

Patterns in veterinary perimortem observations suggest mechanistically-obscure, death-correlated, physical phenomena

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Abstract

Healthcare workers in human hospice sometimes report surprising experiences at the time of their patients' death, such as: sudden temperature changes, electrical malfunctions, and even glowing lights or mist-like formations around the body. We sought to explore whether veterinary professionals performing animal euthanasia have the same "Perimortem Observations" (PMOs), and whether these are merely coincidental or psychological in nature, or involve mechanistically-obscure physical phenomena.

An online, anonymous survey was distributed through a veterinary trade magazine, in-person at veterinary conferences, and through gated online veterinary communities. There were 581 completed responses to our survey, primarily from the USA. Analysis of responses indicates that 1) the same PMOs that occur among human healthcare workers also occur among veterinary professionals during animal euthanasia, 2) a majority of PMOs involve simultaneous observations by multiple individuals present, 3) some PMO types are more tightly temporally correlated with time of death than others, 4) many PMO features, shared across individual responses, are difficult to explain by known physical mechanisms, 5) the psychological effects of PMOs are overwhelmingly more likely to be positive than negative, and 6) a majority of veterinary professionals support PMO research.

Our findings suggest that many PMOs are not hallucinations or mere coincidences, but instead are observations of mechanistically-obscure, death-correlated, physical phenomena that can be recorded and studied by scientific instrumentation during routine veterinary euthanasia procedures.

Introduction

Studies in 2018 and 2022 by Claxton-Oldfield et al. found that hospice workers sometimes have surprising experiences at their patient's time of death, including rapid temperature changes (17.1% - 31.8%), electrical malfunctions (0% - 47.6%), glowing lights (5.7% - 13.6%), and mist-like formations (0% - 13.6%) around the patient's body (^{1,2}). Such experiences have also previously been reported by Fenwick et al. in 2010 (³).

Unfortunately, these past studies used terminology that pooled together experiences of both the dying themselves and of healthy bystanders. This comingling of experiences creates difficulty in productive scientific discussion because experiences of the dying may be side effects of natural neurological decline or pharmaceuticals administered during the dying process (^{4,5}), while experiences of healthy bystanders (medical professionals in particular) are harder to explain. Therefore, we have coined the term "Perimortem Observations" (PMOs), to refer specifically to observations of healthy bystanders at another individual's time of death, and the current study focuses primarily on PMOs of healthcare professionals.

PMOs have been reported to have overwhelmingly positive effects on those who experience them, with one study finding that 63% of healthcare workers consider them to be profound spiritual events (⁶), and relatives of the deceased have described PMOs as positive life-affirming experiences (⁷). Perhaps because of these effects, a majority of hospice workers are very interested in learning more about PMOs, with one survey showing 91.7% support (⁸).

Unfortunately, studies on PMOs among healthcare workers to date have not adequately addressed whether hallucination, or other purely psychological explanations, may be involved. Furthermore, they have often involved small sample sizes, possibly because hospice workers are only occasionally present at a patient's time of death (^{9,10}). Meanwhile, many veterinarians are present at a large number of animal deaths, allowing the possibility of more PMOs and a much larger sample size (¹¹). In addition, the frequent presence of multiple individuals during an animal's euthanasia allows simultaneous observations to exclude the possibility of PMOs being purely psychological in nature. Finally, establishing that PMOs occur during animal euthanasia would

greatly facilitate future research on this topic.

Euthanasia is a common procedure in veterinary medicine ⁽¹²⁾, and has evolved into a pseudo funeral event for many people seeking a more intimate experience ^(13,14). It can occur in a clinic, in a home, or even an outdoor setting ⁽¹⁵⁾. The modern approach to euthanasia includes the administration of a sedative or anesthetic to induce sleep before the euthanasia procedure itself is carried out ⁽¹⁶⁾. Veterinary practitioners are expected to monitor the patient for signs of death, including auscultating the heart to pronounce the patient deceased at the moment they suspect cardiac arrest. Other signs of death include respiratory arrest, body stretching, muscle fasciculations, bladder/bowel release, and corneal glazing ⁽¹⁷⁾.

In the present study, we conducted a survey to:

- 1) Determine whether PMOs occur during animal death.
- 2) Assess the possibility that PMOs are not hallucinations or mere coincidences, but instead involve physical phenomena that are death-correlated and mechanistically-obscure.
- 3) Assess the psychological effects of PMOs on veterinary professionals and bereaved families.
- 4) Quantify support for this research within the veterinary community.

In addition to inquiring about the types of PMOs previously reported by Claxton-Oldfield, we also asked veterinary professionals whether they had observed behaviors of nearby animals or young children that coincided with the patient's time of death. This was done to assess whether these animals and children might be experiencing PMOs of their own, facilitated by the greater olfactory and auditory sensory abilities of some animals ⁽¹⁸⁻²²⁾, and the greater visual sensory abilities of both animals and young children ⁽²³⁻²⁸⁾, compared to adult humans. While all humans have photoreceptors in their eyes capable of detecting ultraviolet light (UV) ⁽²⁹⁻³²⁾, the crystalline lenses of most adults are opaque to these wavelengths, thereby preventing UV from entering the eye ⁽²⁵⁻²⁸⁾. However, this is not the case for animals ^(23,24) and young children ⁽²⁵⁻²⁸⁾, whose crystalline lenses are transparent to UV, allowing UV light stimuli to evoke neural activity in the visual cortex of children, but not adults ^(25,27).

Within this manuscript, to distinguish between the three PMO categories surveyed, we will use the terms animal-PMO, child-PMO, and environmental-PMO to refer to perimortem observations of animal behavior, child behavior, and environmental phenomena, respectively.

Methods

Ethics:




This study was approved by the Colorado State University Institutional Review Board (IRB Protocol #6890). All experiments were performed in accordance with the relevant guidelines and regulations of Colorado State University and the Declaration of Helsinki. Informed consent was obtained from all participants prior to participation.

Survey Design:



An online, anonymous survey was designed using Qualtrics XM. Details of the survey design and validation can be found in the Supplementary Materials. The survey collected basic demographic data, including the approximate number (1 - 50; 50 - 200; 200 - 1000; >1000) of euthanasias performed by respondents during their career. This was followed by an introductory paragraph stating, “Workers in human hospice sometimes report surprising experiences at their patients' time of death. This survey assesses the degree to which such 'time of death experience' may also occur in the veterinary profession.” This was followed by three multiple-choice questions regarding animal-, child-, and environmental-PMOs occurring within a time window “during, or right after, a patient’s cardiac arrest”. These questions, along with multiple-choice PMO options, are shown below, along with respective images that will be used in all subsequent figures.







During, or right after, a patient's cardiac arrest, have you ever

- seen nearby animals do the following

- Stare up into the air 
- Start/stop vocalizing 
- Approach/depart from the body 
- Other

- seen children do the following

- Stare up into the air 
- Point into the air 

- Other
- experienced the phenomena listed below
 - Sudden temperature change in the room 
 - Sudden air flow (e.g., curtains moving, fireplace flames “whooshing”) 
 - Electrical malfunction (e.g., flickering lamps, clocks stopping) 
 - Glowing light around the body 
 - A "misty" or "cloud-like" formation around the body 
 - A "wavy" visual distortion in the air around the body 
 - Other

Respondents who reported a PMO were subsequently asked the approximate number of times they had made such an observation (1, 2-5, ≥ 6), whether anyone else made the observation at the same time (“Yes, someone else noticed too”, “I’m not sure”, “No, just me”), and how the experience affected themselves and others present (“Positive”, “Neutral”, “Negative”). Finally, they were asked for an optional long-form description of the experience. A copy of the full survey can be found in the Supplementary Materials.

Soliciting Responses:

No compensation was provided to respondents. The survey was promoted through the official publication of the American Animal Hospital Association (AAHA). It was also promoted in-person at the North American Veterinary Conference (NAVC) Veterinary Meeting & Expo (The largest veterinary conference in North America), at the Oregon Veterinary Medical Association annual conference, the Student Chapter of the American Veterinary Medical Association (SAVMA), and the Redwood Empire Veterinary Medical Association monthly meeting. Finally, the survey was also promoted in posts on the following gated veterinary professional Facebook groups: Veterinary Professionals Forum, Pet Death Doula Cafe, Housecall & Mobile Veterinarians, IAAHPC Members Group, DVM Moms, Companion Animal Euthanasia Discussion Group, and Open Minded Scientists. Further details of these online groups can be found in the Supplementary Materials.

To reduce self-selection bias, we kept the survey topic somewhat vague in promotional materials and explicitly invited responses from individuals who did not think they had PMOs. The text used in promotions can be found in Supplementary Materials. To reduce attrition bias, the survey was designed to take <5 minutes for those who reported PMOs and <2 minutes for those who did not.

Data Analysis:

Data Cleaning:

Data was exported from Qualtrics XM and analyzed using Matlab and GraphPad Prism. Unless otherwise stated, analysis was only conducted on completed survey responses, and responses of “Other” to the multiple-choice PMO questions were excluded from analysis. For calculations of percentages in our analyses, any instances with $n \leq 5$ were not included (e.g., Figure 5-A, 6, and 8). One exception is in Figure 5-C, in which individual percent contributions to a whole are depicted, and the total n is visually depicted and explicitly noted.

Grouping Decisions:

For all analyses in which comparisons were made between different euthanasia settings (e.g., Figure 2-Top and 3-B), the responses of shelter and clinic respondents were combined into an “in-clinic” category due to the low number of shelter respondents ($n=16$).

Statistical Tests:

To assess the relationship between the number of a respondent’s career euthanasias and the probability of them reporting PMOs, an ordinal logistic regression analysis was conducted. These results are plotted in Figure 3-A, with representative “slice” plots generated for the outcome classes of 10, 21, and 30 euthanasias (21 was selected because 20 was not present in the dataset).

To compare the number of PMOs reported by in-home and in-clinic respondents (Figure 2-Top), a two-proportion z-test was used.

Rough approximations of the frequency of PMOs (Figure 2-Bottom) were calculated from the subpopulation of respondents who reported ≥ 1 PMO, using their reported number of career euthanasias and the number of times they reported the PMO occurring within their career. To compare the pattern of responses in Figure 2-Bottom (frequency of PMOs) to the pattern of responses in Figure 2-Top (percent of veterinary professionals reporting PMOs), a Pearson correlation analysis was conducted.

To assess whether any combination of PMO types were likely to be co-reported by individual respondents, we took the number of respondents reporting “PMO type X” and calculated the percentage of these respondents that also reported “PMO type Y”. This was then plotted in a heat-map to allow visualization of patterns (Figure 7).

Handling of Long-Form Responses:

Although our survey explicitly asked about PMOs occurring “during, or right after, a patient's cardiac arrest”, we quantified the precision of this timing by analyzing long-form descriptions that respondents had optionally contributed to the survey. For each type of PMO, we sorted long-form descriptions that mentioned timing into the following time windows:

- 1) between injection of sedative drug and euthanasia drug
- 2) between injection of euthanasia drug and cardiac arrest
- 3) immediately after cardiac arrest
- 4) at a more vaguely defined time “after” cardiac arrest

Percentage distributions were then calculated and plotted in Figure 5. Details of this sorting can be found in the Supplementary Materials.

Results

We received 648 responses with a 90% completion rate, resulting in 581 completed survey responses. As seen in Figure 1-A, bursts of responses occurred after each survey promotion (solid line with black dots); however, the cumulative percentage of respondents who reported ≥ 1 PMO (PMO-rs) remained relatively constant throughout, starting at 72% and ending at 66% (dashed line). This was even more the case for those reporting ≥ 1 environmental-PMO, with the percentage starting at 24% and ending at 19% (not shown in figure). As shown in Figure 1-B, respondents were primarily veterinarians (84.3%) from the USA (91.1%), euthanizing cats and dogs (96.4%). Those conducting euthanasia in a veterinary clinic were the largest group (59.1%), followed by in-home (38.1%), and animal shelter (2.85%).

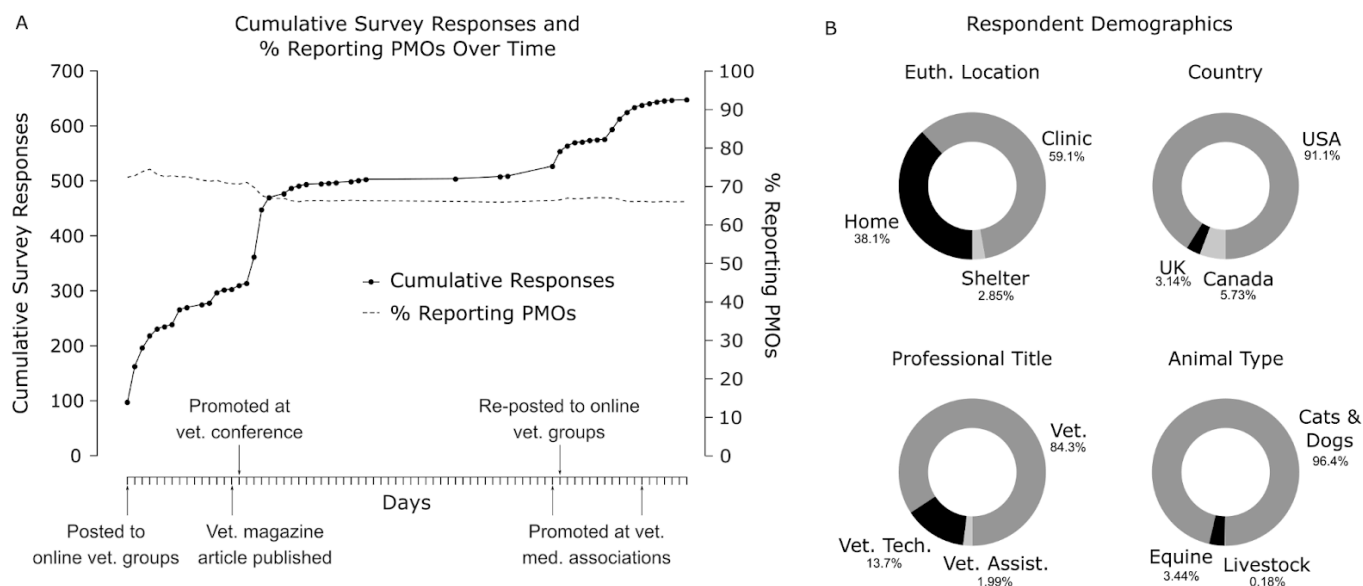


Figure 1. A) A timeline of the 80 days in which the survey was active. Promotional activities are shown on the X axis. The cumulative number of survey responses over time is indicated by the solid line with black dots, which is plotted with respect to the left Y axis. The black dots indicate ≥ 1 response on that day. The cumulative percent of respondents reporting ≥ 1 PMO is indicated by the dashed line, and is plotted with respect to the right Y axis. B) Demographics of respondents, including primary location of euthanasia, country of residence, professional title, and most common animal type(s) euthanized.

Animal-PMOs were reported by 63% of respondents, child-PMOs by 4%, and environmental-PMOs by 19% (Figure 2-Top). Veterinary professionals conducting euthanasia in-home (vs. in-clinic) were significantly more likely to have the following PMOs: animal-“stare up into the air” ($p=0.0050$), animal-“start/stop vocalizing” ($p<0.0001$), animal-“approach/depart from the body” ($p<0.0001$), “sudden air flow” ($p<0.05$), and “electrical malfunction” ($p<0.0001$). The pattern of veterinary professionals reporting each type of PMO (Figure 2-Top) was similar to that of the relative frequency of each type of PMO (Figure 2-Bottom), which was calculated only from those that had reported ≥ 1 PMO. Pearson correlation analysis reveals that this similarity in patterns was statistically significant ($r = 0.95$; $p < 0.0001$).

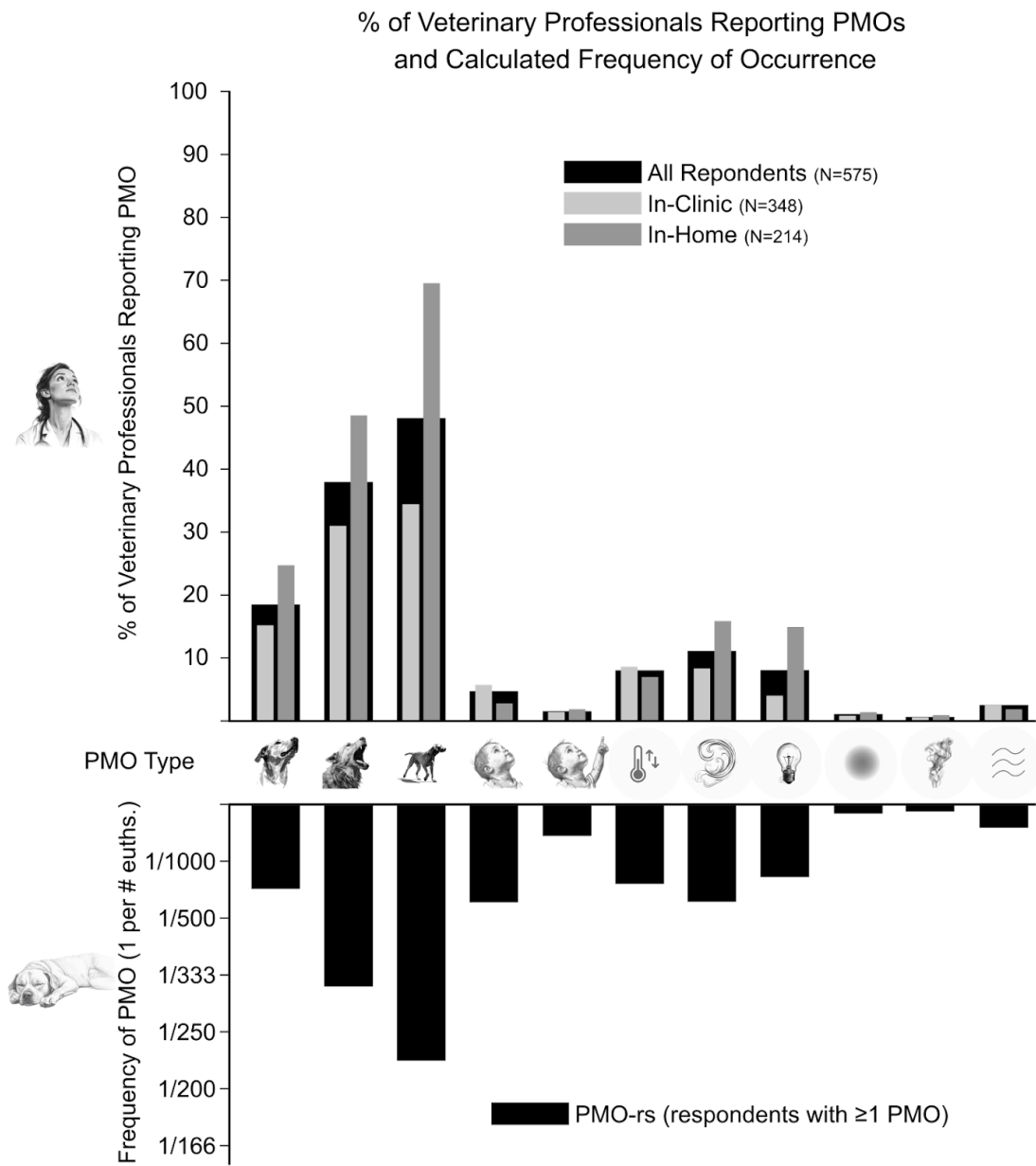


Figure 2. PMOs are listed pictorially on the X axis in the same order in which they were presented in the survey (see Methods section). Top: Percentages of veterinary professionals reporting each type of PMO. Black bars show the overall percentage of all survey respondents. Light-grey bars and dark-grey bars represent In-Clinic and In-Home respondents, respectively. Bottom: Frequencies of PMOs reported by PMO-rs (respondents with ≥ 1 PMO).

Ordinal logistic regression analysis revealed that a higher number of career euthanasias was associated with more environmental-PMOs ($p < 0.01$, $\beta = -0.0009$), and more PMOs in general ($p < 0.0001$, $\beta = -0.0015$), as shown in Figure 3-A. Veterinary professionals conducting euthanasia in-home had significantly more career euthanasias than those conducting euthanasia in-clinic ($p < 0.0001$; two-proportion z-test), as seen in Figure 3-B.

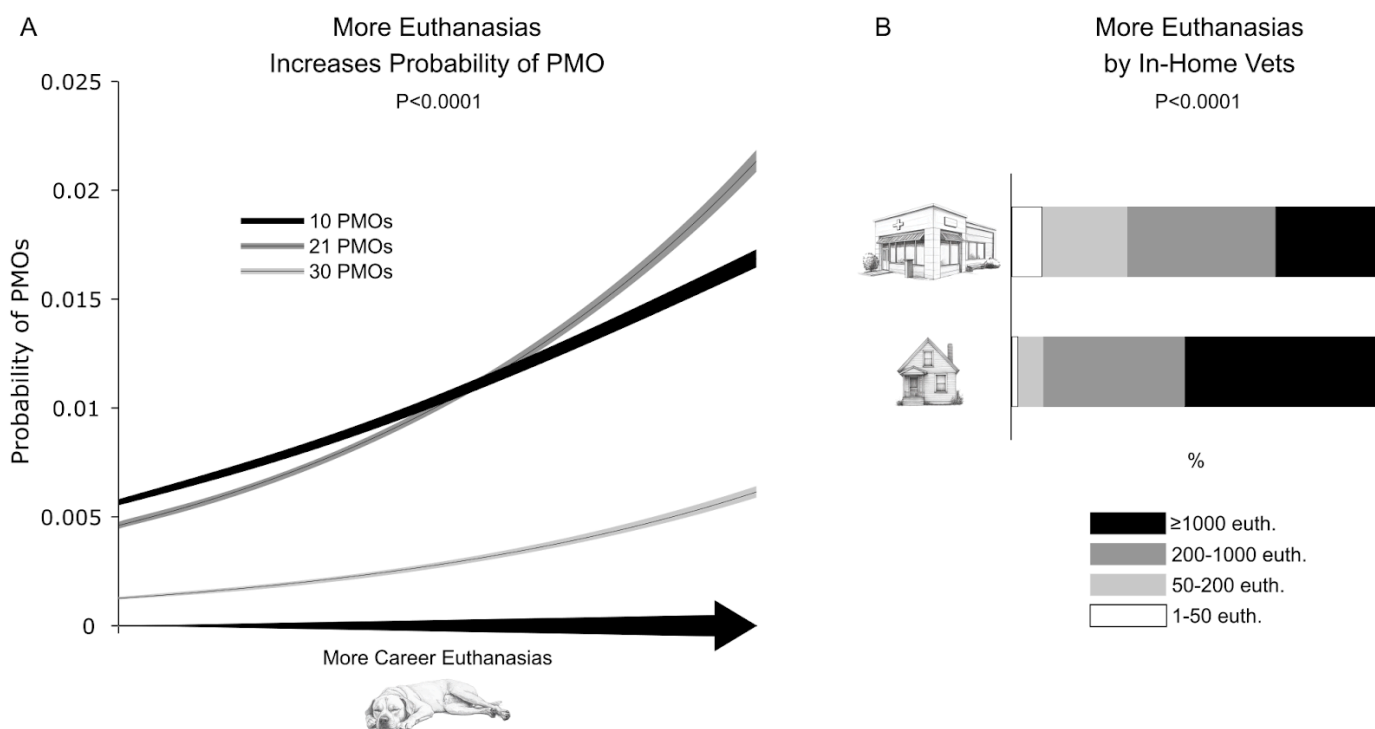


Figure 3. A) Representative output of ordinal logistic regression analysis, where each curve represents the estimated probability of a specific outcome class (10, 21, or 30 PMOs) across a range of career euthanasias reported. Shaded regions represent 95% confidence intervals for the predicted probabilities. B) Stacked bar graphs show a higher number of career euthanasias by in-home vs. in-clinic respondents.

Figure 4 depicts the most commonly reported PMOs paired with one or more long-form descriptions provided by survey respondents. Additional long-form descriptions can be found in the Supplementary Materials.

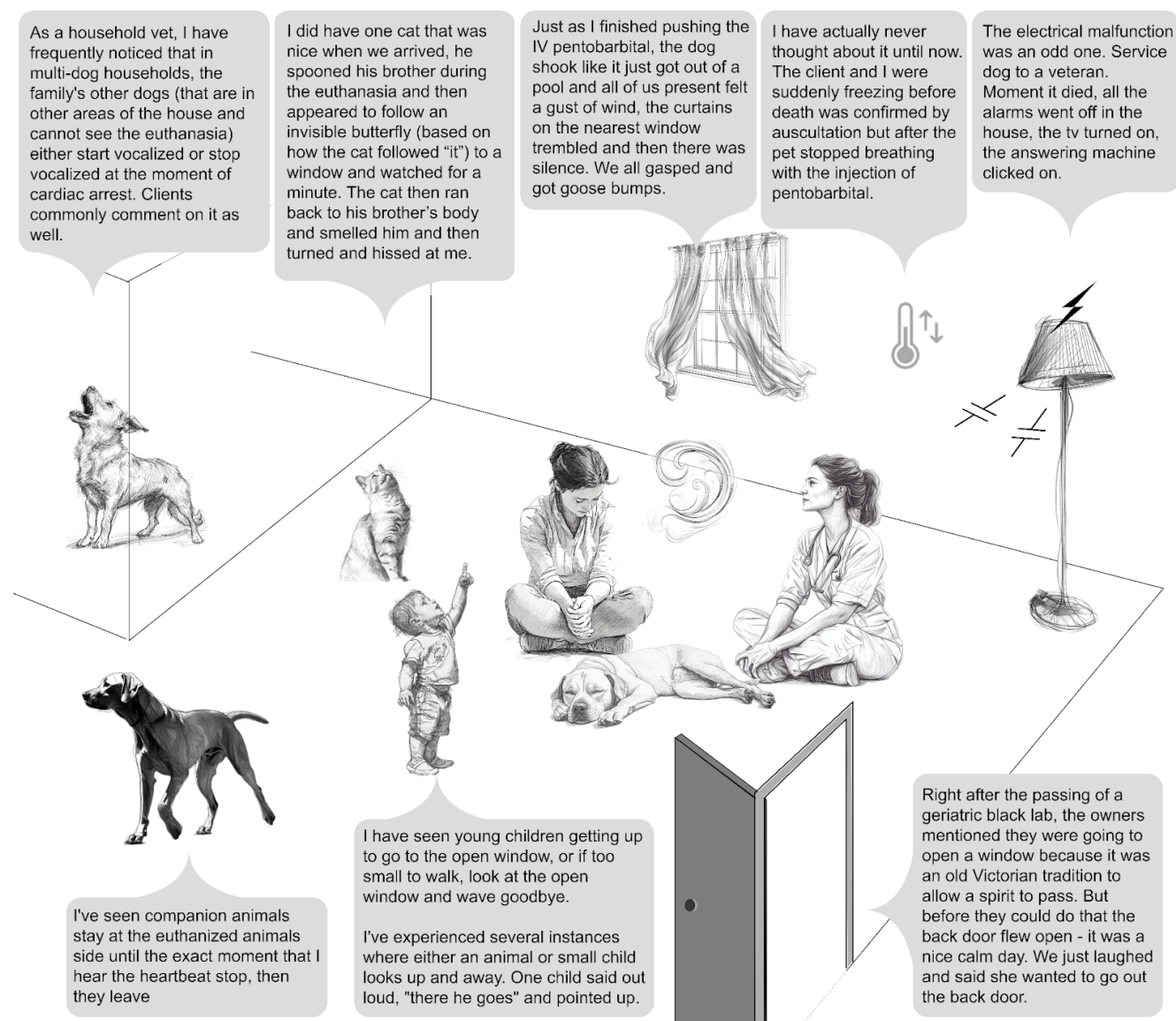


Figure 4. The most commonly reported PMOs paired with one or more long-form descriptions provided by survey respondents. Additional long-form descriptions can be found in the Supplementary Materials.

Spatiotemporal aspects of PMOs were assessed from respondents' long-form descriptions. For temporal analysis (Figure 5A), six PMO types were included, each having a sufficient number of descriptions mentioning timing. Of these, four were very highly concentrated at the time of death (TOD): animal-”stare up into the air” (75%), animal-”start/stop vocalizing” (72%), “sudden air flow” (87%), and “electrical malfunction” (73%). The other two PMO types included in the temporal analysis (animal-“approach/depart from the body” and “sudden temperature change”) showed a more uniform distribution of timing pre- and post-TOD. For spatial analysis, architectural apertures (windows and doors) featured prominently across three PMO types, including ”sudden air flow” (42%), animal-”stare up into the air” (23%), and child-”point into the air” (25%), as illustrated in Figure 5C (also refer to representative examples in Figure 4). Other notable spatial characteristics were that 35% of the long-form descriptions of animal-”start/stop vocalizing” PMOs involved vocalizations by animals that were in separate rooms from the euthanasia procedure (Figure 5B, and example in Figure 4), and 46% of “sudden air flow” PMOs were reported by in-clinic respondents (Figure 5B).

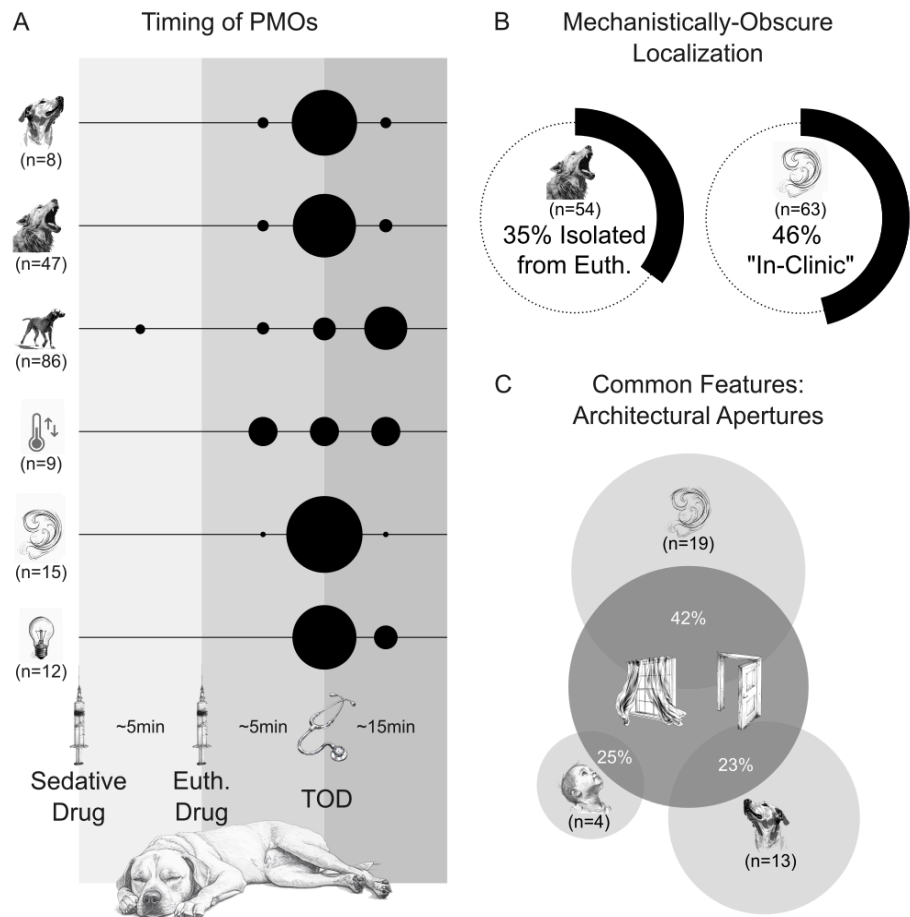


Figure 5. A) Timing of PMOs, as assessed from long-form responses, with circle diameters representing the percentage of each PMO type within each time period. The four time periods include 1) between injection of sedative drug and euthanasia drug, 2) between injection of euthanasia drug and cardiac arrest, 3) immediately after cardiac arrest, 4) at a more vaguely defined time “after” cardiac arrest. B) In 35% of long-form descriptions of animal-“start/stop vocalizing” PMOs, it was mentioned that the vocalizing animal was isolated from the euthanasia in a separate room, and 46% of “sudden air flow” PMOs were reported by in-clinic respondents. C) Windows and doors featured prominently across 39% of three PMO types, including “sudden air flow”, animal-“stare up into the air”, and child-“point into the air”.

Of veterinary professionals reporting an environmental-PMO, 55% reported that others present simultaneously experienced the same PMO (Figure 6). Such shared observations were most likely with “electrical malfunctions”, followed by “glowing light around the body”, “sudden air flow”, “sudden temperature change”, and “‘wavy’ visual distortions”.

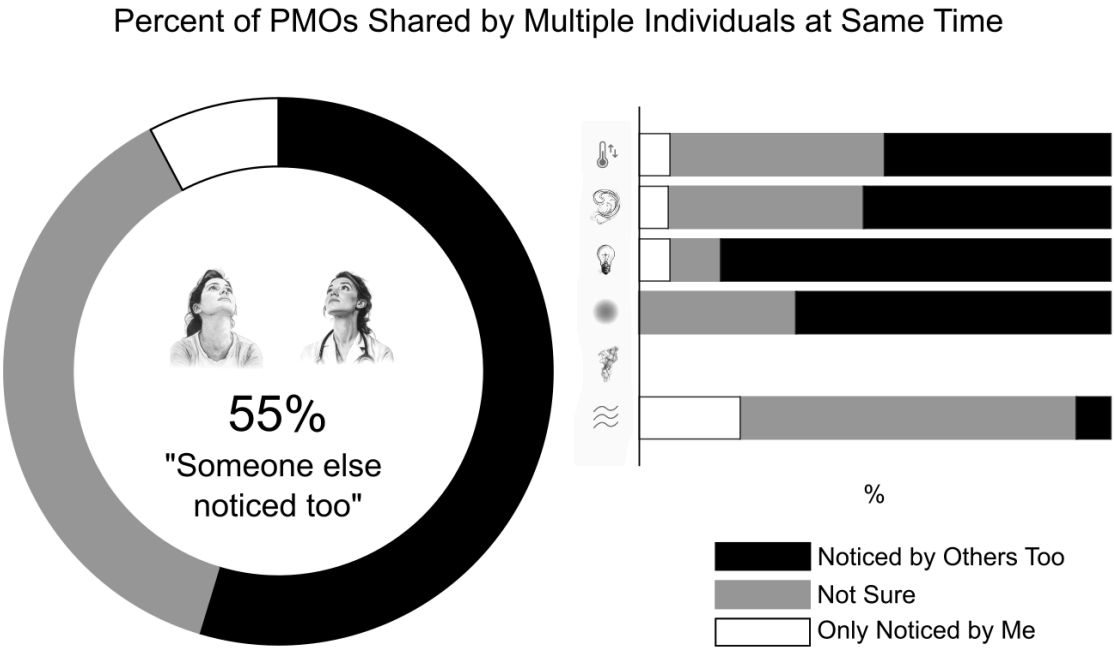


Figure 6. Left: donut plot showing the overall percentage of environmental-PMOs that were simultaneously experienced by others present. Right: bar chart showing the percentage of each environmental-PMO in which “someone else noticed too”. The PMO “‘mist’ formation” was not included (left blank) due to ≤ 5 reports in survey responses.

As seen in Figure 7, an individual respondent reporting a PMO was generally not likely to co-report additional child- or environmental-PMOs, but was likely to co-report additional animal-PMOs.

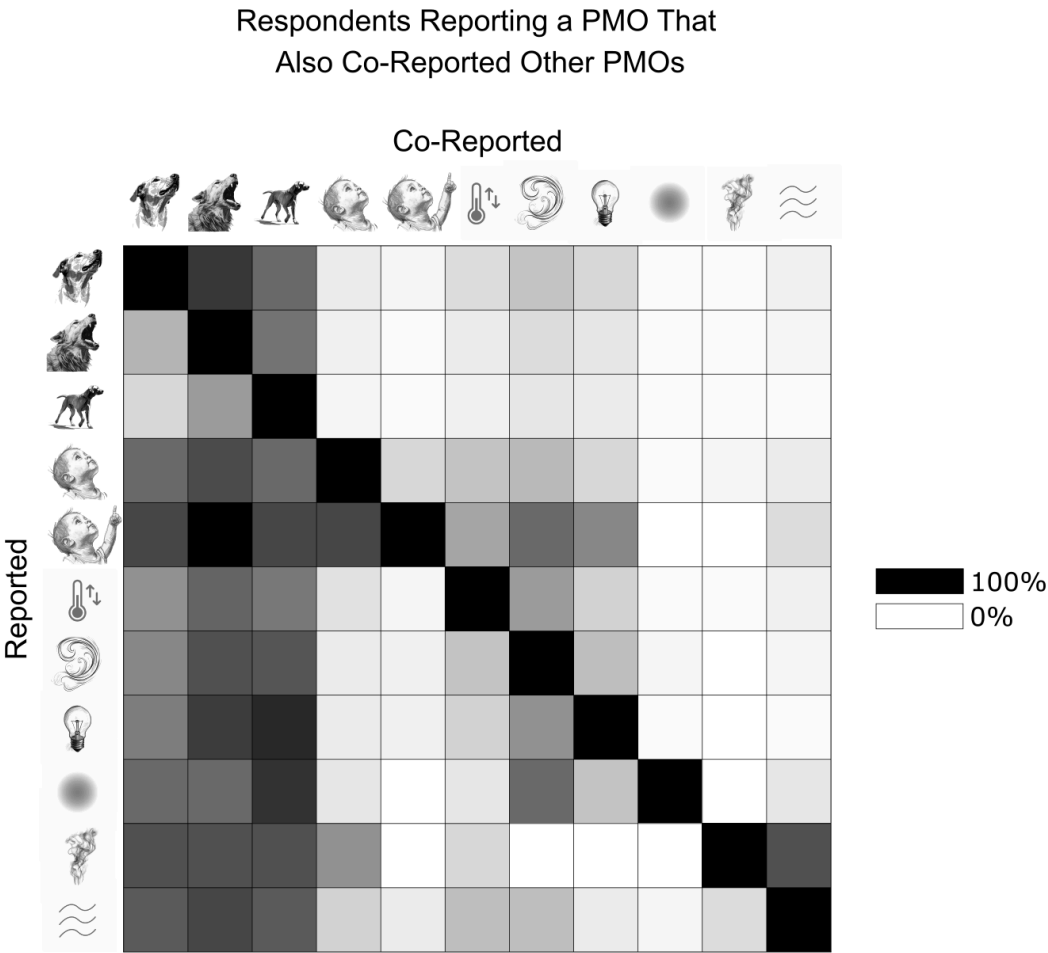


Figure 7. A heatmap showing how frequently each PMO type was co-reported with every other PMO type. Black: 100%; White: 0%.

Perimortem Observations were consistently more likely to have a positive effect than a negative one: 93% of all PMOs had a positive or neutral effect on survey respondents (Figure 8-A), and 86% had a positive or neutral effect on others present (Figure 8-B).

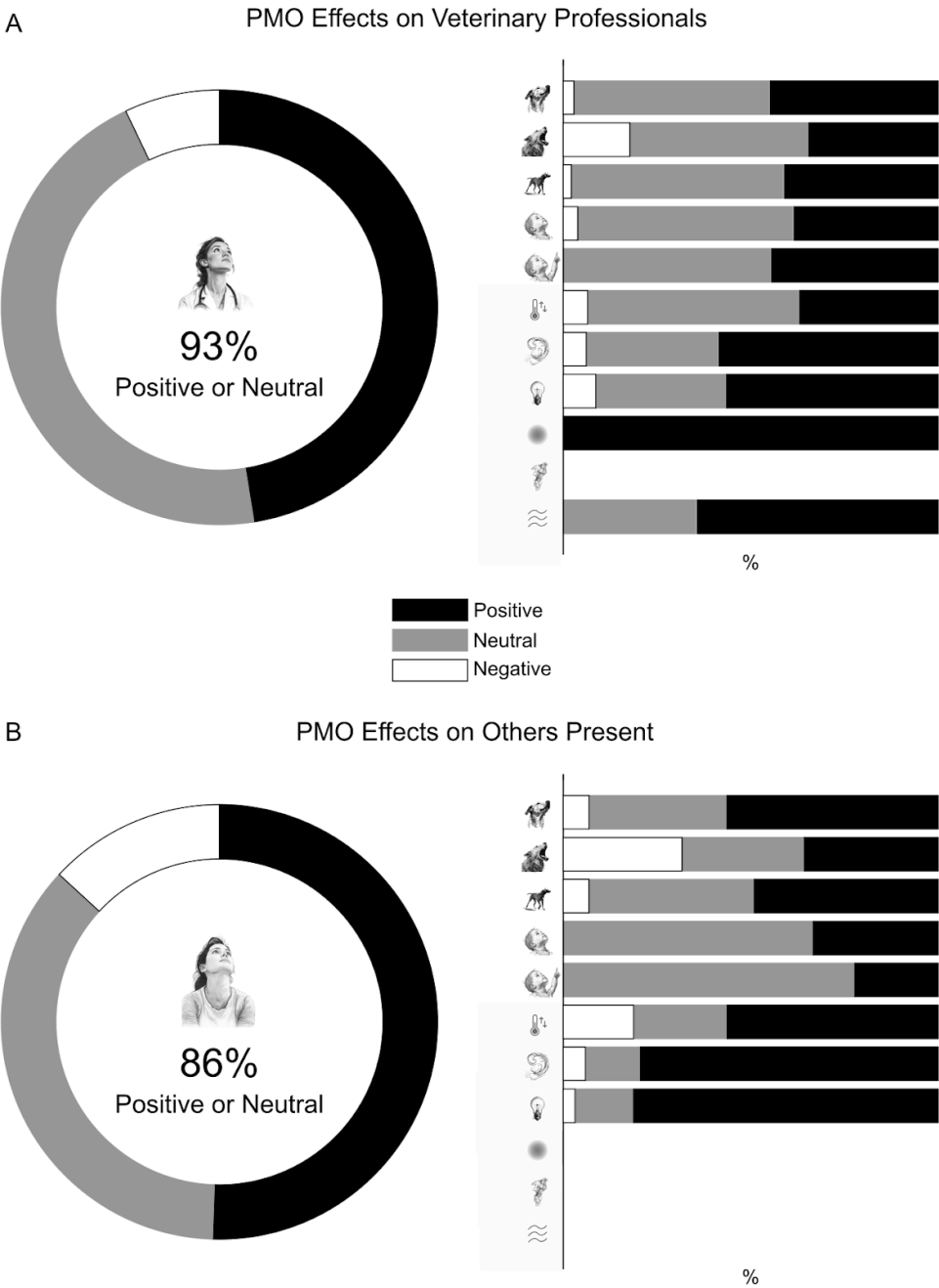


Figure 8. A comparison of positive, neutral, and negative effects of PMOs on A) veterinary respondents and B) others who shared the experience. Left: donut plots showing the overall percentage of different effects. Right: bar charts breaking down the effects of each type of PMO. PMO types with ≤ 5 reports were excluded from analysis.

A majority of veterinary professional respondents were supportive of continued research into PMOs (57%), with greater support among those who reported a PMO (Figure 9). Those with environmental-PMOs were most strongly supportive (86%), followed by those with child-PMOs (78%), and those with animal-PMOs (68%). In this assessment, those reporting “other” PMOs were included in their respective animal-, child-, or environmental-PMO group.

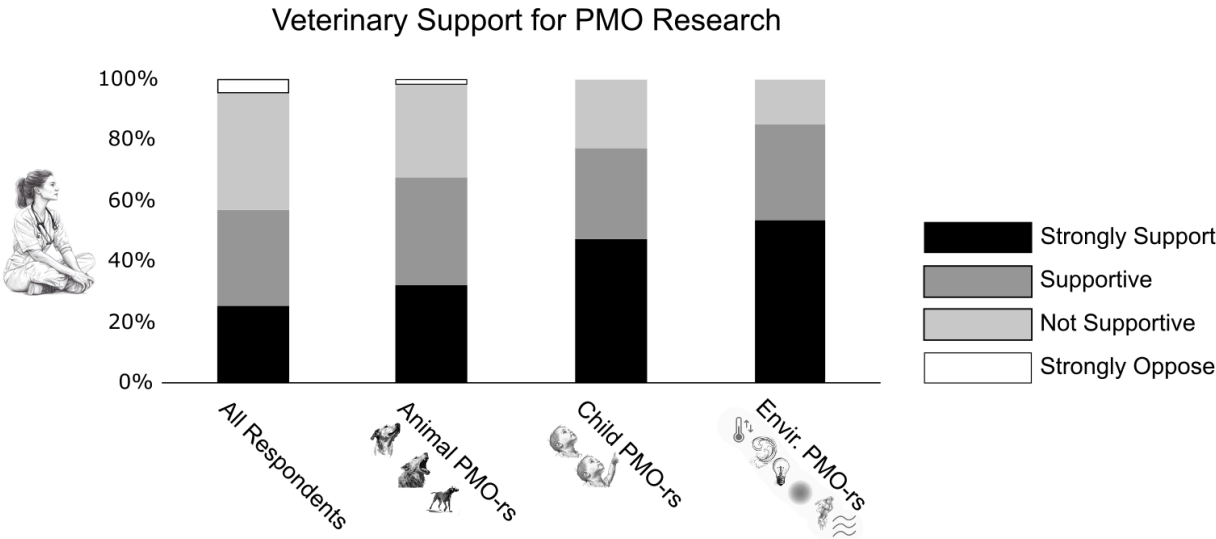


Figure 9. A comparison of support for PMO research among all respondents, and among those who had experienced different types of PMOs (animal-, child-, or environmental-PMO).

Discussion

Patterns in our data suggest that many “Perimortem Observations” (PMOs) may be observations of a death-correlated, mechanistically-obscure, physical phenomenon. If true, this phenomenon could be studied via the scientific method, with scientific instrumentation, in a well-defined time window during routine veterinary euthanasia procedures.

Data validity and credibility

Several aspects of our data support the internal validity and credibility of responses to our survey. First, of the 648 total respondents, 581 completed the survey, yielding a 90% completion rate. This suggests minimal attrition bias and strong respondent engagement. Second, the percentage of veterinary professionals reporting PMOs, and environmental-PMOs specifically, remained stable while the survey was promoted among different groups (Figure 1-A), instead of showing significant early peaks and subsequent declines, suggesting low self-selection bias (^{33–36}). This is further supported by survey responses regarding support for future research on PMOs (Figure 9), in which a majority of respondents chose the moderate “Yes, somewhat” or “No, not really” options, as opposed to the more extreme options of “Yes, definitely” or “No, absolutely not”. This “inverted-U”, rather than “U-shaped”, distribution shows nuanced, rather than polarized views regarding the survey’s main topic, which strongly suggests low self-selection bias (^{37–40}). Third, individual respondents did not report all PMO types indiscriminately (Figure 7), suggesting specificity and selectivity in their responses, as well as a lack of overgeneralization or suggestibility. Only animal-PMOs were frequently co-reported with other PMO types, as would be expected given their high prevalence (Figure 2-Top). Finally, while memories are known to be susceptible to distortion over time, memories of PMOs may be relatively immune from degradation, as studies have shown that memory distortions are least likely to occur in scenarios involving 1) a negative mood (as is often the case during veterinary euthanasia) (⁴¹), and 2) a memory-forming event that triggers positive emotions (as is often the case with veterinary PMOs, as seen in Figure 8) (⁴²). Furthermore, because of general apprehension around discussing PMO-type events (⁴³), these memories are also less likely to become distorted over time by social influence (⁴⁴). Further, extensive description of survey validation can be found in the Supplementary Materials.

PMOs seem to involve physical phenomena and not delusions, illusions, or hallucinations

Our data suggests that many PMOs involve real physical phenomena, and are not delusions, illusions, or hallucinations. First, the survey's low self-selection bias (see "Data validity and credibility" section above) suggests our dataset does not disproportionately reflect responses from individuals with fixed false beliefs (i.e., delusions). Second, 55% of those reporting environmental-PMOs reported that others present also observed the same phenomenon at the same time, strongly suggesting that these observations were not illusions, delusions, or hallucinations. Third, we found a strong positive association between the number of euthanasias an individual performed and the number of environmental-PMOs that they reported, suggesting an exposure-related effect, as would be expected if environmental-PMOs involve real, physical phenomena occurring with a set probability. Finally, the relative prevalence of different PMO types (i.e., the percentage of respondents who witnessed each type) closely matches the rank order of reported frequency (i.e., how often each type was experienced by those who witnessed them) (Figure 2-Top and -Bottom). This strong alignment between the frequency of observations by individuals and the overall prevalence of witnesses within the community suggests that those experiencing environmental-PMOs (and PMOs in general) are not having individual delusions, illusions, or hallucinations, but are observing physical phenomena that occur with somewhat consistent probability across all individuals in the veterinary community.

"PMOs of interest" suggest physical phenomena that are death-correlated and mechanistically-obscure, and therefore not "mere coincidences"

As stated above, our analyses suggest that many PMOs involve true, physical events, and not delusions, illusions, or hallucinations. However, the question remains as to whether such physical events 1) are merely coincidental with known mechanisms, or 2) are death-correlated and mechanistically-obscure. To answer this question, we assign a "mechanistic obscurity score" to each PMO type, which takes into account if it had:

- 1) high probability of involving a physical phenomenon (>50% multi-observer in Figure 6).
- 2) high temporal correlation with cardiac arrest (>50% at cardiac arrest in Figure 5-A).
- 3-4) high likelihood of psychological effects on the survey respondent and others (>50% positive or negative effect in Figure 8), which informs whether the PMO was perceived as mere coincidence by those present.

- 5) involvement of architectural apertures (Figure 5-C), which, shared across multiple PMO types, suggests a shared, obscure mechanism.
- 6) occurrence of the PMO in difficult-to-explain locations (Figure 5-B).

We will focus the rest of our discussion on the four “PMOs of interest” (highlighted in grey in Figure 10 below) that had mechanistic obscurity scores ≥ 4 ; They include animal-”stare up into the air”, animal-”start/stop vocalization”, “sudden air flow”, and “electrical malfunction”.

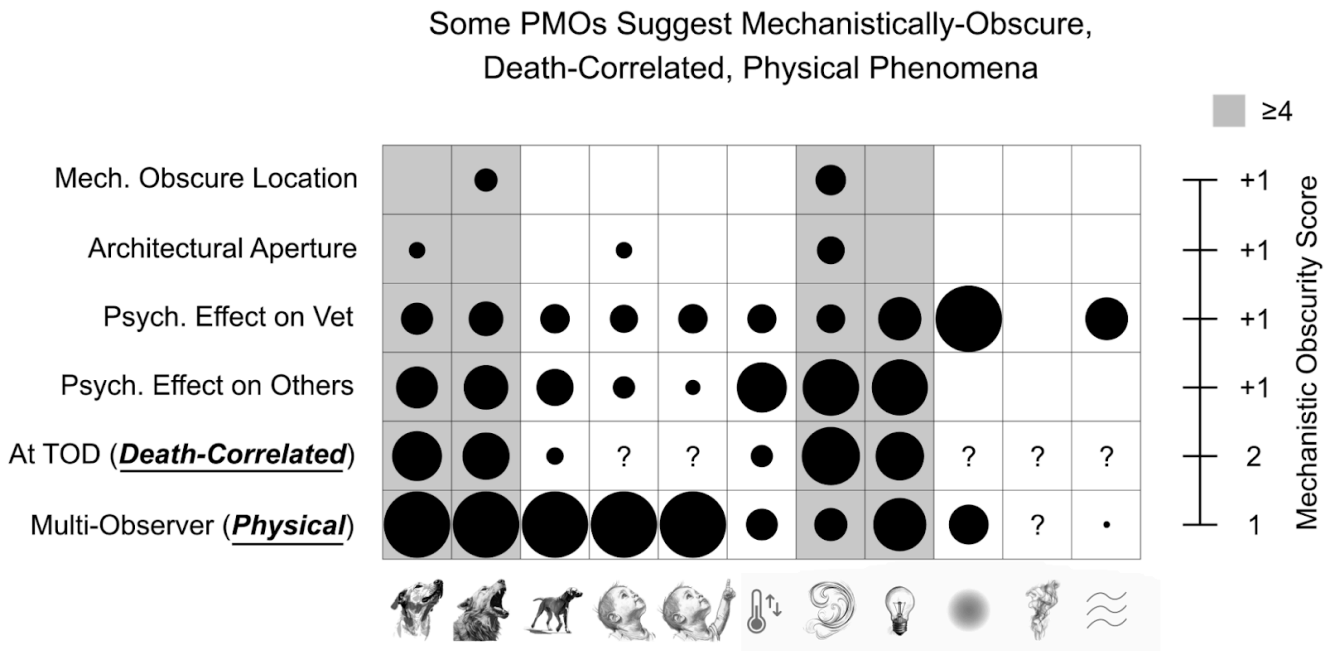


Figure 10. An illustration of how we selected four “PMOs of interest” (highlighted in grey) based on high “mechanistic obscurity scores” (see scale on right), which are derived from a consolidation of data that we have previously presented in Figures 5, 6, and 8. Circle diameters indicate the percent of each PMO type that falls into each row category. In the “Multi-Observer” row (a summary of Figure 6), “100% circles” were placed in animal- and child-PMOs because the survey did not inquire about multiple observers for these PMO types, as their basis in physical reality is less in question. The row labeled “At TOD” shows the percentage of long-form descriptions of each PMO that reportedly occurred at time of cardiac arrest (a summary of Figure 5-A).

Intriguingly, two PMOs of interest (Animal-”stare up into the air” and “Sudden air flow”) often involve architectural apertures, such as windows, doors, and even fireplaces, suggesting that they might share a

common, obscure, underlying mechanism. Examples of this can be read in Figure 4, and the overall pattern is quantified in Figure 5-C. We start by discussing these particularly interesting PMOs of interest.

PMO of Interest - “Sudden air flow”:

Mechanistic obscurity score = 6

- Physical - 50% multi-observer
- Death-correlated - 88% at cardiac arrest
- Significant psychological effects on veterinary professionals - 43%
- Significant psychological effects on others present - 85%
- Involvement of architectural apertures - 42%
- Occurrence in environments with low likelihood of coincidental air flow - 46%

The significant involvement of architectural apertures in “sudden air flow” PMOs can be reasonably expected if these windows or doors were open at the time of the PMO. However, many long-form responses suggest, or explicitly state, that windows and doors were closed during these PMOs, and most, if not all in-clinic PMOs can be assumed to also have closed windows. While some clinic rooms may occasionally have outdoor-facing windows ⁽⁴⁵⁾, in the authors’ professional experiences, they are typically not open during euthanasia procedures for privacy and environmental control reasons. Despite this, 8.3% veterinary professionals conducting euthanasia in-clinic reported “sudden air flow” PMOs, and 41.4% of these were reportedly experienced by multiple individuals present, which suggests a travel path and/or volume of flow that impacted multiple nearby individuals and an airflow velocity of >0.25 m/s, exceeding the threshold for human detection ⁽⁴⁶⁾. An obvious physical mechanism for such sudden airflow in a calm, closed environment, with a high temporal correlation to the time of cardiac arrest is difficult to imagine. Indeed, 51.7% of in-clinic veterinary respondents and 70% of others present were significantly affected by these experiences, indicating that they did not consider them to be mere coincidences.

PMO of Interest - Animal-”stare up into the air”:

Mechanistic obscurity score = 5

- Physical - 100%

- Death-correlated - 75%
- Significant psychological effects on veterinary professionals - 48%
- Significant psychological effects on others present - 63%
- Involvement of architectural apertures - 23%

While children may be culturally or religiously conditioned by parents on how to behave during a pet's euthanasia, this is not the case for animals, and yet animal-"stare up into the air" PMOs were highly correlated with the time of cardiac arrest, and 23% included an architectural aperture as a prominent feature. With regard to known mechanisms that could potentially explain the high correlation with cardiac arrest, some animal species (e.g., cattle), can be host to long-term residential flying insect parasites (e.g., horn flies) that may fly off the body at the time of death (⁴⁷), but this is not the case for dogs, cats, or horses (⁴⁸), which make up the vast majority of euthanasias performed by our survey respondents. We therefore believe many animal-"stare up into the air" PMOs may be mechanistically-obscure, and consequently, it is possible that at least some child-"stare up into the air" PMOs may be mechanistically-obscure as well, due to the previously described shared spectral sensitivities of dogs, cats, and young children (²⁵⁻²⁸).

PMO of Interest - Animal-"start/stop vocalization":

Mechanistic obscurity score = 5

- Physical - 100%
- Death-correlated - 66%
- Significant psychological effects on veterinary professionals - 52%
- Significant psychological effects on others present - 67%
- Occurrence among animals that had been intentionally isolated from the euthanasia - 35%

Our quantification of long-form descriptions showed that vocalizations were highly correlated with the time of cardiac arrest, even though 35% of these cases involved animals isolated in separate rooms from the patient being euthanized (Figure 5-B). If these are mere coincidences, one would expect them to happen more frequently in veterinary clinics where there is 1) a higher probability of other animals being present in neighboring rooms, and 2) a higher prevalence of stressful stimuli that might cause them to start/stop vocalization at any given moment. However, animal-"start/stop vocalization" PMOs were reported more

in-home (49%) than in-clinic (31%). Meanwhile, if these changes in vocalization are actual reactions of isolated animals to the time of death, this is difficult to explain, as cardiac arrest can only be determined by veterinary professionals through careful stethoscope auscultation. One possible explanation could be the nearby animals reacting to hearing the veterinary professional's own vocalizations or actions after confirming time of death. Therefore, while very intriguing, thorough testing of these various alternative possibilities is warranted before more confidently concluding mechanistic obscurity for this PMO type. However, this PMO is of particular interest to future research because it combines a significant potential for mechanistic obscurity with a relatively high frequency of occurrence.

PMO of Interest - "Electrical malfunction":

Mechanistic obscurity score = 4

- Physical - 80%
- Death-correlated - 75%
- Significant psychological effects on veterinary professionals - 65%
- Significant psychological effects on others present - 84%

While electrical malfunctions can occur for myriad reasons, many potential causes are closely tied to the surrounding environment, such as a house with faulty wiring, or a municipality with a power grid overwhelmed by a heatwave. Therefore, one way to assess the probability of an electrical malfunction being a mere coincidence is to ask someone with intimate knowledge of the environment in which the malfunction occurred. We approximated this by looking at the emotional impact of "electrical malfunction" PMOs on "others present", who were presumably residents of the home where the PMO usually occurred (a very large majority of "electrical malfunction" PMOs occurred in-home). These individuals, with intimate knowledge of the location where the PMO occurred, largely did not consider them to be mere coincidences, with 81% of "electrical malfunction" PMOs having a positive psychological effect on "others present", as seen in Figure 8-B.

While "PMOs of interest" exhibit a wide array of phenotypes, and a variety of different features suggestive of mechanistic obscurity, we hypothesize that they may all share one unifying physical mechanism that underlies them, as discussed below.

Hypothesized involvement of a known physical mechanism: moving air ions

Collectively, the “PMOs of interest” described above, and highlighted in Figure 10, have led us to hypothesize the existence of a mechanistically-obscure, death-correlated, physical phenomena, with the following characteristics:

- 1) movement towards / through architectural apertures
- 2) causes air flow
- 3) causes electrical malfunctions
- 4) visible to animals, perhaps children, and rarely adult humans

We will refer to these ostensibly death-correlated, physical phenomena as “Perimortem Environmental Phenomena” (PMEP). Intriguingly, the diverse characteristics of PMEP listed above are also all characteristics of a single, scientifically established physical mechanism: moving, electrically charged particles (e.g. moving air ions). In the following paragraphs, each of these shared characteristics is briefly discussed, and a summary is presented in Figure 11, followed by a discussion of the limitations and shortcomings of this hypothesis.

PMEP characteristic - “movement towards / through architectural apertures”:

Self-contained ionized particle phenomena have been studied under controlled laboratory conditions (^{49–51}), and have also been recorded with scientific instrumentation in a naturally occurring state (⁵²), where they have been documented to move through open windows, down hallways, or along architectural contours (^{53,54}). This apparent interaction with the surrounding environment, is hypothesized to result from self-organized electromagnetic confinement or attraction to electric field gradients near conductors (^{55–57}), and has been replicated to a limited extent in laboratory conditions as well (^{58,59}).

PMEP characteristic - “causes air flow”:

When ionized air molecules move, they collide with nearby neutral particles in the air, creating “ionic wind” (⁶⁰), which can have velocities up to 5 m/s (⁶¹), exceeding the 0.25 m/s threshold for human detection (⁴⁶). In

laboratory settings, this movement of ionized air molecules has usually been actuated by the presence of an electric field ^(60,61).

PMEP characteristic - “causes electrical malfunctions”:

The movement of air ions generates electromagnetic fields that can give rise to transient electrical discharges, induce currents in adjacent conductors, and perturb the operation of sensitive electronic systems ^(62–64).

PMEP characteristic - “visible to animals, perhaps children, and rarely adult humans”:

During the ionization of molecules in air, electrons can be excited to higher energy levels and then return to lower levels, emitting photons in the process ⁽⁶⁵⁾. This process, when occurring in air, almost exclusively emits photons in ultraviolet (UV) wavelengths ^(66–68), due to air’s high nitrogen gas (N₂) content. UV light can be seen by cats and dogs ^(23,24,69), and to some extent by young children, but only rarely, and to a lesser extent by some adult humans ^(25,26,70,71). Meanwhile, at much higher energy levels, charged particles would generate broad-spectrum wavelengths of light via “continuum emission”, which is readily visible by all humans ⁽⁷²⁾.

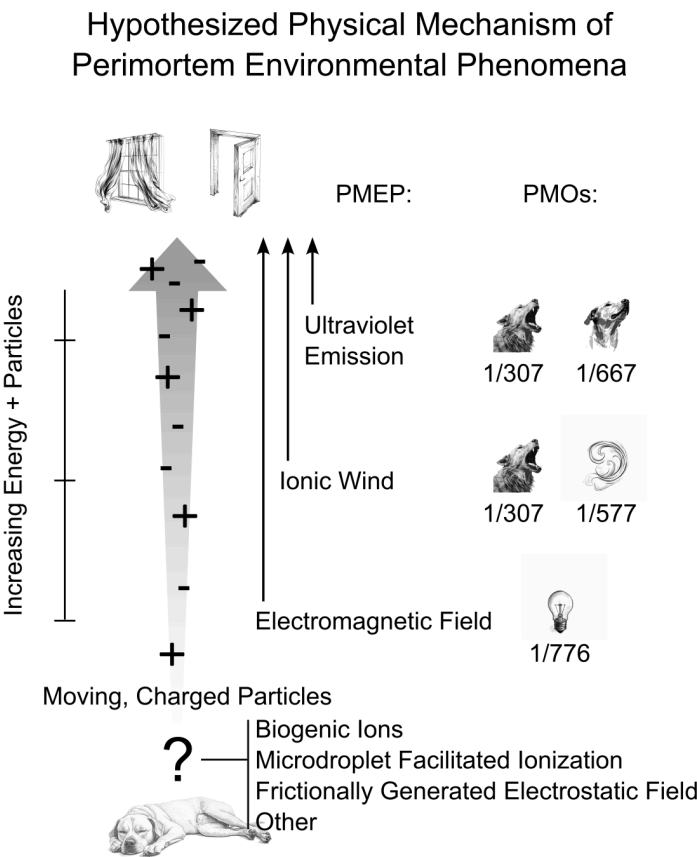


Figure 11. An illustration showing alignment between scientifically established characteristics of moving air ions and ostensible characteristics of PMEP. A large question remains as to how these hypothesized moving air ions might be generated. Fractional numbers underneath each PMO image indicate the approximated frequency of the PMO's occurrence (1 PMO / # euthanasia procedures), which is also shown in Figure 2-Bottom.

Despite the fascinating correlation between diverse characteristics of moving air ions and PMEP, we are left with the problem of how moving air ions could be generated around the time of death. Because there is no obvious answer to this question, we provide an overview of possibly relevant research regarding sources of gaseous ions and motive forces in an effort to inform future research, while acknowledging the obvious limitations of these possibilities.

Ion Source? - Biogenic Ions:

All aerobic organisms constantly produce ions, known as superoxide anion radicals (O_2^-), as a byproduct of normal mitochondrial function (⁷³⁻⁷⁵). These ions are produced in most cells, including those of the lung (alveolar macrophages and alveolar epithelial cells), which rapidly increase production of superoxide anions in response to inflammatory stimuli (⁷⁶) and ischemia (⁷⁷), which occur during euthanasia (⁷⁸). The exposure of alveolar epithelial cells' intracellular contents to the alveolar air space (and subsequently to the outer atmosphere) could occur via their lysis during pulmonary edema, which sometimes occurs as a side effect of euthanasia drugs (^{78,79}). However, even then, the high solvation energy of superoxide anion radicals would inhibit their diffusion into the air space (⁸⁰). Instead, a transition into the air space in a gaseous state would require an aerosolization of the anion within microdroplets, and subsequent evaporation of the droplet. This could conceivably happen with higher probability at time of death due to a final, rapid inhalation and deep exhalation (not uncommon at end-of-life), which causes a twelve to eighteen fold increase in respiratory aerosolization (⁸¹) compared to normal breaths.

Ion Source? - Microdroplet-Facilitated Air Ionization:

It has recently been found that neutral droplets of water naturally self-assemble into positively and negatively charged microdroplets, which, when in close proximity, induce electrical discharges ("microlightning") with

sufficient energy to ionize surrounding neutral gas molecules ⁽⁸²⁾. This occurs naturally without any external voltage applied. It is at least conceivable that such microdroplets could form more prevalently at the time of death during euthanasia due to 1) a higher than normal fluid content in the lungs due to drug-induced edema ^(78,79), and 2) a final, rapid inhalation and deep exhalation (not uncommon at end-of-life), which can cause an eighteen fold increase in the degree of respiratory aerosolization ⁽⁸¹⁾. However, in the case of drug-induced, non-cardiogenic edema, any aerosolized microdroplets would likely have high protein and lipid content ⁽⁸³⁾, which would likely reduce the probability of proximity-induced electrical discharges between them.

Motive Force? - Frictionally Generated Electrostatic Fields:

Animal fur exhibits high positive charge affinity, making it an excellent electron donor. When brought into frictional contact with materials that have a high negative charge affinity (e.g. polyester or polypropylene fabrics), a multi-kilovolt electrostatic field can be generated ^(84–86), sufficient to accelerate ions and induce ionic winds with speeds above the 0.25 m/s human threshold of perception ^(46,87). Such electrostatic charge-inducing frictional contact could conceivably happen with higher probability at the time of death during euthanasia due to drug-induced involuntary muscle fasciculation of the panniculus carnosus muscle (not uncommon at end-of-life)^(88,89), which causes skin twitch movements in dogs, cats, and horses.

As previously stated, our hypothesis regarding the potential involvement of moving charged particles in PMEP / PMOs is limited by our need to identify a source for such particles. As such, while intriguing, the hypothesis is far from being complete.

PMOs have practical, positive effects on veterinary professionals and bereaved families

Irrespective of the underlying mechanisms of PMOs, our data indicates that they are far more likely to cause positive psychological effects, rather than negative, for both veterinary professionals and their patients' families (Figure 8). This pattern coincides with previous studies by Claxton-Oldfield et al. The one outlier, with a higher likelihood of negative effect, is the animal-"start/stop vocalization" PMO. We believe that this may be due to animals that have been deliberately isolated from the euthanasia still audibly responding to the patient's time of death (as illustrated in Figure 4-Top Left), thereby causing distress.

A majority of veterinary respondents support PMO research, particularly those who have experienced them (Figure 9). Specifically, environmental-PMOs are associated with the strongest support (and a higher likelihood of positive psychological effects), perhaps because it is more challenging to disregard these observations as coincidences.

All of these findings suggest that further education about PMOs could allow a broader audience to benefit from their positive effects, including those who have never experienced them and those who previously experienced them with negative effects.

Conclusion

Our data suggests that some “Perimortem Observations” (PMOs) may be caused by mechanistically-obscure, death-correlated, physical phenomena, which we refer to as “Perimortem Environmental Phenomena” (PMEP). The hypothesized existence of PMEP can be tested, with support from veterinary professionals, during routine animal euthanasia procedures. We propose that moving, charged particles are a promising initial candidate for investigations into the underlying physical mechanisms of PMEP. A better understanding of both PMOs and PMEP has the potential to have positive effects on both veterinary professionals and bereaved families.

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Author Contributions:

LMvK. conceived the study. All authors designed the survey. LMvK., KC, and KG solicited survey responses. LK collected the data. LMvK developed the analytical tools and analyzed the data. LMvK wrote the manuscript with input from all authors. All authors reviewed and approved the final version of the manuscript.

Data Availability:

Data is provided within the Supplementary Materials files.

Competing Interests:

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