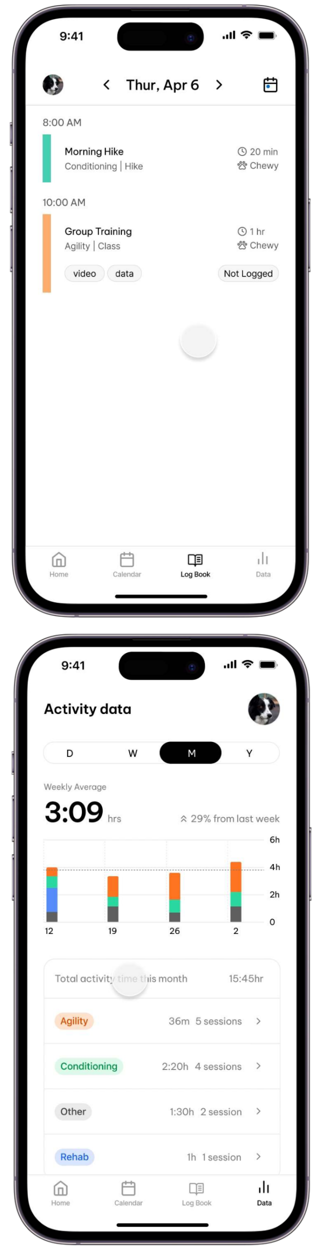

Figure 7: The (a) Log Book and (b) Data tabs of the application.

B AGILITY OBSTACLES

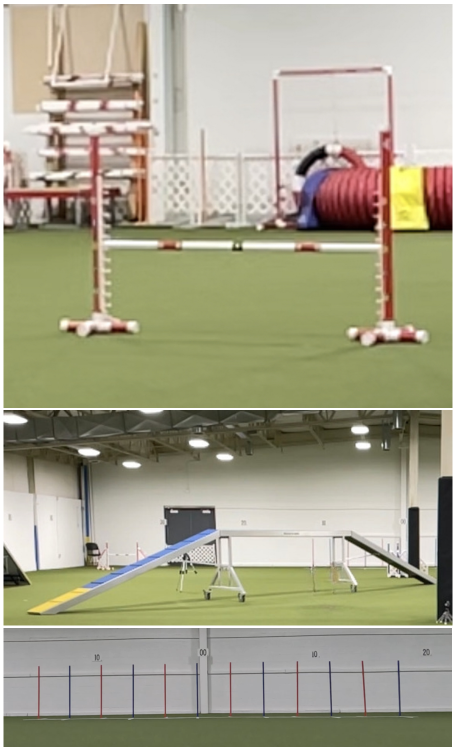

Figure 8: The (a) jump, (b) dog walk, and (c) 12 weaves obstacle.

Figure 9: The (a) teeter, (b) tunnel, and (c) a-frame obstacles.