Automated canine scent-detection apparatus: Technical description and training outcomes

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Abstract

To date, laboratory scent-detection work with dogs has been a manual process whereby some or all aspects of the procedures are mediated by researchers. Automation of this process would eliminate issues associated with cuing, subjectivity in data collection, and reinforcement delivery. Herein, I describe an automated apparatus that can accommodate almost any type of sample that can be brought into the laboratory. The apparatus consists of a 17-segment carousel that rotates behind a panel. Dogs can access a single sample at a time through a port in the panel. Infrared beams are used to detect sample observations and indications, and a dog-activated switch is used to advance the carousel to the next sample. Correct indications are reinforced with an automated feeder. After screening 12 dogs, 5 dogs were selected and trained to use the apparatus to classify samples containing amyl-acetate. All dogs achieved hit rates and correct rejection rates at or near 100% in fewer than 25 half-days of training (mean: 19.6, range: 12 – 24). These data suggest that the apparatus can be used to obtain accurate sample classification without excessive training requirements. Future improvements to the apparatus and training protocols may reduce the training requirements further.

Key words: carousel; dogs; experimental equipment; olfaction, olfactometer

Introduction

Dogs are well known for their exceptional olfactory abilities, which have been of significant value to their human companions for millennia. Dogs have been used for a wide range of applications, many of which involve taking the animal into the field and conducting *in situ* detection (Browne et al., 2006). However, samples can also be collected from the field and evaluated in a laboratory or other controlled setting. Collecting samples from the field may be more efficient than taking a dog into the field. For example, samples that are set up for evaluation by a single dog can be evaluated by multiple dogs. In the laboratory, the conditions under which the samples are evaluated can be controlled and, when conducting applied research or doing operational scent-detection work, arranging for the insertion of samples with known status for maintenance training is more straightforward than doing so in a field setting.

Manual approaches to laboratory scent-detection research with dogs, such as the sample "lineup," are inexpensive to set up and do not have extensive technical requirements. Therefore, these approaches to research and practice may continue to be used indefinitely. However, they are also associated with some disadvantages, particularly those related to potential cuing (see Lit et al., 2011); subjectivity involved in the identification of the indication response and data collection in general; and the immediacy, accuracy, and reliability of reinforcer delivery. For these reasons, Edwards et al. (2017) suggested that an optimal laboratory-based approach to scent-detection research and operations is fully automated. However, few, if any, automated solutions for applied scent-detection research with dogs have been described in the literature and no such apparatus is available commercially.

Ellis et al. (2018) described a semi-automated lineup apparatus which was developed for use with giant African pouched rats. The ten sample wells in the floor of the apparatus are

covered with plates that are manually opened and closed to control access to samples and to ensure that they are evaluated sequentially. Each sample well is fitted with an infrared beam sensor, and the indication response — breaking the infrared beam above a sample for a specified duration — is recorded automatically. Food delivery is also achieved automatically, via activation of a food hopper. This apparatus addresses some of the issues associated with manual lineup approaches, particularly those associated with identifying the indication response, collecting data, and delivering reinforcers. However, with this approach there is still some potential for cuing, given that the handler controls the animal's access to the samples. No reports of such an apparatus for use with dogs have yet appeared.

Mancini et al. (2015) developed a pressure-sensitive sample holder that can be used to automatically detect dogs' responses to samples situated in the holders. By recording the intensity and duration of pressure applied to each sample holder, samples can be classified as indicated or not indicated. The pressure-sensitive sample holders could be situated in a line-up or carousel arrangement. The combination of this technology with other features, such as automatically delivered reinforcement, could represent an automated solution to the lineup or carousel approach to scent-detection research with dogs.

Automated olfactory stimulus operant chambers have been developed for basic research with rats and mice and are available commercially for such purposes (for example, through Med Associates Inc®). These devices employ pumps and valves to pipe air into sampling ports and to introduce the headspace from one or more chemicals into the airstream going to each sampling port. Stimulus presentation, data collection, and reinforcement are entirely automated with this type of apparatus. Hall et al. (2016) developed and used an apparatus that operated under similar principles (piping air with and without target odorants into sample ports) for research with

domestic dogs. However, with this apparatus, most aspects of the procedure were not automated, including response evaluation and reinforcer delivery.

An automated scent-detection apparatus should be capable of detecting observations, detecting indications, delivering reinforcement, and presenting samples to the dog. The *observation* measure provides some indication that the dog has interacted with the sample and, except under unusual circumstances, an observation response should be required before the animal is presented with additional samples. For example, breaking an infrared beam at the entrance of a sample port for at least 500 ms might be considered an "observation." The *indication* measure is used to classify the sample as detector-positive. One example of an indication response is an extended infrared beam-break (3000 ms) in a sample port; another example is the activation of a "yes" lever following an observation response.

The apparatus should be capable of activating a reinforcement sequence. A typical reinforcement sequence involves the presentation of an immediate, distinctive cue followed by food delivery. The reinforcement sequence can be programmed to occur only when certain positive samples are indicated (intermittent reinforcement of hits) but can also be programmed to occur when certain negative samples are correctly rejected. One advantage of the former arrangement, in which only hits and no correct rejections are reinforced, is that the experimenter only needs to have information regarding the true status of some positive samples to program for reinforcement. In many applied research or operational scenarios, confirmed negative samples can be difficult to obtain (see Edwards et al., 2017 for additional discussion of this point).

The automated apparatus should present samples to the dog in such a way that the research requirements can be met without any human input during the session. The samples should be housed in such a way that cross-contamination of sample headspace is minimized.

A general-use fully automated canine scent-detection apparatus that is compatible with a wide variety of samples could be used for research and operations in laboratory settings and would significantly improve the reliability and validity of scent-detection research with canines. Herein, I describe such an apparatus, standard operating procedures for its use, and data obtained in the training phase of a research project that was carried out using the apparatus.

Methods

Apparatus

Hardware. The apparatus consists of a carousel housed in a 1-m^3 aluminum frame (see Figure 1 and S1). The 760-mm diameter carousel sits on a central vertical axle (Figure 1 [g]) and is supported by four omnidirectional castors (Figure 1 [f]) for stability. The carousel contains 17 wedge-shaped 230-mm high segments (Figure 1 [i] and S2) sandwiched between two circular 3-mm thick stainless-steel plates (Figure 1 [h]).

Segments, constructed of 1.2-mm thick stainless steel, are laser-cut with high precision to minimize air escaping from the segment when the top plate is in place. The front of each segment has a 100-mm by 100-mm square opening situated 100 mm above the bottom of the segment. The opening is situated near the top of the segment to prevent dogs from contacting samples placed in the bottom of the segment. A stainless-steel flap is fastened inside each segment with a hinge at the top of the flap (see S2). A weighted L-bracket holds the flap closed unless they are pushed inward. The L-bracket also prevents the flap from opening beyond 28° when the top plate is in position, which prevents dogs from entering the segment far enough to contact samples and prevents the flap from contacting the sidewalls of the segment. Each segment is held in position on the lower plate by stainless-steel pins that protrude vertically from the lower circular plate and

fit inside each corner of the segment, allowing them to be quickly removed and replaced. The volume of each segment is 3.57 L.

The carousel is turned with a motor (Figure 1 [e]) driving an 85-mm diameter wheel with rubber tread (Figure 1 [b]). The motor is mounted vertically on a horizontal plate on the right side of the apparatus. The motor-mount plate is attached to the frame of the apparatus with a single shear pin on the left-rear corner of the plate (Figure 1 [d]). The pivoting motor-mount plate is spring-loaded (Figure 1 [c]) such that the wheel makes contact with the outer rim of the lower plate. The tension of the spring is adjusted to provide adequate traction to turn the carousel but not enough traction to cause injury to an animal or damage to the apparatus in case the carousel's movement is blocked while it is turning and the automated safety feature (described below) fails. A row of optical sensors is positioned on the frame of the apparatus below the carousel in such a way that a 5-bit binary code associated with each segment (achieved with matte black tape applied to the bottom of the carousel's lower plate) can be read and relayed to the controller. An additional two sensors on the outer edge of the plate are used to slow the carousel prior to the target position and stop on position without abrupt movement (binary patterns provided in S3). The intertrial interval (time required to move from one segment to another) when moving between adjacent segments is approximately 1400 ms.

[Figure 1 around here]

The front panel of the apparatus is constructed of acrylic and contains a single 90-mm diameter sample port (Figure 1 [j]) through which a single segment of the apparatus can be accessed by inserting the nose into the port and pushing open the relevant segment's flap. A grid of 3 infrared beam sensors are installed such that the entry of any object larger than 15 mm in diameter into the port will result in the breakage of at least one beam. Sample port beam

interruption is used to detect observation and indication responses. An omnidirectional limit switch (a switch that closes when pushed sufficiently far in any direction), is situated on the right side of the front panel at the same height as the sample port (Figure 1 [a]). This switch is used to advance the carousel to the next sample following an observation response. A strip of LED lights across the top of the front panel illuminates when an experimental session begins and extinguishes when the session ends (note, "session" is used henceforth to refer to the period from when the apparatus has been activated by the researcher until all samples have been evaluated by a single dog and the apparatus has been automatically deactivated).

A circuit board is fixed to the frame near the motor (see S3 for circuit diagram and microcontroller program). The circuit board sends carousel position readings from the optical sensors and sample port beam breaks from the infrared beam sensors to the controlling computer and controls motor movement according to input from the computer and with feedback from the optical sensors. When any of the sample port infrared beams are broken, a speaker on the circuit board emits a beep for the duration of the beam break to provide feedback for successful beam breaks to the dog. The circuit board also controls a remotely operated feeder according to input from the computer. The feeder in use at the time of this writing is a standard feeder manufactured by Premier®, the Treat & Train Remote Reward Dog Trainer®. The handheld remote-control device for this product is wired directly to the circuit board so that "virtual" button presses activate the feeder, which can be positioned anywhere within the vicinity of the apparatus. When the feeder is activated, a relay switch on the circuit board produces a "click" and one or more pieces of dry food are dispensed into the feeder tray, according to input from the program. When food is being dispensed, the feeder also produces distinctive auditory stimuli. A list of standard hardware components used in the construction of the apparatus is provided in S4.

Software. The controlling software written for this apparatus is used to control the apparatus and to receive and compile event data from the apparatus (software provided in S3). The apparatus as used in the research described herein is programed such that a sample port beam break of a specified duration (typically 500 ms) is required for a sample/segment to be considered "observed," at which point activation of the limit switch will result in the carousel rotating to the next programed segment. The software allows for segments to be presented in any order, but when segments are presented out of sequential order, the intertrial interval will not be consistent. Activation of the limit switch prior to an observation response has no programmed consequences. Sample port beam breaks of a longer specified duration (typically 5500 ms) are required for a sample/segment to be considered "indicated." If a sample that is classified as a positive/reinforcement sample is indicated, a reinforcement cycle is activated. The reinforcement cycle consists of a "click" from the circuit board and activation of the feeder and, following a specified duration (typically set at 1000 ms), the carousel automatically rotates to the next programed segment. If a sample with any other classification (other than positive/reinforcement) is indicated, no consequences are programed to occur, and the limit switch must be activated to progress to the next sample/segment. If the reinforcement cycle occurs or the limit switch is activated on the final segment of the session, the apparatus is deactivated and the LED lights on the front panel are extinguished.

While the carousel is rotating, if the infrared beam is broken, the carousel ceases to rotate until the infrared beam is no longer obstructed. This is a safety feature to prevent injury and to prevent the animal from interfering with the rotation of the apparatus, as premature port entry will delay access to the next sample. The feedback beep is not produced if the infrared beam is broken and the carousel has not completed its rotation. When the carousel has arrived at the

programed location and the next sample is ready for evaluation, the speaker on the circuit board emits a brief beep.

The software reads session information from configuration files that specify the following information: (1) maximum session duration; (2) minimum sniff time (sample port beam break duration) required for an observation response; (3) minimum sniff time required for an indication response; (4) delay between the start of the reinforcement cycle and rotation of the carousel; (5) number of times all segments will be presented (if set at "1", each segment will be presented in the programed order once); (6) the number of reinforcers to be delivered each time the reinforcement cycle is activated; and (7) the status of each sample/segment (if a sample status is set at "1," indications of that sample will be reinforced; with all other status numbers, indications are not reinforced and separate numbers can be used for other classification purposes). Separate configuration files are created for individual dogs and modified as needed to meet training and research requirements. Videos of dogs using the apparatus are available in S6.

Subjects

Out of 12 dogs who were evaluated for participation, 5 dogs passed the initial screening process and were trained to use the apparatus (Table I). Of the 7 dogs who were removed from the study during the screening process, 3 were removed because of signs of inter-dog aggression, 2 were removed because of sustained arousal in the laboratory environment, and 2 were removed because delivery of dry food rewards (kibble) was not adequately reinforcing. All dogs were brought into the laboratory by their owners, typically for 2 half-day trainings per week. No animals were housed in the facility overnight. The University of Waikato Animal Ethics Committee approved the training and handling procedures associated with this research (protocol 1014).

Samples

Samples were presented in 7-mL glass vials (60 mm tall, 15 mm in diameter). Negative samples consisted of 4 mL of demineralized water. Positive samples consisted of 4 mL of a 0.25% amyl acetate, demineralized water solution. A small section of aluminum tubing that was riveted into the bottom-rear of each segment of the apparatus held each sample. Sample randomization was achieved by placing the samples in a randomized order in the apparatus and presenting the samples in sequential order to achieve consistent intertrial intervals.

The apparatus was situated in the corner of a 3.2-m by 4.3-m room. The room temperature was maintained at 21° C with an air-conditioning unit situated on the opposite side of the room from the apparatus. After samples were loaded into the apparatus and the top plate was placed over the segments, the trainer allowed a period of at least 10 minutes to elapse prior to running the first session to allow for headspace equilibrium to be achieved. Samples were used for a maximum period of 180 minutes, with multiple dogs evaluating each sample arrangement prior to replacing samples.

Cleaning the apparatus between sessions within days consisted of wiping down the top and bottom plates and the segments with a 67% isopropyl alcohol aqueous solution and allowing the parts to airdry before replacing the segments and placing new samples into the apparatus. Cleaning between days consisted of wiping the top and bottom plates with the same alcohol solution, scrubbing the segments in hot water with a Sunlight® Power Max dishwashing tablet, rinsing the segments, dipping them in a 50% isopropyl alcohol aqueous solution, and allowing them to airdry.

Procedures

Training dogs to use the apparatus involved an initial shaping procedure followed by a gradual transition to dogs' independent operation of the apparatus (see S5 for Standard Operating Procedures for training). The trainer used the method of differential reinforcement of successive approximations to the target behavior (shaping) to train each dog to insert its nose into the sample port and, subsequently, used the same method to train dogs to activate the limit switch. Training of limit switch activation was initially accomplished with direct food delivery but, in subsequent training and testing, limit switch activation provided access to the next sample and did not result directly in food delivery. Because food was only available when positive samples were present, access to positive samples came to function as conditioned (secondary) reinforcement. Some, but not all, switch activations resulted in access to positive samples, so this behavior was reinforced intermittently.

In the first trainings in which both positive and negative samples were presented in the apparatus, some prompting was required before the dogs emitted the appropriate sequence of behaviors on positive and negative trials. Once dogs were responding independently, the trainer no longer entered the room but observed the dogs through closed-circuit video. Sessions consisted of the researcher activating the apparatus, releasing the dog into the room, closing the door, monitoring the dog on a screen in the adjacent room, then opening the door when the session was completed. Positive and negative samples were presented at a ratio of 8:9 or 9:8 positive to negative samples (approximately 50% positive). The indication threshold (beam-break duration required before food delivery on positive trials) was initially set at 1,000 ms and gradually increased over the course of training. Criteria for increasing the indication threshold included a hit rate above 80% for three consecutive sessions and other indications that the dog would continue to perform well with a higher indication threshold, including low latency to

sample observation on each trial. Once accuracy with both positive and negative samples was high and stable, the indication threshold was held constant (optimal indication threshold was determined on an individual basis).

Results

Data related to initial training consisted of notes describing progress with training steps and other relevant observations from training. Accuracy data from these training activities are not reported because some trials involved prompts from the trainer and others did not. Figure 2 displays hit rates and correct rejection rates across training sessions for each dog from the point at which they were no longer reliant on prompts from the trainer to complete sessions and the trainer was no longer in the room with the dog. Phase lines in the figure correspond with increases in the indication duration requirement, as indicated. Some dogs became prompt-independent at different indication thresholds.

[Figure 2 around here]

The most noteworthy consistency across dogs is that hit rate was initially high while correct rejection rate was quite low. As the indication threshold increased, the hit rate remained high and the correct rejection rate increased until both measures were at or near 100%. Table II displays the number of half-days required to train the dogs until they could work independently and the number of half-days and total sessions required for dogs to learn to classify samples accurately once they were working independently. Terminal criteria were defined as three consecutive sessions with both hit rate and correct rejection rate above 80%. This table also displays the mean session length (the time required to evaluate all 17 samples once) in the three final sessions in which criteria were met. Because the initial training period (prior to dogs working independently) did not consist of standard sessions (as defined under Hardware), only

the number of half-days of training are reported for this period. In all training stages, a single researcher trained up to three dogs each half-day. While one dog was in training, the other dogs rested or were taken for walks. Therefore, the half-day metric is a conservative estimate of the time required for training.

[Table II around here]

Discussion

Training data obtained using this apparatus suggest that it can be used to conduct scent-detection research and may be useful for operational work, as accurate sample classification can be obtained without excessive training requirements. Direct comparisons with the training requirements observed in other studies is not straightforward because of differences in protocols, accuracy criteria, the previous experience of subjects used in those studies, and missing details regarding training requirements. In an evaluation of the amount of training required for dogs to accurately identify multiple olfactory targets, Williams and Johnston (2002) found that, following initial habituation, shaping, and training stages, dogs without any known scent-detection experience required approximately 29 sessions, on average, to meet criteria (five consecutive sessions with no errors) with the first target substance, allyl sulfide. Sessions consisted of evaluations of 10 samples, half of which were target samples. Although fewer trials (evaluations of individual samples) were required to meet stricter criteria than applied in the present demonstration, Williams and Johnston used undiluted target and control substances, and they did not specify the amount of time required to complete the early training stages.

Comparisons with studies involving forced choice procedures, in which a single target is selected from a group of samples (such as Lazarowski et al. 2015), are not meaningful because of fundamental differences between forced choice procedures and procedures involving separate

evaluation of all samples, for which the current apparatus was developed. See Gadbois and Reeve (2016) and Edwards et al. (2017) for discussion of the limitations of forced choice procedures, particularly in the context of applied scent detection.

Further refinements to the present apparatus could expedite and simplify the training procedure. One such refinement could entail increased automation of the shaping procedure. For example, the software could be programmed to automatically increase the indication duration threshold following a series of hits or decrease the threshold following a series of misses. Additionally, more salient auditory or visual cues could be used to prompt sample port entry or activation of the switch. The code was modified after the present data were collected such that two brief beeps are emitted when the carousel has completed its rotation to the next programed segment. This change was made with the intention of reducing sample port entries before the next segment is in position. The standard operating procedures, particularly for shaping, improved over the course of the present demonstration and could be improved further, thereby reducing the time required for training. One such improvement was the addition of instructions for dealing with dogs who had learned to break the beam but not to open the segment flap. Some of the dogs' training was delayed prior to this addition.

When the apparatus is configured to reinforce hits and not correct rejections, as it was in the demonstration reported herein, the indication duration threshold is an important determinant of the correct rejection rate. Indications of negative samples function as self-imposed "timeouts." Because the duration of false indications is determined primarily by the indication threshold (the response duration required for reinforcement of positive sample indications), with longer indication thresholds, the self-imposed timeout is also lengthened. An investigation of the

specific influence of the indication threshold on hit rate, correct rejection rate, and other performance measures is currently underway.

To evaluate the airtightness of the segments, a leakage test was conducted in which 1 μL of 99.5% purity ethyl acetate was placed in one segment and air was sampled from the adjacent segment for 5 min with the front flap of the sampled segment open. Ethyl acetate was detected in the sampled segment at 0.03% of the concentration in the spiked segment (see S7 for a detailed description of this test and the results). This test revealed that some leakage occurred and, therefore, that some improvement to the airtightness of the segments is possible. Given that high specificity (correct rejection rate) was obtained in the present analysis, however, this degree of leakage may not be problematic. Furthermore, such tests have rarely, if ever, been reported for alternative canine scent-detection apparatus (e.g., line-up approaches), which are likely to have a higher degree of cross-contamination (leakage) given that samples are typically not enclosed.

This apparatus was developed with the aim of improving laboratory-based research and operations with scent-detection dogs (for example, medical detection research and operations), and not to serve as a general training resource for dogs that will eventually work outside of a laboratory setting. The extent to which performance with this type of apparatus would generalize to performance in the field is unknown and would likely depend upon the specific nature of the field work; such research may be warranted.

One of the greatest obstacles to widespread adoption of this type of apparatus may be the cost and technical expertise associated with the construction and maintenance of such an apparatus. The prototype described herein was constructed at a cost of approximately $5,000 (USD), but the technical support was not included in these costs, as an experienced full-time technician was available to support the development and construction of the apparatus. However,

material costs associated with a prototype are often higher because of the requirement of custom components and the need to purchase or construct a component multiple times when the first iterations are not successful. It is likely, therefore, that such a device could be manufactured commercially at a cost that would be affordable for most research groups or those interested in using the apparatus for operational purposes. In the absence of a commercially available apparatus, researchers with adequate financial and/or technical support should be able to construct a functional apparatus of this sort using the present description as a reference.

Conflict of Interests

The author declares no conflicts of interest.

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Table I. Dog characteristics; NM indicates neutered male, NF indicates neutered female

Dog	Breed	Age	Weight	Sex
Ash	American Staffordshire Terrier mix	1	35 kg	NM
BJ	Beagle	10	12 kg	NF
Bramble	English Springer Spaniel	3	24 kg	NF
Onyx	Labrador Retriever	2	40 kg	NM
Rylea	Labrador Retriever	6	23 kg	NF

Table II. Number of half-days of training required to complete initial training stages; number of half-days of training and number of sessions (completed within those half-days) required to meet criteria following transition to fully automated training conditions; mean session length during sessions in which training completion criteria were met

Dog	Habituation, Shaping, & Training with Prompts[a]	Automated Training	Mean Session Length[b]
Ash	17 half-days	7 half-days; 37 sessions	165 sec
BJ	7 half-days	5 half-days; 30 sessions	177 sec
Bramble	19 half-days	4 half-days; 35 sessions	165 sec
Onyx	18 half-days	4 half-days; 19 sessions	145 sec
Rylea	12 half-days	5 half-days; 29 sessions	168 sec

[a]Session data are unavailable for initial training stages as a variety of training activities of varying durations were carried out during these stages.

[b]Data are from the three sessions in which accuracy criteria (hit rate and correct rejection rate above 80%) were first met.

Figures

Fig. 1. Line drawings of the apparatus showing (a) the omnidirectional limit switch for advancing to the next segment, (b – e) the drive wheel mechanism for rotating the carousel, (f) casters for stabilizing the carousel, (g) the vertical axle, (h) the top and bottom plates of the carousel, (i) the sample segments, and (j) the sample port. See main text for additional details.

Fig. 2. Hit rate and correct rejection rate for each dog while training under automated conditions. Phase lines indicate changes in the minimum response time required to indicate a sample as positive.

Figure 1

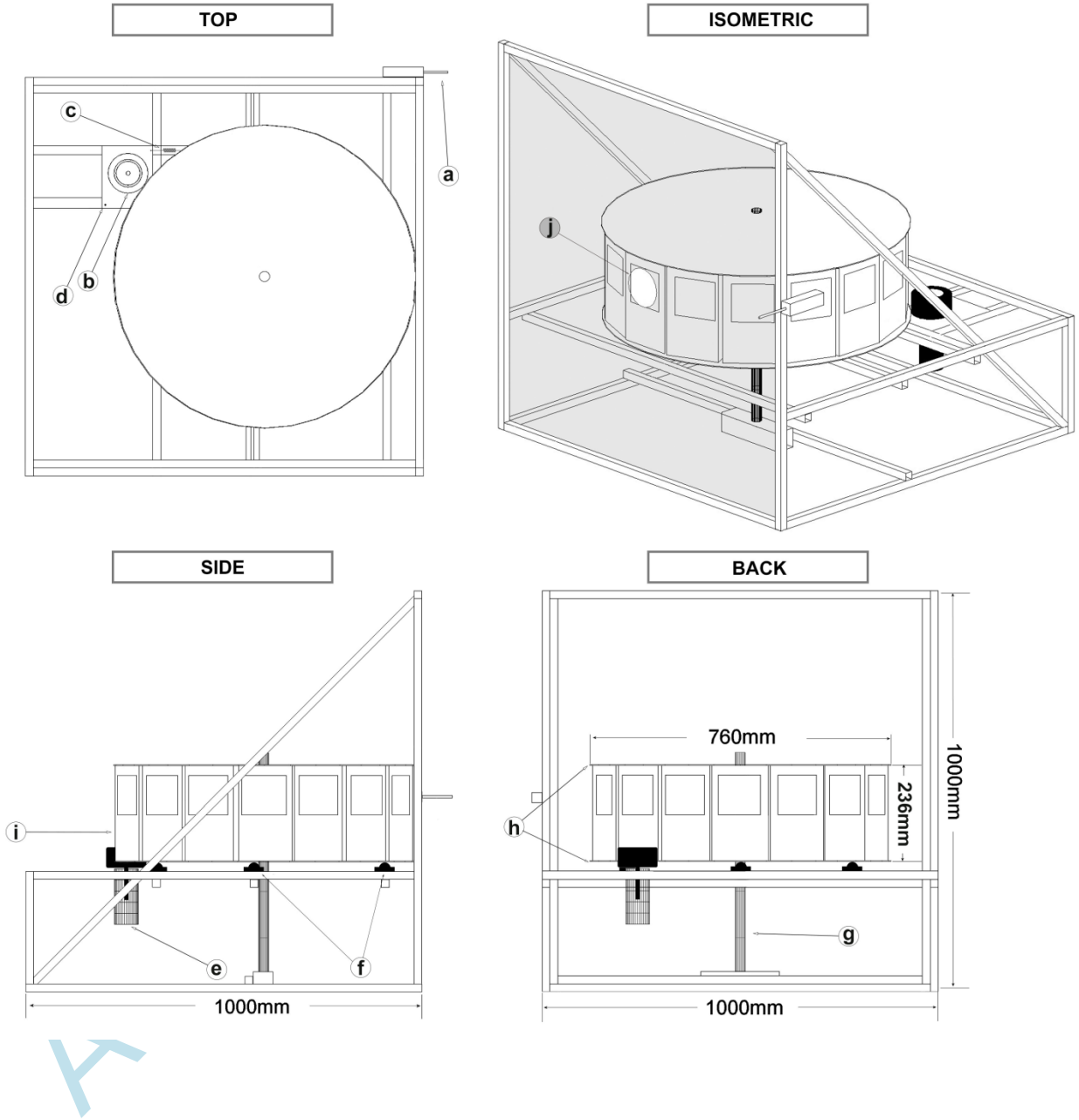

Figure 2